UNIVERSITY OF STRATHCLYDE

The Use of Accommodating Resistance as Part of a Cluster Set to Enhance Lower Body Power

This Thesis is submitted in fulfilment of the requirement for the degree of M.Phil. in Biomedical Engineering

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Declaration

I certify that I wrote this thesis entirely on my own and that it was not previously submitted, in whole or in part, with any other application for a degree. The material offered is completely my own, unless it specifically stated otherwise via reference or acknowledgement.

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Abstract

Accommodating resistance, which involves the use of single link steel chains, has diverse applications in sports for altering biomechanical characteristics and enhancing peak power output in established training methods. Furthermore, the use of cluster set training has become popular in strength and conditioning, with scientific research showing conflicting results on its effectiveness. This study aims to assess the impact of accommodating resistance methods during a cluster set to enhance lower body power and to examine its effects on forces during squat movements. It also seeks to explore optimal barbell loads and the benefits of incorporating the cluster technique into resistance training. Twelve participants with resistance training experience underwent two sessions: one involving a 1-repetition maximum (1RM) back squat with chain familiarisation, and another with repeated submaximal back squats using accommodating resistance. During the second session, participants performed three repetitions at 60% 1RM with varying percentages of chain resistance (20%, 25%, and 30%) on portable force plates (PFPs). Output characteristics from each chain mass attempt were compared to traditional movements, revealing that traditional movements generally produced greater output benefits than accommodating resistance ($p < 0.05$), with the 25% accommodating resistance showing the most favourable results. Acute lower body power improvements were most noticeable during the traditional back squat movement with the use of cluster sets ($p < 0.05$), although accommodating resistance demonstrated advantages in peak acceleration (m/s^2). It can be argued that this slight decrease across various output measures isn't substantial enough to significantly affect performance, especially considering the biomechanical benefits of accommodating resistance. This suggests that in practical S&C sessions, if accommodating resistance is preferred over traditional methods, the accommodating chain mass should be set at 25%. This study contributes to understanding the optimal prescription of movement intensity in accommodating resistance training and the necessary equipment for effective data collection and athlete monitoring. It also uncovers concepts that enhance future research understanding, such as the benefits of incorporating chains to diversify exercises and prevent performance plateaus. Additional insight was gained into the practice of lightening the eccentric phase by utilising chains, which helps alleviate delayed onset muscle soreness (DOMS) and promotes faster recovery, thereby allowing for more frequent high-intensity training sessions. Furthermore, cluster set training promotes proper movement patterns, reduces injury risk, and enhances athletic performance by maximising effort during concentric movements, activating type II muscle fibers. Additionally, incorporating the cluster technique enhances data collection efficiency, promotes proper movement patterns, and reduces injury risk, offering valuable insights for future strength and conditioning practices.

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1RM - 1 Repetition Maximum
ART - Accommodating Resistance Training
CMJ - Counter-Movement Jump
DOMS - Delayed Onset Muscle Soreness
DSI - Dynamic Strength Index
ERT - Elastic Resistance Training
FWSPT - Free Weight Strength and Power Training
LPT - Linear Position Transducer
MSPT - Motorised Strength and Power Training
PADO - Peak Acceleration Downwards Output
PAO - Peak Acceleration Output
PFP - Portable Force Plates
PFO - Peak Force Output
PFP - Portable Force Plates
PPO - Peak Power Output
PPO - Peak Power Output
PVO - Peak Velocity Output
RAMP - Raise, Activate, Mobilise, and Potentiate
RBR - Rubber-Based Resistance
RFD - Rate of Force Development
ROS - Reactive Oxygen Species
RPE - Rate of Perceived Exertion
SLS - Standard Link Steel
SSC - Stretch-Shortening Cycle
VRT - Variable Resistance Training

Chapter 1 General Introduction

Resistance training encompasses diverse workout methods utilising free weights or machines, with goals including injury prevention, enhanced fitness, and preparation for competitive sports (Stone et al., 2007). Resistance training has grown in popularity over the last two decades due to its capacity to improve performance in a variety of areas, including muscle strength, power, velocity, hypertrophy, stability, and coordination (Kraemer et al., 2000).

Previous study suggestions have indicated that weightlifting contributes to the improvement of diverse physical attributes, bolstering the idea that an individual's capacity to produce power is influenced by three main pillars, all of which align with the output metrics observed in this study. Firstly, the attribute of A - Maximum Strength is relevant as it encompasses both force and power outputs, which are integral metrics for this research. Secondly, B - Rate of Force Development (RFD) holds importance as it addresses the velocity at the point of peak force generation for all individuals. Additionally, C - High Load Speed Strength is noteworthy as it pertains to the acceleration of individuals during the movement.

While resistance training was once restricted to certain people such as powerlifters and bodybuilders (Kraemer et al., 2004), advancements in training methodologies have resulted in personalised strength and conditioning (S&C) practices for athletes and sports teams (Harris et al., 2000; Stone et al., 1999). Resistance training efficacy may be influenced by a variety of parameters, including movement type, intensity, volume, and training approach (Fleck & Kraemer, 1997).

Resistance training, with the addition of steel chains, one of the key pieces of equipment within this study, can provide a range of stimuli and enhancements to strength adaptations (Soria-Gila et al., 2015; Baker & Newton, 2009; Joy et al., 2016. Steel chains, commonly known as accommodating resistance when utilised during a movement, are especially effective for assisting athletes with the "sticking point" during a barbell squat (Elliott et al., 1989). The "sticking point" occurs at the moment of least biomechanical advantage, which, in this instance, is the peak eccentric point during a barbell back squat. However, the advantages of this style of resistance training on measures such as peak power output and rate of force development are still ongoing (Elliot et al., 1989).

Previous studies have left uncertainty regarding the appropriate amount of steel chain mass to be applied in specific movements, resulting in a mixed understanding. Therefore, it was crucial to incorporate various percentages of chain mass in this study to determine the optimal mass for enhancing specific output metrics. As elite athletes seek to gain a competitive edge over their rivals, identifying the optimal chain mass to maximise training benefits becomes paramount.

The initial goal and purpose of this study was to explore the impacts of accommodating resistance, specifically by examining how the use of chains affects forces during squat movements. The second objective was to refine the selection of accommodating resistance loads to maximise peak power output, achieved through analysing different optimal barbell mass and their effects on training intensity. To enhance the likelihood of achieving greater output measures, cluster set-style training was introduced as a resistance training method that modifies rest periods to boost outputs. This aligns with the third objective, which focuses on improving peak power outputs by assessing the benefits of cluster set training to identify the most effective approach. By pursuing these specific aims and objectives, this research aims to contribute valuable insights and enhance the existing understanding of the topic.

This research holds significance beyond filling specific knowledge gaps; it also carries broader implications for both accommodating resistance training and cluster set training, aiming to identify optimal outcomes. Thus, this study aims to address this gap in knowledge by investigating the use of accommodating resistance as part of a cluster set to enhance lower body power. The findings of this study can further aid S&C coaches in identifying potential variations in training approaches to improve athletic performance. By achieving its research aims and objectives, this investigation seeks to offer valuable insights that can inform future research endeavours and practical implementations.

Previous study suggestions have indicated that weightlifting contributes to the improvement of diverse physical attributes, bolstering the idea that an individual's capacity to produce power is influenced by three main pillars, all of which align with the output metrics observed in this study. Firstly, the attribute of A - Maximum Strength is relevant as it encompasses both force and power outputs, which are integral metrics for this research. Secondly, B - Rate of Force Development (RFD) holds importance as it addresses the velocity at the point of peak force generation for all individuals. Additionally, C - High Load Speed Strength is noteworthy as it pertains to the acceleration of individuals during the movement.

This study comprises six main chapters that explore various aspects of resistance training using accommodating resistance. The initial chapter, the General Introduction, is followed by an extensive review of literature in Chapter 2, providing the reader with background understanding before delving into the methodology. Chapter 3, titled Research Rationale, Aims, and Objectives, outlines the study's goals and objectives, detailing the desired outcomes. Subsequently, Chapter 4, Methodology, outlines how these objectives are implemented to collect data from the participants. The collected data is then examined and analysed in Chapter 5, Results, where trends and key points are identified. Finally, in Chapter 6, Discussion, the study is comprehensively analysed, highlighting key findings and insights, as well as suggesting areas for future research.

Chapter 2 Literature Review

2.1.0 Factors Influencing Muscle Hypertrophy

Hypertrophy, the physiological process characterised by an increase in muscle size, represents a fundamental goal for many individuals engaged in resistance training. Factors leading to hypertrophy; the trio of mechanical tension, muscle damage, and metabolic stress have gathered attention in exercise physiology research (Evans, 2002; Jones & Rutherford, 1987; Shinohara et al., 1998; Yandenburgh, 1987).

2.1.1 Role of Mechanical Tension, Sarcomere Lengthening, and Neural Adaptations

Stretch and mechanical tension generated through force creation and contraction are believed to be essential for muscle development (Goldspink, G. 2002; Hornberger, T. A. & Chien, S. 2006; Yandenburgh, H. H. 1987). The combination of these stimuli has been found to have a positive impact on muscle growth by promoting the recruitment of muscle fibres and stimulating protein synthesis, the cellular process responsible for building proteins (Goldspink, G. 2002; Hornberger, T. A. & Chien, S. 2006; Yandenburgh, H. H. 1987). The following section explores the crucial role of mechanical tension in muscle development, considering its impact on growth, adaptation, and hypertrophy. Drawing on studies and a recent review, we examine how factors such as resistance training, range of motion (ROM), and time under tension influence the intricate dynamics of muscular physiology.

Mechanical tension, the physical contraction of muscles in the body, plays an essential role in muscle development, as supported by Goldberg et al. (1975) who noted that it can promote muscle growth, while unloading can lead to muscle atrophy. Additionally, Valamatos et al. (2018) found that resistance training, a form of exercise that involves resistance to induce muscular contraction, with a full or larger ROM is particularly effective in developing muscle strength and size. This can occur as these movements increase mechanical stress and promote sarcomere lengthening, supporting the importance of mechanical tension in muscle adaptation and growth.

While mechanical strain, the overstretching or overexertion of muscles, can independently cause muscle hypertrophy, it is unlikely to be the only factor in hypertrophic improvements whilst performing resistance movements (Jones, D.A. and Rutherford, O.M. 1987). This is due to resistance movements that involve increased muscular tension may primarily induce neural adjustments without hypertrophy (Côté, C. et al. 1988; Vissing, K. et al. 2008).

A review by Mang, Z. A. et al. (2022) highlights the significance of high-volume resistance training, emphasising its role in promoting aerobic adaptations. This is supported by the idea that increased time under tension, the amount of time your muscles are actively contracting during an exercise, provokes a physiological response within the skeletal muscle tissue. Increased time under tension produces several critical factors, including heightened skeletal muscle energy, and an increased state of metabolic stress.

2.1.2 Metabolic Stress and Intensity in Promoting Muscle Hypertrophy

Numerous studies have shown that resistance training-induced metabolic stress, the accumulation of metabolic byproducts, such as lactate, and other waste products, in the cells and tissues, has anabolic effects (Rooney et al., 1994; Schott et al., 1995; Carey Smith et al., 1995), which highlights the significance of metabolic stress as a key factor in promoting muscle growth. Alternatively, some researchers have suggested that metabolite accumulation may be more important than peak force development in maximising hypertrophic adaptations during exercise (Shinohara et al., 1998). This emphasises the potential advantage of focusing on metabolite accumulation as it may offer a more targeted approach to achieving muscle hypertrophy through resistance training.

Metabolic stress, while not deemed essential for muscle development according to Folland et al. (2002), has gathered attention around hypertrophy research due to its evident impact, either through direct or indirect mechanisms. This increased metabolic response, particularly evident during varied intensity exercises can be justified by the rapid glycolysis process, which ultimately leads to increased energy levels, as highlighted by Robbins et al. (2010). Intensity in resistance training typically refers the amount of resistance involved in the exercises. Low-intensity resistance training is a form of training that utilises lighter resistance, specifically targeting certain muscle groups (20-40% of the individual's 1 Repetition Maximum (1RM)). Similarly, moderate intensity (40-60% 1RM) and high intensity (60-100% 1RM) exercises can be described in the same manner. The term 1RM signifies the maximum amount of intensity a person can lift in a single movement.

Bartolomei et al. (2017) demonstrated that high-volume movements produce greater metabolic stress than high-intensity movements, while maintaining consistent mechanical stress levels across both exercise approaches. This finding is significant as it highlights the potential mechanisms behind hypertrophic responses during strength training, physical exercises that focus on improving the strength and endurance of muscles. Furthermore, metabolic stress, as indicated by factors such as improved fibre recruitment, (Nishimura et al., 2010; Goto et al., 2005; Gordon et al., 1985; Takarada et al., 2000), is thought to play an important role in promoting muscle growth.

Considering the need for fibre activation and adaptation in response to resistance training (Kraemer & Ratamess, 2004) it was found that movements at higher intensities appear crucial for promoting muscular growth. Suga et al. (2009) found that only 31% of individuals performing exercises at 20% 1RM exhibited fast twitch fibre recruitment, the activation and utilisation of specific muscle fibres, compared to 70% in those exercising at 65% 1RM. This discrepancy highlights the significance of higher-intensity training in effectively engaging fast twitch fibres, which are essential for muscle hypertrophy. Furthermore, the increased number of contractions in high-volume movements may contribute to muscle damage and compensate for lower workloads compared to high-intensity regimes (Talbot & Morgan, 1998), further supporting the importance of exercising at higher intensities for optimal muscle growth.

2.1.3 Mechanisms and Implications of Muscle Damage

Resistance training can induce localised muscle tissue damage, a process known as muscle hypertrophy, which is believed to contribute to muscle growth. This damage prompts the body to repair and strengthen the affected muscle fibres, resulting in increased muscle mass and strength (Evans, 2002; Hill & Goldspink, 2003).

Early stages of resistance training are associated with a significant increase in muscle damage, potentially attributable to muscle inflammation rather than true muscle hypertrophy (Damas et al., 2017). This observation emphasises the importance of distinguishing between muscle damage and hypertrophy in the initial phases of resistance training, as it highlights that the initial soreness and inflammation experienced by beginners may not necessarily translate into substantial muscle growth.

Delayed onset muscle soreness (DOMS), the pain and stiffness that occurs in muscle, commonly occurs after periods of rest followed by high-intensity resistance or aerobic training. This is primarily due to eccentric movements cause more severe and frequent micro-injuries compared to other muscle actions such as concentric, the shortening of muscle fibres as it generates force, or isometric contractions (Cheung et al., 2003). These injuries trigger an inflammatory response, contributing to the characteristic pain and discomfort associated with DOMS.

The selection of contraction velocity, the rate at which a muscle shortens or lengthens, is essential as it influences various aspects of muscle adaptation and damage. Increased velocity eccentric movements, as demonstrated in Chapman et al.'s 2011 study, lead to greater improvements in isometric strength, ROM, and DOMS when compared to a decreased velocity eccentric movement. This highlights the significance of selecting an appropriate velocity for maximising specific training outcomes and optimsing muscle response.

Muscle damage during eccentric contractions is thought to be caused by muscle cross-bridge, the connection formed between two specific protein structures, disruptions due to lengthening and greater force contractions, which are associated with increased force production, muscle damage, and hypertrophy (Farthing & Chilibeck, 2003). This occurs due to eccentric contractions placing a greater mechanical stress on the muscle fibres, leading to the formation of greater cross-bridge connections that can be disrupted during lengthening.

VRT has been observed to induce notable training-induced fatigue responses. This is likely attributed to both acute fatigues, stemming from the immediate demands of variable resistance exercises, and physiological responses characteristic of this specific training method, as evidenced by research conducted by Walker et al. in 2013.

Rapid concentric velocities are frequently linked to neural adaptations and enhanced strength gains as they challenge the nervous system's ability to recruit motor units efficiently, creating enhanced force production. In contrast, focusing on greater eccentric time under tension promotes muscular hypertrophy by causing muscle fibres to sustain increased mechanical stress and damage, which can stimulate muscle growth. Importantly, prioritising eccentric work does not compromise neural adaptations, ensuring a holistic approach to strength development (Wilk et al., 2021).

2.1.4 The Importance of Rate of Force Development and Muscular Power

Rate of Force Development (RFD) refers to the velocity at which muscles contract and generate force (Aagaard et al., 2002). This parameter has gained significant attention in scientific research due to its consistent association with improved athletic performance across various domains. Numerous studies have shown that an increased RFD is linked to enhanced jumping abilities (Laffaye & Wagner, 2013; Laffaye et al., 2014; Haff et al., 2005; McLellan et al., 2011; Haff et al., 1997; Kawamori et al., 2006; Nuzzo et al., 2008), increased sprint velocity (Slawinski et al., 2010), and developed weightlifting capabilities (McLellan et al., 2011; Haff et al., 1997). Furthermore, enhancing muscular power is necessary in various sports performances, as evidenced by multiple studies (Baker & Nance, 1999; Comfort et al., 2011; Comfort et al., 2012; Cormie et al., 2007; Cronin et al., 2001; Garhammer & Gregor, 1992). Additionally, top-level sprinters with higher RFD levels, as indicated by Slawinski et al. (2010), exemplify the importance of this attribute in achieving peak athletic performance.

The categorisation of exercises into slow (greater than 250 milliseconds) and quick (less than 250 milliseconds) stretch-shortening cycle (SSC), the combination of eccentric and concentric muscle movement, activities is essential as it helps us understand their unique characteristics and performance outcomes. This difference is supported by research, as evidenced by Turner & Jeffreys (2010), Laffaye et al. (2014), and Taylor & Beneke (2012). Slow SSC movements, exemplified by exercises like the counter movement jump (CMJ), a type of jump where you start by quickly bending your knees and then immediately extending them to jump upward, are associated with longer SSC durations, allowing for the gradual buildup of force, leading to higher peak forces, as emphasised by Kawamori et al. (2006) and Jensen et al. (2008). Conversely, quick SSC activities, such as sprinting movements, face the challenge of producing peak force within a brief SSC period, as highlighted by Kawamori et al. (2006), McLellan et al. (2011), and Markström & Olsson (2013). This categorisation aids in tailoring training and performance strategies to optimise results based on the specific SSC characteristics of an exercise.

Fast SSC movements are associated with fewer joint displacements, the movement of a joint due to the contraction or relaxation of muscles, (Ebben et al., 2007), which is beneficial as it minimises unnecessary stress on the joints, reducing the risk of injury and promoting joint longevity. Additionally, adaptations in muscle-tendon stiffness, the resistance of a muscle and its associated tendon to deformation, as indicated by Kubo et al. (2001) and Burgess et al. (2007), contribute to improvements in RFD. Furthermore, during the early stages of the SSC, there is an increase in neural drive, the control of voluntary muscle movements, in the nervous system, (Cutsem et al., 1998; Vila-Cha et al., 2012), which are essential for optimising muscle recruitment and overall performance. However, factors such as variations in muscle fibre type, and composite material, two or more materials with significantly different physical or chemical properties, (Andersen et al., 2010) can negatively impact RFD, emphasising the importance of understanding these elements for effective training and performance enhancement. Reduced muscle soreness resulting from fast SSC movements (Blazevich et al., 2009) further stresses their practical significance for athletes and individuals seeking to minimise DOMs.

The development of muscular power in the lower body is of great interest to athletic researchers in elite sports (Baker et al., 2001). This emphasis on lower body power is justified as it plays a pivotal role in athletic performance, particularly in explosive strength, also known as explosive power or power, refers to the ability of a muscle or group of muscles to generate maximum force in a short period, movements like sprinting and jumping. Consequently, there is ongoing debate regarding the optimal training resistance or load that promotes peak power output (PPO), the maximum amount of power that an individual can generate or produce at a specific point in time, during these maximum intent efforts (Baker, 1995; Wilson et al., 1996).

Previous studies have suggested that resistance training aimed at increasing muscular power output may be the most effective approach for power development in explosive movements (Wilson et al., 1993). This argument aligns with the well-documented principle that resistance training primarily enhances concentric force and RFD, making it necessary for improving explosiveness. Furthermore, plyometric movements with light loads and high velocities improve the ability to generate force eccentrically, thus complementing the concentric gains achieved through resistance training (Wilson et al., 1996). Nevertheless, the ongoing debate among researchers about the ideal load for achieving PPO highlights the complexity of this field and the need for further investigation to establish a consensus.

2.1.5 Muscle Hypertrophy Overview

In conclusion, this section has highlighted the multifaceted factors influencing muscle hypertrophy, a key objective in resistance training. The interplay of mechanical tension, sarcomere lengthening, and neural adaptations highlights the importance of deliberate exercise approaches, emphasising the significance of increased volume resistance training. Metabolic stress has an important role in promoting muscle growth, with its known relationship with intensity and volume. The inclusion of isometric, eccentric, and power training strategies broadens our understanding of multiple training modalities and their implications for muscle development. Muscle damage, another influential aspect of resistance training, prompts considerations of contraction velocity and the role of eccentric movements. RFD and muscular power emerge as crucial determinants of athletic performance, with a detailed exploration of their relevance in diverse sporting activities. This comprehensive examination features the intricacies of muscle hypertrophy, guiding practitioners and researchers toward a nuanced understanding of optimal training strategies for varied outcomes. In examining the importance of resistance training and muscle hypertrophy, a closer investigation of the core principles underlying resistance training will enhance the comprehension of basic movement patterns.

2.2.0 Core Principles of Resistance Training

Resistance training, a practice that has seen continuous development since the 19th century, provoked the interest of respected physiologists primarily within the last half-century (Stojiljković et al., 2013). This delayed recognition is due to the limited scientific exploration of the field until the mid-20th century, when research began to uncover the physiological responses and mechanisms of adaptations associated with resistance training, ultimately establishing its significance (Kraemer et al., 2017).

Early developments in resistance training as a science stemmed from practical knowledge of how programs influenced athletes' S&C goals (Kraemer, 2016). The foundational concepts established by Nobel Laureate Archibald Vivian Hill in the 1920s and 1930s provided the basis for future investigations into muscle mechanics and function, contributing to resistance training across different demographics (Hill, 1924-1935).

2.2.1 Foundations of Strength Training and Performance Optimisation

Understanding and incorporating fundamental strength exercises such as the barbell squat, an exercise that primarily targets the muscles of the lower body, a barbell bench press, an exercise that primarily targets the muscles of the upper body, and barbell deadlift, an exercise that primarily targets the muscles in the lower back, hips, glutes, and hamstrings, in training is essential, as highlighted by Williams et al. (2017). These movements serve as the foundation for resistance training, enabling the development of various exercises that can ultimately result in improved athletic ability. This is due to resistance training which aims to enhance muscle strength by utilising the body's athletic ability to counteract the force generated by the procribed mass. This type of training plays a crucial role in improving an athlete's capacity to generate force and power, as stated in the Oxford Dictionary of Sports Science & Medicine (2007). Understanding and applying optimal techniques for maximising strength, as emphasised by MacDonald, C. J. et al. (2012), is essential to ensure that athletes reach their full potential and reduce the risk of injuries, making it crucial area for this research topic.

Bartolomei et al.'s 2021 study investigates absolute strength, the maximum amount of force or load that a person can generate or lift, differences between male and female athletes, emphasising variations in upper-body movements. The research likely employs assessments like 1RM testing across diverse samples, revealing that males generally exhibit greater upper-body strength. The study highlgihts the necessity of tailoring training programs to address gender-specific strength variations, advocating for adjustments in exercise selection, volume, intensity, and progression. By recognising and accommodating these disparities, tailored training programs aim to optimise performance for both male and female athletes, contributing to more effective and targeted athletic development.

Explosive strength is essential in many sports (Issurin, V. & Tenenbaum, G., 1999). This is due to the increased muscular strength not only enhancing overall performance but also playing a pivotal role in improving specific skills such as maximum velocity running and jumping (Suchomel,

T. J. et al., 2016). Additionally, maximum strength is closely linked to the capacity for generating power in various parts of the body, as indicated by numerous studies (Baker, D., 2001; Nuzzo, J. L. et al., 2008; Peterson, M. D. et al., 2006; Asci, A. & Acikada, C., 2007).

2.2.2 Comparative Analysis of Compound and Specialised Training Approaches

Compound training, the involvement of multiple joints and muscle groups in a single exercise, represents the general approach to resistance training for several reasons. Firstly, it allows individuals to target both strength and power, catering to a broader spectrum of fitness goals. Secondly, the inclusion of sessions with increased resistance (70-90% 1RM) supports the development of raw strength, the power or force created without any refinement or specialised skill, promoting muscle growth and functional capabilities. Conversely, sessions with decreased resistance (30% 1RM) facilitate ballistic, a form of exercise that involves dynamic, explosive movements, and plyometric training, enhancing power and change of direction. This approach, as demonstrated by Stasinaki et al. in 2015, optimises athletic performance and overall physical fitness by addressing multiple dimensions of training within a single regime.

A study on healthy men found that compound training led to increased jumping and throwing performance, while both complex and compound training improved strength in exercises like a barbell bench press, leg press, a stationary strength training exercise that targets the muscles in the lower body, and box squat, a variation of the traditional squat exercise where the lifter performs the movement by sitting back onto a box (Stasinaki, A.-N. et al. 2015). This highlights the versatility and effectiveness of compound training, as it not only develops functional performance but also significantly contributes to strength gains in various exercises, making it a well-rounded approach.

Pyramid training, a strategy that involves gradually increasing or decreasing the mass lifted in successive sets within a workout, represents another variation of compound training to stimulate and promote strength gains. Through previous research is has been found that the pyramid training strategy promotes muscle hypertrophy and strength gains (Fischetti, F. et al., 2019), making it an effective method for overall muscle development.

Previous research has also suggested that neuromuscular fatigue, a temporary decline in the ability of a muscle to generate force or perform a specific task, is more common when performing compound lifts with heavy loads (80% 1RM) and increased volume (Barnes, M. J. et al. 2019). This finding is significant as it stresses the importance of carefully managing training variables, such as load and volume, to optimise outcomes and minimise the risk of overexertion and potential injury.

Additionally, cluster set training represents a strategic approach in optimising strength-based regimens, as highlighted by Nicholson and colleagues in their 2016 study. This training methodology goes beyond conventional strength training by carefully managing both load and velocity aspects during exercises. The incorporation of brief rest intervals within cluster sets plays a pivotal role in preserving the quality of each repetition. These intermittent breaks not only aid in mitigating fatigue but also contribute to sustaining the desired level of force and velocity throughout the workout. This approach to strength training acknowledges the interconnected nature of load and velocity, recognising that an optimal balance between the two is essential for maximising performance gains.

Complex training is another effective approach that combines heavy-load resistance movements with plyometric exercises in a single set. This method is supported by research by Freitas et al. in 2017, which highlights its effectiveness in enhancing power and strength simultaneously. By combining these two types of exercises, complex training induces the potentiation effect, where the heavy resistance exercise primes the neuromuscular system, the complex interaction between the nervous system and the muscles, for improved performance in subsequent plyometric movements.

Muscular power training, achieved through various methods of resistance training and plyometrics, is essential for competitive sports (Smilios, I. et al., 2005), as it enhances athletes' explosiveness on the field. Strength and power training programs, including exercises like back squats and power clean, a full body barbell exercise that is part of the Olympic weightlifting repertoire, develop change of direction velocity (Keller, S. et al., 2020).

Compound and cluster training are preferred for their multifaceted benefits and adaptability. Compound exercises offer a comprehensive approach to resistance training, targeting strength and power across various muscle groups. Their versatility is evident in studies on jumping, throwing, and traditional strength exercises. Cluster set training strategically manages load and velocity, preserving repetition quality and optimising force and velocity throughout the workout. These methods align with the goal of improving muscular power in competitive sports through a combination of resistance training strategies.

2.2.3 Principles of Resistance Training Overview

In conclusion, the current section has provided a comprehensive exploration of the core principles of resistance training, delving into its historical development and foundational concepts. The significance of understanding and incorporating fundamental strength exercises, such as the barbell squat, bench press, and deadlift, has been highlighted, emphasising their role in building a solid foundation for resistance training. This section also explored the nuances of absolute strength differences between male and female athletes, highlighting the importance of tailored training programs. The comparative analysis of compound and specialised training approaches showcased the versatility and effectiveness of compound training in addressing multiple fitness dimensions within a single regime. Additionally, pyramid training, cluster set training, and complex training were discussed as strategic approaches to optimise strength-based regimens. Overall, this section sets the stage for a deeper exploration of resistance training methodologies, laying the groundwork for understanding how various approaches contribute to improving athletic performance.

2.3.0 Impact of Resistance Training on Athletic Performance Attributes

Resistance style movements like weightlifting, such as the snatch, when the barbell is moved from the ground to an overhead position in one smooth and explosive motion, and clean & jerk, when the barbell is moved from the ground to the shoulders (the clean), and then lifting it from the shoulders to overhead in a single motion (the jerk), have accumulated strong support from scientific research (Hori, N. et al. 2005; Garhammer, J. & Gregor, R. 1992) for their proven ability to significantly enhance athletic performance. Furthermore, studies have demonstrated a direct correlation between the power clean and improvements in sprinting and vertical jumping (Hori, N. et al. 2008). Given the biomechanical similarities in power and force production, weightlifting exercises are a valuable training tool for athletes in high-velocity sports like football and athletics (Docherty, D. et al. 2004; Hoffman, J. R. et al. 2004; Stone M. H. et al. 1980), as they are instrumental in maximising power outputs and performance.

Weightlifting holds a leading position in athlete programs, with strong acceptance from S&C coaches across various sports organisations. Due to its high utilisation rates, it's clear that weightlifting is considered an essential training tool in high schools (97%), the NFL (88%), the NHL (100%), and the NBA (95%) (Duehring, M. D. et al. 2009; Ebben, W. P. & Blackard, D. O. 2001; Simenz, C. J. et al. 2005; Ebben, W. P. et al. 2004). This widespread adoption is further justified by its direct impact on a critical performance factor: the RFD, as highlighted in studies such as McLellan, C. P. et al. 2011 and Haff, G. G. et al. 1997. Notably, weightlifting exercises, such as mid-thigh isometric pulls, demonstrate an impressive RFD, surpassing rates achieved by standard movements like deadlifts and barbell back squats, as supported by Kawamori, N. et al. 2006 and Swinton, P. A. et al. 2011, 2012.

Studies have shown that it is important to prioritise velocity training exercises over traditional barbell squats or deadlifts for athletes in power-oriented sports. This recommendation is based on research conducted by Channell and Barfield in 2008, which revealed significantly higher power outputs during weightlifting movements. Additionally, a study by Helland and colleagues in 2017 further supports this notion by demonstrating that motorised strength and power training, the integration of specialised equipment that utilises motorised components to provide variable resistance, is a time-efficient alternative to traditional strength and power training, with comparable and/or superior outcomes in sprint performance and vertical jump height. These findings emphasise the potential advantages of incorporating velocity-based training methods for athletes aiming to enhance their power-related athletic performance.

Training programs focused on weightlifting have been associated with improvements in sprinting, jumping, and balance (Arabatzi, F. et al. 2010; Chaouachi, A. et al. 2014). This evidence underlines the advantages of weightlifting, demonstrating its positive impact on key athletic skills. Furthermore, the notable peak power output displayed by weightlifters during vertical jumps, as documented by Carlock, J. M. et al. in 2004, lends credence to the efficacy of this training approach. These findings collectively suggest that weightlifting enhances various physical attributes, supporting the hypothesis that an individual's power-producing capacity is influenced by seven distinct attributes:

A - Maximum strength
B - Rate of force development (RFD)
C - High load speed strength (greater than 30% of 1RM)
D - Low load speed strength (less than 30% of 1RM)
E - Reactive strength
F - Power endurance
G - Skill performance
(Newton, R. U. & Dugan, E. 2002)

These specific attributes are relevant to this study through a variety of output metrics. Firstly, the A - Maximum Strength attribute is appropriate as it encompasses both force and power outputs, which are essential metrics for this research. Secondly, B - RFD is essential as it addresses the velocity at the point of peak force for everyone. Additionally, C - High Load Speed Strength is significant as it refers to the acceleration of individuals during the movement. It's worth noting that the approach used for this study could have been applied to loads below 30% of an individual's 1RM for future research. Furthermore, it's important to acknowledge that in this current study, there won't be analysis on reactive strength, power endurance, or skill performance. These unexplored aspects hold potential for providing valuable insights in future studies within this field.

2.3.1 Improving Athletic Performance through Squat Movement Variations

Baker's (1996) evaluation recommends a comprehensive approach to enhancing vertical jump performance. This involves incorporating both generic strength training, such as barbell squats, and specialised strength training like depth jumps. The inclusion of depth jumps allows for variations like squat jumps and CMJs, providing flexibility in training methods. However, Baker's (1996) emphasises the superiority of weightlifting movements and jump squats as the most effective strength training techniques, highlighting their significance in achieving optimal vertical jump improvements. In discussing both squat jumps and jump squats in this section, it is important to initially recognise the fundamental features of each movement in order to differentiate between the two styles. In a squat jump, the athlete performs a body weight jump from a stationary position where the hip and knee parallel to the ground as shown in Figure 1. However, a jump squat is a dynamic exercise that uses a standard barbell squat movement with an explosive CMJ as shown in Figure 2.

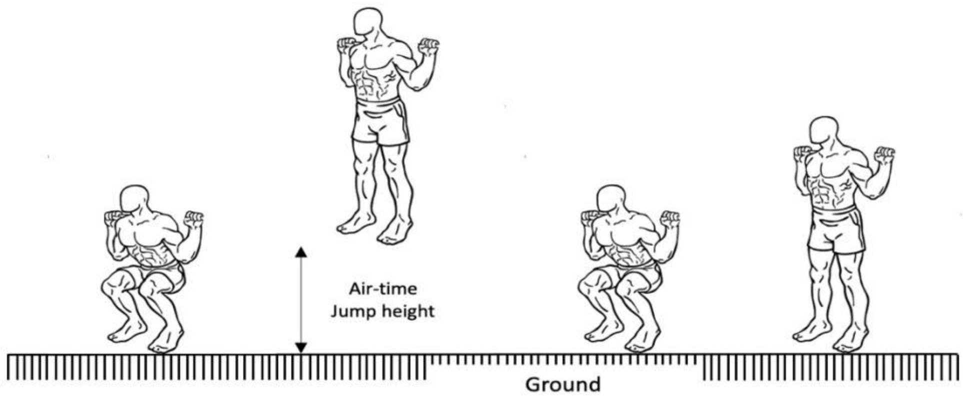

Figure 1. Performing a squat jump movement from ground level.

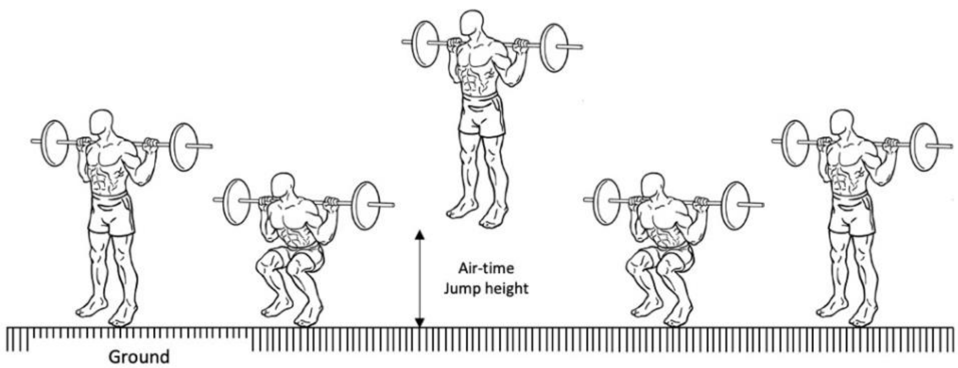

Figure 2. Performing a jump squat movement from ground level.

The jump squat test is a valuable tool for assessing peak lower-body power, commonly referred to as speed strength, as supported by studies by Young (1995) and Markovic et al. (2004). It is practical to base the jump squat mass on an individual's 1RM for the barbell back squat, as suggested by Haun (2015), given the biomechanical similarities between these exercises. This approach provides coaches and investigators the adaptability to manipulate the barbell mass percentage, promoting the monitoring of various output metrics and enhancing the test's effectiveness.

Coaches and investigators are utilising performance profiling, the analysis of an athlete's strengths and weaknesses in various aspects related to their sport, particularly "force-power-velocity profiling" (Morin, J.-B. & Samozino, P. 2016), as it allows for tailored training programs. The squat jump, established as a dependable indicator of lower body power (Markovic, G. et al. 2004), naturally lends itself to monitoring performance across various athletic goals (Docherty, D. et al. 2004, Abernethy, P. et al. 1995, Harman, E. 1993, Sale, D.G. et al. 1991). This technique helps optimise training by focusing on specific strength and power aspects essential for individual athletes.

Furthermore, a jump squat exercise (Harris, N. K. et al. 2008) and relative strength, the amount of force or muscular strength a person can generate in relation to their body mass, during a 1RM barbell back squat (Haun, C. T. 2015) was found to be strongly correlated with sprint velocity success. This relationship emphasises the significance of incorporating jump squats to an athlete's training schedule to develop sprinting performance capabilities. While this method shares similarities with VRT, it distinguishes itself by predominantly targeting the lower extremities of a person's 1RM during jump squat load prescription. Nevertheless, the methods employed for tracking results in jump squats can be applicable to VRT, making it a potential alternative to substitute 1RM testing.

From either plyometric testing or variable resistance testing, it is hypothesised that focusing on an athlete's weakest power characteristics leads to the greatest performance gains (Newton, R. U. & Dugan, E. 2002). This hypothesis is crucial as it stresses the significance of tailored training programs that address individual weaknesses, ensuring optimal athletic development and performance enhancement with the inclusion of VRT.

2.3.2 Integrating Resistance Training for Improved Dynamic Correspondence

Dynamic correspondence, the practice of replicating sport-specific movements in S&C routines, has gathered support from multiple studies. These studies, including research by Chaouachi et al. (2014), Ozbar et al. (2014), Lake and Lauder (2012), and Rønnestad et al. (2015), consistently demonstrate that this technique into training programs can enhance sports performance.

Generally, training routines should align with the principle of specificity, as emphasised by Sale et al. (1981). This principle advocates that the exercises performed should closely mimic the specific athletic movements one aims to improve, considering factors like muscle contractions, movement patterns, and force generation. Weightlifting is often compared to various sporting actions due to its dynamic nature. Research by Canavan et al. (1996) and Garhammer and Gregor (1992) has shown that the jerk's push position and the final pull stages of the snatch and clean bear kinematic, the description of motion, without considering the forces that cause the motion, and kinetic, the forces acting on or generated by bodies in motion, similarities to jumping movements commonly found in sports.

Training movements should surpass the system's neuromuscular capacity during specific sports activities, like vertical jumping, to enhance performance (MacKenzie, S. J. et al. 2014). This occurs due to pushing the limits of the system's neuromuscular capacity through intense training which can lead to adaptations that result in greater strength and explosiveness, essential for achieving higher vertical jumps. The concept of "triple extension" highlights the significance of dynamic joint movements in sport, emphasising the explosive coordination of the hip, knee, and ankle. This synchronisation is crucial for athletes engaging in activities like weightlifting and basketball, where movements like snatch and jumping dunk rely on the same triple extension mechanics. Furthermore, research indicates that rapid performance improvements can be achieved during rapid drop manoeuvres, often referred to as rapid deceleration movements, when transitioning from triple extension, when an athlete extends or straightens the hip, knee, and ankle joints simultaneously, generating maximum power and force, to triple flexion, a coordinated bending or flexing action of the three joints (Campos et al., 2006; Garhammer, 1985). This highlights the importance of not only training for explosive extension but also optimising the transition between extension and flexion, which can significantly impact an athlete's overall performance.

The rapid drop-down manoeuvre in clean and snatch is an essential element during the catch phase, requiring explosive power and coordination. Incorporating plyometric movements into weightlifting training is justified as they involve rapid eccentric and concentric movements, enhancing explosiveness and power (Duda, M., 1988, Steben, R.E. et al. 1981). Plyometric training is versatile, benefiting not only rehabilitation in later stages (Chmielewski, T. L. et al. 2006) but also S&C, making it an essential component for improving performance (Davies, G. et al. 2015).

2.3.3 Impact of Resistance Training Overview

In conclusion, this section has delved into the profound impact of resistance training on various athletic performance attributes, particularly emphasising the efficacy of weightlifting exercises. Scientific research has consistently supported the integration of weightlifting, such as snatch and clean & jerk, in training programs to enhance power outputs, sprinting, and vertical jumping. The widespread adoption of weightlifting in various sports organisations further builds on its significance. Additionally, the focus on squat movement variations, including squat jumps and jump squats, has been explored, shedding light on their role in improving lower-body power and sprinting performance. The importance of tailoring training programs to individual weaknesses, as highlighted by the hypothesis that targeting an athlete's weakest power characteristics leads to the greatest performance gains, is a key takeaway. Furthermore, the integration of resistance training for dynamic correspondence, replicating sport-specific movements, has been discussed, underlining its potential to enhance sports performance through neuromuscular adaptations and explosive coordination. Overall, this section highlights the multiple benefits of resistance training, providing valuable insights for athletes and coaches aiming to optimise their training regimens for superior athletic performance. Elevating athletic performance through strategic training methods draws upon these insights, offering a comprehensive exploration of how strategic training approaches, rooted in resistance training principles, can effectively optimise an athlete's performance across various sports.

2.4.0 Elevating Athletic Performance through Strategic Training Methods

2.4.1 The Importance of Ballistic Training in Enhancing Athletic Power and Performance

The term "ballistic" is commonly used in fitness and sports training to describe a technique that involves forcefully launching gym equipment or one's body into a phase of flight while performing actions like throwing, striking, and jumping (Moir et al., 2016). This approach to training emphasises the manipulation of the load to enhance movement velocity, as opposed to traditional lifting methods that rely on heavier weights to develop neuromuscular capacity, the ability of the neuromuscular system to generate and sustain force, through increased force generation (Turner, 2009).

Various studies (Fleck & Kraemer, 2014; Berger, 1963; Elliott et al., 1989; Frost et al., 2008; Wilson et al., 1993; Young & Bilby, 1993) have highlighted the limitations of conventional weightlifting in improving power production. This extensive citation of studies highlights the well-established nature of this issue in the literature. Due to the need of decelerating the weight to a full stop during the movement (Fleck & Kraemer, 2014), the amount of deceleration can range from 24% to 52% of the concentric contraction (Elliott et al., 1989; Newton & Wilson, 1993). These specific references provide numerical evidence for the significant deceleration component in conventional weightlifting. When athletes try to move quickly with lighter weights, the deceleration component increases, hindering muscular power performance (Newton et al., 1994). This explanation clarifies the practical implications of the deceleration issue. Ballistic training addresses this issue by allowing athletes to maintain velocity throughout the exercise (Fleck & Kraemer, 2014), offering a clear solution to the problem previously established by these studies.

Ballistic training, as demonstrated by Davies et al. (2015), offers unique advantages compared to plyometrics. Unlike plyometrics, it eliminates the need for eccentric pre-stretching, also known as eccentric loading, followed by a rebound. This characteristic distinguishes ballistic training as a highly effective approach for enhancing muscular power (Kawamori & Haff, 2004; Newton & Kraemer, 1994). Muscular power is a fundamental attribute relevant to a wide range of athletic activities (Cormie et al., 2011; Haff & Nimphius, 2012). Notably, ballistic training has been linked to a superior RFD (Turner, 2009), a critical factor recognised for its influence on an athlete's performance (Aagaard et al., 2002; Stone et al., 2003; Suchomel et al., 2018).

Heavy resistance exercises can enhance muscular power when performed with maximal intent, as indicated by Behm et al. (1985). However, the justification for favoring weightlifting lies in its ability to engage a greater number of motor units compared to endurance movements, as highlighted by Suchomel et al. (2018). This increased motor unit recruitment ultimately results in a higher potential for improving power capabilities. To tailor training programs effectively, the dynamic strength index (DSI), which reflects the balance between an individual's isometric and ballistic force, is a valuable tool (Thomas et al., 2015). By assessing an individual's DSI through ballistic tests like the barbell squat, CMJ and isometric tests such as the mid-thigh isometric pull, a variation of an isometric exercise, as demonstrated by Weiss et al. (2002) and Thomas et al. (2015), researchers can develop more precise and targeted strategies to enhance both power and strength in athletes and individuals seeking performance gains.

2.4.2 A Review of Optimal Load Selection for Peak Power Output

The following study by McBride et al. (2010) reported that the optimal load for PPO in a comparison of back squats with box squats was 60% of 1RM, emphasising the significance of this load for PPO enhancement. Similarly, Alcaraz et al. (2011) found that PPO consistently occurred at 60% of 1RM in their study, further supporting the reliability of this load as a reference point for PPO training. More recently, McBride et al. (2011) discovered that the ideal load for increasing

PPO in athletes was 50% of their 1RM, suggesting potential variability in optimal loads and highlighting the importance of considering individual differences in PPO responses.

In contrast, these highlighted studies provide valuable insights into the optimal external loads for achieving PPO during various resistance exercises. Bevan et al. (2010) suggest that a wide range of external loads, from 0 to 80% of 1RM, may develop PPO, highlighting the versatility of training intensities. Baker et al. (2001) emphasises the importance of using resistances averaging 85-95% or 55-59% of 1RM for maximising PPO during ballistic squats, stressing the significance of a moderate load range. Additionally, Cormie et al.'s research (2007) specifically identifies the ideal load of 56% of participants' 1RM for PPO in barbell back squats, providing a precise guideline for optimising training intensity in this exercise. The findings collectively emphasis the importance of tailoring load selection to the specific exercise and individual goals to achieve the highest PPO.

2.4.3 Significance of 1RM Testing in Evaluating and Enhancing Athlete Strength

To further enhance the efficiency of specific training approaches, it is recommended to regularly conduct strength testing. The 1RM test is widely considered the optimal method for assessing an athlete's strength outside a laboratory setting (Levinger et al., 2007) as it provides a straightforward and practical measure of an individual's maximum strength capacity, a commonly used term referring to absolute strength. Coaches frequently use 1RM testing to evaluate strength capabilities, movement imbalances, and the effectiveness of training regimens (Braith et al., 1993), making it a valuable tool in optimising an athlete's performance. Improving an athlete's strength from their 1RM is fundamental for enhancing athletic performance (Wisløff et al., 2004; Comfort et al., 2014; Sander et al., 2013). This focus on developing strength is justified by a substantial body of research highlighting its direct impact on athletic success and overall performance.

Various studies have utilised different rest intervals between 1RM attempts, ranging from as short as 1-2 minutes (Levinger et al., 2007; Faigenbaum et al., 2003; Seo et al., 2012; Rydwik et al., 2007; Phillips et al., 2004) to as long as 3-5 minutes (Ribeiro et al., 2014; Urquhart et al., 2015). This variability in rest intervals allows researchers to explore the impact of rest duration on 1RM performance, considering factors like fatigue and recovery, thus contributing to a more comprehensive understanding of optimal training protocols.

1RM testing is a safe and accurate way to assess strength in various populations, as supported by numerous studies (Faigenbaum et al., 2003, 2012; English et al., 2008; Bezerra et al., 2013; Seo et al., 2012; Ribeiro et al., 2014; Urquhart et al., 2015; Levinger et al., 2007). However, caution is advised for inexperienced weightlifters, as some research suggests that they should avoid 1RM testing due to the risk of extreme discomfort and potential injury (Braith et al., 1993; Dohoney et al., 2002). This diversity of findings stresses the importance of individualised assessment strategies based on a person's experience and training level.

While a particular training approach may derive additional advantages from assessing 1RM, there is a prevailing belief that concerns about potential injuries during maximum testing could be mitigated adopting other techniques. To mitigate the risk of significant discomfort and potential harm, integrating VRT for regular monitoring of an athlete's output levels is proposed. Since VRT involves submaximal effects at reduced volume, this approach would permit minimal DOMS and facilitate faster recovery.

2.4.4 Athletic Performance Overview

In conclusion, this section has delved into the intricacies of elevating athletic performance through strategic training methods, with a specific focus on ballistic training and optimal load selection for peak power output. The limitations of conventional weightlifting in improving power production have been thoroughly explored, emphasising the deceleration component and its impact on muscular power performance. Ballistic training emerges as a viable solution, enabling athletes to maintain velocity throughout exercises and offering unique advantages over plyometrics. This section also delves into the nuanced discussion of optimal load selection for peak power output, highlighting the variability in recommendations and further highlighting the importance of tailoring loads to specific exercises and individual goals. Considering this, the decision to utilise a 60% 1RM mass contribution in this study was made to maximise the impact on peak power output. Additionally, the significance of 1RM testing in evaluating and enhancing athlete strength is emphasised, providing valuable insights into the practical aspects of strength assessment and its impact on athletic success. The current section concludes by proposing the integration of VRT as a safer alternative, a key aspect of this study, for regular monitoring of an athlete's output levels, mitigating potential risks associated with maximal testing and promoting faster recovery. These insights have highlighed the need for a comprehensive understanding of performance enhancements through VRT and exercise considerations.

2.5.0 Performance Enhancements Through Variable Resistance Training and Exercise Considerations

A decade ago (Simmons L. P. 1999), elite powerlifting, a strength sport that consists of three main lifts: squat, bench press, and deadlift, embraced variable resistance training, which has since become popular in various S&C settings (Anderson, C. E. et al. 2008, Bellar, D. M. et al. 2011, Cronin, J. et al. 2003, Ebben, W. P. & Jensen, R. L. 2002, Ghigiarelli, J. J. et al. 2009, Israetel, M. A. et al. 2010, Rhea, M. R. et al. 2009, Stevenson, M. W. et al. 2010, Wallace, B. J. et al. 2006). This adoption reflects the increasing recognition of the method's efficiency in enhancing S&C across various sports and athletic disciplines, further substantiating its significance within the field of performance training.

VRT has gained recognition as an effective approach compared to traditional methods for enhancing maximal strength in untrained individuals and sporting athletes (Soria-Gila et al., 2015). This innovative approach introduces variability and progressive resistance, thereby challenging muscles in unique ways over time, ultimately contributing to additional strength gains in a diverse range of individuals.

Variable resistance through elastic bands or chains provides a valuable training tool for strength and conditioning (S&C) coaches. Research studies by Baker and Newton (2009) and Joy et al. (2016) have shown that these methods induce neural adjustments, the changes that occur in the nervous system in response to resistance training, assisting athletes to enhance their strength, especially in terms of their 1RM. By incorporating elastic bands or chains into their routines, coaches can introduce diverse stimuli, thus preventing training plateaus and continually challenging their athletes to make progress in standard resistance training programs.

2.5.1 Comparative Analysis of Standard Link Steel Chains and Rubber-Based Resistance Bands

Standard link steel (SLS) chains and rubber-based resistance (RBR) bands are systems that provide flexible training stimulus (Mcmaster, D. T. et al., 2010). These versatile tools offer adaptability in resistance levels and exercise variations, making them suitable for a wide range of users and purposes. Both athletes and professionals in S&C, as well as those involved in rehabilitation, utilise these types of resistance (Mcmaster, D. T. et al., 2010), as they can be tailored to meet specific training goals and accommodate varying fitness levels, making them valuable additions to any training regimen.

The discrepancy between SLS chains and RBR bands in terms of their resistance behavior is important to understand as it impacts their practical applications. The research by McMaster et al. (2010) established that while both experience resistance increases with distortion and displacement, RBR bands exhibit a curvilinear rise in resistance, which means their resistance changes nonlinearly, while SLS chains demonstrate a linear rise. This discrepancy informs us about the unpredictable behavior of these materials when subjected to different types of stress or loading conditions. Furthermore, the nature of RBR bands, as highlighted by Özkaya et al. (2012), introduces an additional layer of complexity, as they display both elastic and non-elastic resistance qualities when stretched or twisted. Lastly, Wallace et al. (2006) suggests that the tension or resistance in RBR bands is influenced by their stiffness, which is determined by various factors. This knowledge emphasises the need to carefully control and manipulate these parameters when utilising RBR bands in practical settings, ensuring that their resistance properties align with the desired outcomes.

Previous research has shown the linear and curvilinear tension-deformation areas and relationships for RBR bands (Hughes, C. J. et al., 1999; Page, P., 2000; Thomas, M. et al., 2005; Wallace, B. J. et al., 2006). This extensive body of work provides a robust foundation for understanding the behavior of RBR bands under different tension or stress levels and the resulting internal strain or deformation (Hughes, C. J. et al., 1999; Page, P., 2000; Thomas, M. et al., 2005; Wallace, B. J. et al., 2006), enhancing our knowledge of their mechanical properties and applications in various fields.

2.5.2 Exploring the Benefits, Considerations, and Impact of Accommodating and Variable Resistance Techniques

The terminology used to describe VRT can vary across different studies. It is crucial to differentiate between VRT and Accommodating Resistance Training (ART) initially. VRT encompasses the general application of variable resistances in training methods, specifically involving the use of RBR bands. On the other hand, ART involves SLS chains in its application. Within this investigation, the term ART will refer to the utilisation of SLS chains, while VRT will signify the application of RBR bands. When utilising ART and VRT, it is essential to consider their advantages, application, and safety. These diverse approaches ensure that individuals can harness the full potential of ART and VRT while minimising the risk of injury.

During resistance-based exercises, the addition of SLS chains provides variable resistance, altering the weight lifted throughout the range of motion (Nijem et al., 2016). This technique creates a linear mass-displacement relationship, where the participants height determines the load lifted. The use of SLS chains as an accessory to weightlifting movements, along with traditional mass, is increasingly common in competitive and commercial settings (Coker, C. A. et al., 2006). This trend is driven by the hypothesis that using SLS chain accommodating resistance during deadlift movements could help maintain a neutral spine by minimising mass at the sticking point (Nijem, R. M. et al., 2016). This practical consideration can also be applied to barbell back squats, where the mass is lightest during the peak eccentric point. While the impact on lumbar forces and injury risk is still uncertain, the potential benefit of preserving spinal integrity is a compelling reason to explore the use of SLS chains in these weightlifting exercises.

It is important to consider the impact of increased SLS chain mass on muscular power, velocity, and RFD since these effects are influenced by variables like movement choice and initial barbell load. Additionally, recognising the distinct biomechanical stimulations, the application of mechanical forces to the body or its tissues to elicit specific physiological responses, induced by SLS chains and RBR elastic bands is vital, especially when dealing with higher levels of ART and VRT, as these differences can significantly affect exercise effectiveness and muscle engagement. (Swinton, P. A. et al., 2011).

Athletes' perceptions of the psychological impact of chains may result in increased effort exertion during the movement. This heightened psychological motivation can complement the physiological benefits, making the overall impact of chains on performance more profound. While the physiological versus psychological impact of using chains is debatable, if their implementation doesn’t cause harm or threaten the athlete and the individual believes in their benefits, it can serve as substantial evidence for their use (Coker, C. A. et al., 2006).

The addition of chains may be particularly advantageous for individual athletes in sports like weightlifting and powerlifting, rather than team-based sports with a larger number of participants, due to the complexity involved in determining suitable chain mass percentages based on 1RMs, designing exercises, and establishing set ranges, repetitions, and working volumes (Berning, J. M. et al., 2008). This is due to individual athletes in sports like weightlifting and powerlifting have more control over their training variables and can fine-tune their SLS chain usage to maximise their personal performance, whereas team-based sports may face logistical challenges in implementing such precise training methods for a large group of athletes.

Drawbacks during training sessions, such as the cost of additional equipment and the extra labor involved in handling and assembling systems like adjusting RBR bands and SLS chains, can potentially hinder training efficiency (Ebben, W. P. & Jensen, R. L., 2002). However, Soria-Gila, M. A. et al. (2015) provided a compelling justification for implementing VRT exercises with barbells, highlighting their cost-effectiveness and simplicity. Additionally, the ease of connecting and disconnecting RBR bands and SLS chains allows S&C practitioners to quickly recommend alternative activities, saving valuable training time (Soria-Gila, M. A. et al., 2015). This illustrates how the benefits of ART and VRT can outweigh their drawbacks in terms of cost and labor, ultimately optimising training sessions.

In terms of dynamic correspondence, when exercises have similar biomechanical movement characteristics, the barbell squat demonstrates the closest biomechanical relationship to ballistic movements like CMJ, which involve PPO. This connection is significant as it implies that training with barbell squats can potentially enhance an athlete's ability to generate muscular power, a vital aspect in various sports and activities. When combining SLS chain or RBR bands with weighted bumper plates, athletes may be able to handle higher maximum loads. This additional resistance during the concentric phase of exercises such as squats can lead to improved mechanical benefits by challenging the muscles more intensively and potentially yielding greater gains in power and strength (Ebben, W. P. & Jensen, R. L., 2002).

2.5.3 Exploing the Impact of Accommodating and Variable Resistance Training Through Chains and Elastic Bands

ART is a valuable approach as it strategically enhances muscle force output by adjusting to the biomechanically advantageous phases of a lift (Nijem et al., 2016). For instance, the incorporation of SLS chains in barbell squat or bench press exercises dynamically increases resistance during the concentric phase, matching the ascending strength curve, the resistance of an exercise increases as the joint angle or muscle force generation improves throughout the ROM. (Baker & Newton, 2009; Nijem et al., 2016; McMaster et al., 2009). This use of ART prompts athletes to position themselves optimally, ensuring they can generate the highest possible force.

Additionally, ART is a valuable training method which also addresses the challenge of barbell deceleration and reduced force output in the concluding stages of strength-based exercises (Swinton et al., 2011). For example, during the bench press, athletes must actively slow down the barbell as they approach the end of the lift to ensure control. However, in exercises like a bench throw, this deliberate deceleration becomes unnecessary as the barbell is intentionally released. Utilising ART helps mitigate the need for active deceleration, thus enabling the preservation or even enhancement of force production and barbell acceleration during the critical final phase of the exercise (Swinton et al., 2011; Baker & Newton, 2005; Simmons, 1999).

Swinton et al. (2011) conducted a study demonstrating increased peak impulse, the change in momentum of an object, and force during a barbell deadlift when using ART. This finding suggests that ART can enhance an individual's ability to generate greater force, which may be valuable in strength training or powerlifting programs. However, it's important to note that the same study revealed a decrease in peak barbell velocity and power, average velocity, and power, as well as peak RFD. This indicates that while ART may be effective for improving peak force, it may not be the ideal choice if the primary goal is to enhance barbell velocity or muscular power. This knowledge can aid coaches and athletes to make informed decisions regarding the incorporation of ART into their training regimens based on their specific performance objectives.

Another study conducted by Swinton et al. (2011) holds significant importance within the literature as it advances our understanding of ART. The use of 20% and 40% 1RM loads during the compound deadlift aligns with research that highlights the need for accommodating resistance to exceed 15% of 1RM for optimal force production (McMaster et al., 2009). In contrast, earlier studies with 5% (Berning et al., 2008) and 8% 1RM loads (Ebben & Jensen, 2002) failed to demonstrate changes in force production. Additionally, the study by Nijem et al. (2016) found no benefits with a 20% 1RM accommodating resistance deadlift, but it is important to consider the participant population—Swinton et al. worked with trained athletes, while Nijem et al. used recreational gym-goers. This stresses the importance of utilising trained athletes in ART research, as it may require a certain level of strength and stability to exploit the advantages of this training method effectively (Soria-Gila et al., 2015). Furthermore, the distinction between RBR bands and SLS chain resistance training, with the former exhibiting a curved length-load connection, the non-linear pattern of the resistance correlation under a variable load, as depicted graphically, and the latter showing a linear, the statistical measure of how closely two variables change together in a straight-line fashion, correlation (McMaster et al., 2010), further emphasises the specific conditions and requirements for successful implementation of these training modalities.

The cited studies, conducted by Anderson et al. (2008) and Wallace et al. (2006), provide valuable insights into the effects of a 7-week RBR band training program. The study revealed that this program resulted in increased maximum strength across exercises like the barbell back squat and bench press. Additionally, the absence of significant gains in muscle cross-sectional area, the area of the muscle when viewed in a cross-section, as noted by Anderson et al. (2008), implies that neural adjustments may be the primary driver of these strength improvements. Furthermore, Wallace et al. (2006) found that individuals completing the program exhibited enhanced muscular power production during the barbell back squat, specifically with loads at approximately 85% of their 1RM. Interestingly, while Anderson et al. (2008) observed significant improvements in mean lower-body power, they did not observe notable adaptations in upper-body power, highlighting the specificity of training effects.

When the training objective is to accelerate strength gains within a very short period (e.g., 2 weeks), variable resistances may be superior to traditional methods. For example, an athlete returning from injury and needing to quickly resume training may adopt variable resistance protocols. Variable resistance offers the advantage of tailored resistance throughout the ROM, which can be beneficial for rehabilitation and rapid strength recovery. Nevertheless, for developing power adaptations in ballistic exercises over the same timeframe, traditional strength training could be the preferred option (Loturco et al., 2020). This would apply to plyometric athlete's dependent on jumping for their sport. Traditional strength training allows athletes to focus on explosive movements and technique refinement, which aligns better with the specific needs of plyometric athletes aiming to enhance their power output within a short time frame.

The concept of the SSC is commonly associated with variable resistance due to its potential to enhance muscle contraction, the process in which muscle fibres generate tension and exert a force by shortening or lengthening, and eccentric loading. RBR bands are believed to aid in the accumulation of elastic energy, thereby improving the effectiveness of subsequent concentric motions (Soria-Gila et al., 2015). However, despite this expectation, studies have produced inconsistent findings regarding the impact of variable resistance on RFD during the concentric phase, as indicated by research by Wallace et al. (2006) and Newton et al. (2002).

Wallace et al. (2006) reported an increase in peak power with variable reistance, which is significant as enhanced peak muscular power can lead to improved athletic performance and functional strength. However, the study lacked specificity regarding the stage of the concentric movement at which peak power was achieved, leaving room for further investigation and refinement of training protocols. Addressing the concept of the "sticking point,", the point at which the body has the least biomechanical advantage, as emphasised by Anderson et al. (2008), is essential when implementing variable resistance. Identifying and improving this weakest joint position can have a profound impact on an individual's maximum resistance capacity. RBR band resistance is hypothesised, as suggested by Soria-Gila et al. (2015), to enhance the initial RFD and counteract mechanical disadvantages precisely at the sticking point. This hypothesis emphasises the potential of variable resistance to optimise performance by targeting and overcoming biomechanical limitations within a movement.

Variable resistance is believed to play a vital role in facilitating an unloading phase and aiding athletes in accelerating through the barbell, thus enabling them to overcome the sticking point during lifts (McMaster et al., 2009). The documented benefits of long-term variable resistance in enhancing maximum strength provide substantial evidence for its potential contribution to addressing the sticking point (Soria-Gila et al., 2015). Additionally, the practical application of increasing resistance at the end of an athlete's ROM assumes that it amplifies the neuromuscular demands, potentially leading to an increased RFD (Soria-Gila et al., 2015).

Wallace et al. (2006) demonstrated that incorporating variable resistance can elevate muscular power and peak force, providing a potential advantage over traditional bumper plates. However, as previously mentioned with variable resistance, it's important to note that the effectiveness of RBR bands varies depending on factors such as experience level. Soria-Gila et al. (2015) and Shoepe et al. (2011) caution that for inexperienced individuals, the fluctuating resistance of RBR bands may result in decreased peak force output. In contrast, Cronin et al. (2003) and Aboodarda et al. (2014) highlighted the benefits of using RBR bands during the eccentric phase of movements, as it can enhance muscular activation and improve the RFD and impulse. This enhancement has been linked to improved jumping performance, where eccentric RFD is considered a more reliable indicator than concentric RFD. These varied findings stress the importance of considering individual factors and training objectives when deciding to incorporate elastic bands into resistance training routines.

2.5.4 Variable Resistance Training Overview

In conclusion, this section delves into the understanding of performance enhancements through VRT and explores the comparative analysis of SLS chains and RBR bands. The section highlights the increasing recognition of VRT efficiency, particularly using RBR bands and SLS chains, in enhancing S&C across diverse sports and athletic disciplines. By examining the benefits, considerations, and impact of accommodating and variable resistance techniques, this section also sheds light on the application of SLS chains and RBR bands. It emphasises the need for careful control of parameters when utilising these tools, considering their resistance behavior, and acknowledges the importance of individualised approaches in optimising training outcomes. Furthermore, the exploration of the impact of accommodating and variable resistance techniques provides valuable insights into their effects on muscle force output, biomechanical advantages, and potential contributions to addressing sticking points in lifts, all crucial factors within this current study. The current section concludes by highlighting the diverse findings in the literature, highlighting the need for tailored approaches based on individual factors and training objectives when incorporating variable resistance into training routines. In the context of optimising strength performance, the preceding exploration of accommodating and variable resistance techniques further links to the discussion on increasing strength through cluster sets, exercise variations, and testing protocols.

2.6.0 Increasing Strength Performance Through Cluster Sets, Exercise Variations, and Testing Protocols

Muscle fatigue, the decline in the ability of a muscle to generate force or sustain a level of force during repeated contractions, significantly affects movement performance and muscle recovery (Allen et al., 2008; Mileva et al., 2009; Mohr et al., 2007). This shows the importance of finding variations in training to understanding and overcome muscle fatigue as it directly impacts an individual's ability to generate strength and power.

Comparing two resistance training methods, Bartolomei et al. (2017) found that higher volume training leads to greater muscular fatigue due to increased lactate concentrations, a byproduct produced when your muscles break down glucose (sugar) for energy. This conclusion is supported by additional studies, such as the one conducted by Byrne and Eston (2002), which observed lower limb power and strength deficits lasting up to 72 hours following increased volume training. Similarly, Flores et al. (2011) demonstrated a decrease in elbow flexor strength, the ability of the muscles that flex the elbow joint to generate force, lasting five days in novice lifters who underwent higher volume training. These findings collectively underline the physiological impact of higher volume training on muscle fatigue and strength, further highlighting the importance of considering training volume in exercise program design.

In contrast, experienced athletes can recover more efficiently following increased-intensity workouts, allowing for more frequent training of the same muscle groups (Bartolomei et al., 2017). This is supported by long-term research conducted by Baker and Newton, which confirms that the rate of progression in power and strength development diminishes over time as strength levels increase. Furthermore, their study shows that simultaneous endurance and resistance training can enhance strength and power regardless of volume (Baker & Newton, 2006), highlighting the adaptability and potential for continued improvement in athletes with experience.

2.6.1 Comparing Traditional and Cluster Set Rest Strategies for Optimal Progression

A traditional in-set resistance training consists of consecutive repetitions without breaks, followed by a predefined rest period before the next set, as shown in Figure 3 (Tufano et al., 2017). This structured approach helps maximise muscle engagement during each set by minimising interruptions, leading to improved strength and endurance gains over time.

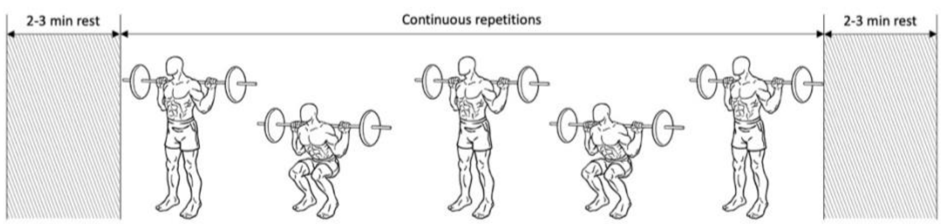

Figure 3. Traditional consecutive set of two repetitions with predefined rest periods.

However, cluster sets use brief rest periods between repetitions within a set, as illustrated in Figure 4, enabling faster lifting velocities without sacrificing the mass lifted (Nicholson et al., 2016). The method helps reduce fatigue, maintain power, and force production, and lessen cardiovascular stress, the strain or pressure placed on the heart and blood vessels, associated with continuous repetitions (Dias et al., 2020). Further research comparing cluster sets to traditional sets demonstrated a significant increase in mean propulsive velocity, the velocity at which a person can generate force and propel themselves forward, and decreased blood lactate levels, the concentration of lactate, a byproduct of anaerobic metabolism, in the bloodstream, during cluster set training (Iglesias-Soler et al., 2012; Oliver et al., 2015).

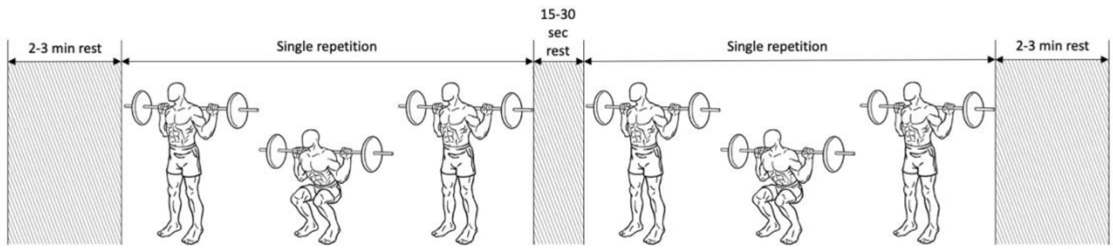

Figure 4. Cluster training method of a two-repetition set separated by a short rest followed by a predefined rest period.

When aiming for maximal strength gains, inter-set rest intervals, the amount of rest time taken between sets, of 2-3 minutes are recommended (Tufano et al., 2017). This duration allows the body to recover from fatigue, and optimise neural recruitment, the process by which the brain allocates and activates specific neural resources in response to a task, promoting efficient muscle contractions and ultimately leading to greater strength gains (Tufano et al., 2017). Intra-set rest periods, the short breaks taken within a single set of exercises, which help manage fatigue and maintain proper technique. Meanwhile, inter-repetition rest refers to rest periods between individual repetitions, aiding in sustaining quality movement patterns and reducing the risk of injury during strength-focused workouts (Tufano et al., 2017).

To provide additional support for adopting cluster set training over traditional approaches, Tufano, J. J. et al. (2017) conducted a systematic review to examine the theoretical and practical aspects of various cluster set structures. The following passage highlights significant discoveries derived from this comprehensive review.

After excluding the work conducted by Tufano et al., four primary studies within the review stood out. Oliver et al. discovered that, during acute testing, 12 subjects with resistance training and 12 untrained subjects executed back squats at 70% of their 1RM. The participants completed either 4 sets of 10 traditional repetitions or 4 sets of 10 cluster repetitions, with a 30-second rest between each attempt. The study revealed that cluster attempts led to increased power output and volume load (Oliver, J. M. et al., 2015). This experimental design was subsequently replicated by Oliver et al. to explore an alternative response output to the method. In this follow-up study, it was observed that during cluster set attempts, velocity and power output were consistently maintained compared to traditional sets (Oliver, J. M. et al., 2016).
Hansen et al. also supported this observation in Oliver et al.'s secondary study. In their study, 18 elite rugby union players underwent acute, a movement that has a short duration, testing performing barbell back squats and pull movements at 85-90% 1RM. Participants executed 3-5 sets of 3-8 traditional repetitions and 3-5 sets of 3-8 cluster repetitions with a 10-30 second rest between each attempt. The conclusion of the study indicated that both movements led to increased strength, with noticeable changes in power and velocity (Hansen, K. T. et al., 2011).

Tufano et al. conducted a study exploring variations in output when analysing traditional versus cluster training. In their acute study, 12 resistance-trained men performed barbell back squats at 60% 1RM, completing 3 sets of 12 traditional repetitions and 3 sets of 12 cluster repetitions with a 30-second rest period between each attempt. The findings indicated that cluster attempts outperformed traditional methods in maintaining muscular power and velocity (Tufano, J. J. et al., 2016). According to the analysis of these specific cases, it is evident that the application of cluster set training results in an equal or enhanced increase in muscular power and velocity compared to traditional methods.

2.6.2 Performance Enhancements Through Cluster Sets and Exercise Variations

Introducing exercise variations is important to maximise performance enhancements, as familiar movements yield lower improvements (Hodges et al., 2005). Traditionally, sets involve continuous repetitions with pauses between each repetition, utilising an inter-repetition resting time of 10 to 30 seconds (Haff et al., 2003). Cluster sets can be structured as undulating or ascending designs, where resistance is increased with each repetition in the ascending set and follows a pyramidal pattern in the undulating set (Haff et al., 2003). This variability in set structure not only helps prevent plateaus but also challenges different aspects of muscle adaptation, promoting a more comprehensive development of strength and endurance.

The hypothetical model presented by Haff et al. (2003) indicates that performance traits tend to decline with repeated conventional sets but can be enhanced when incorporating brief rest periods. Additionally, the utilisation of a cluster set configuration has the potential to improve average power output by strengthening an athlete's individual repetition power, as demonstrated by Lawton et al. (2004). This reduced fatigue associated with cluster sets, as supported by Lawton et al. (2004) and Rooney et al. (1994), may play a crucial role in augmenting an athlete's power-generating capacity.

The combined positive impacts on power output attributed to cluster set arrangements are likely linked to psychophysiological factors, as indicated by González-Hernández et. al. 2020, and metabolic processes, as highlighted in Gorostiaga et. al. 2014, 2010. These mechanisms contribute to a decreased sense of exertion and diminished acute muscular fatigue, as discussed in studies by Tufano et al. in 2016 and 2017.

2.6.3 Cluster Set, Exercise Variation, and Testing Protocol Overview

In conclusion, this section has delved into the intricate relationship between training methodologies and their impact on strength performance. The understanding of muscle fatigue's influence on movement performance and recovery is a crucial segment of this study, further emphasising the need for diverse training approaches. The comparison between increased volume and intensity training has revealed nuances in muscle fatigue and recovery, particularly in experienced athletes. The exploration of traditional versus cluster set rest strategies has shed light on the potential benefits of the latter, exemplified by increased power output and maintained velocity. Furthermore, the analysis of performance enhancements through cluster sets and exercise variations highlights the importance of incorporating variability to avoid plateaus, another crucial aspect of the current study, and enhance different aspects of muscle adaptation. As we navigate the complexities of strength training, it becomes evident that a creative approach, considering factors such as volume, intensity, rest intervals, and exercise variations, is essential for optimising strength gains and overall performance. This comprehensive understanding lays a foundation for exploring the practical implementation of precision measurement tools in monitoring athletic performance.

2.7.0 Monitoring Athletic Performance with Precision Measurement Tools

2.7.1 Performance Measurement Tools

For decades, athletic performance evaluation relied on qualitative assessments, but to accurately gauge progress, quantitative methods have become indispensable. These tools enable precise measurement of crucial parameters such as force, power, velocity, acceleration, time, and position, providing invaluable insights into an athlete's development and performance.

2.7.2 Linear Position Transducers

Researchers frequently employ a linear position transducer (LPT) to gauge barbell power output and ascertain the "optimum power zone", the intensity at which an athlete can generate a maximum power output (Loturco et al., 2015; Talpey et al., 2014). This systematic approach ensures a more accurate assessment of power generation and informs training strategies accordingly. Applying LPTs can also determine a barbell's displacement and velocity (Harris, N. K. et al. 2010). This capability is invaluable for enhancing S&C training, enabling precise tracking of performance metrics. S&C institutions now frequently use LPTs due to the extensive use of velocity-style training (Mann, J. B. et al. 2015, Mann, B., 2016).

LPTs play a pivotal role in modern training regimens, facilitating data-driven adjustments to exercise intensity. However, the reliance on velocity-style training and the precise tracking of performance metrics through LPTs may lead to an overemphasis on quantitative data, information that can be measured and expressed numerically, at the expense of qualitative data, non-numerical information that describes the characteristics of an object, aspects of training. While quantitative measurements provide valuable insights into an athlete's output, they may not fully capture the nuances of technique, skill development, or individual biomechanical differences. Additionally, LPTs can monitor barbell distance and can be used to measure an individual's readiness for exercise by assessing vertical jump elevation (Wadhi, T. et al. 2018). However, the use of LPTs for assessing an individual's readiness for exercise may have limitations in providing a comprehensive understanding of an athlete's physical state. Relying solely on a single metric for readiness assessment may oversimplify the complex and multifaceted nature of an athlete's physical preparedness.

2.7.3 Portable Force Plate

The development of reliable portable force plates (PFPs) has significantly expanded the degree of biomechanical research by enabling testing in remote and unconventional settings. This innovation has not only simplified data collection in controlled laboratory environments but has also brought biomechanical assessments to previously inaccessible locations such as training venues for elite sports teams (Walsh et al., 2006).

PFPs are a valuable tool as they provide a simplified and time-efficient means of measuring mechanical characteristics. This is supported by research conducted by Walsh et al. in 2006, which highlights the efficiency of PFPs when coupled with specialised software. However, the reliance on specialised software, as emphasised by Walsh et al. (2006), raises concerns about accessibility. The efficiency highlighted in the research may be reliant on the user's familiarity and proficiency with the software, potentially creating a barrier for practitioners without extensive technical expertise.

Additionally, elite sprinters' performance metrics, such as peak power, peak force, and jump height, correlate with their maximum sprinting abilities. The use of PFPs during movements like CMJ and squat jumps, as demonstrated in studies by Loturco et al. (2015), Markström and Olsson (2013), and Maulder et al. (2006), strengthens the justification for adopting the apparatus in sprint testing protocols. While these studies showcase the effectiveness of PFPs in assessing performance metrics of elite sprinters, it is essential to acknowledge the diversity of athletes and the potential variability in results across different populations. The generalisation of findings from such studies to broader demographics, including recreational athletes or individuals with varying training backgrounds, is still to be determined.

The development of valid and reliable large PFPs is necessary as they enable testing in various settings, including on-site at sports team training venues that were previously impractical (Walsh, M. S. et al., 2006). However, the concerns regarding the accuracy and precision of PFP measurements need to be addressed. PFPs are often designed to be lightweight and compact for convenience, but these features may compromise their ability to capture subtle nuances in force production. Factors such as surface stiffness, plate size, and calibration methods can influence the reliability of data obtained from PFPs.

The advancement in PFPs allows S&C coaches to quickly assess an athlete's ability to generate higher levels of power and strength, which are essential for achieving fast sprinting velocities over short distances (Loturco, I. et al., 2019; Andersen, L. L. & Aagaard, P., 2006). Furthermore, PFPs provide a reliable estimation of measurements obtained from in-ground force platforms in laboratory settings, making them particularly valuable when analysing the impact phase of jump-land movements (Walsh, M. S. et al., 2006).

2.7.4 Specialised Applications of Portable Force Plates in Power Generation

PFPs play an essential role in enhancing our understanding of body-power measurements. Loturco et al. (2013, 2015) demonstrated that the most effective bar-power generation is achieved when using moderate weights, highlighting the significance of PFP analysis. Soriano et al. (2015) further supported these findings. However, the reliance on moderate weights for optimal bar-power generation may not universally apply to all athletes or training scenarios. Individual variations, such as body composition, training history, and biomechanics, can significantly influence the response to different loading conditions.

The application of PFPs in assessing system power, the inclusion of both body and bar power, and comparing movements may be subject to technological and methodological considerations. Lake et al. (2012) stressed the importance of considering power production during lower body resistance movements as a comprehensive system, rather than fixating solely on the barbell. Their study illuminated a critical insight: the velocity of the barbell significantly surpassed that of various lower body segments and the trunk. This finding highlights the need of not overlooking the kinematics of these lower body components during resistance training, as failing to account for them can result in a substantial overestimation of applied power to the entire system (Lake et al., 2012).

2.7.5 Precision Measurement Tool Overview

In conclusion, this section delves into the intricacies of monitoring athletic performance through precision measurement tools, with a focus on PFPs, LPTs, and their specialised applications. The arrival of reliable PFPs has revolutionised biomechanical research, extending assessments beyond controlled environments to diverse settings, including elite sports training venues. While PFPs offer efficiency in measuring mechanical characteristics, concerns arise regarding accessibility due to the reliance on specialised software. LPTs, essential for gauging barbell power output, provide a systematic approach to assess power generation, yet their emphasis on quantitative data may overshadow qualitative nuances in technique and skill development. PFPs contribute significantly to understanding body-power measurements, particularly in power generation with moderate resistance. However, the validity of assessments in non-laboratory environments poses challenges, emphasising the importance of considering individual variations and methodological considerations. In essence, these precision tools provide valuable insights into athletic performance but necessitate a balanced approach that integrates quantitative and qualitative aspects for a comprehensive understanding of an athlete's capabilities.

Chapter 3 Research Rationale and Aims

3.1.0 Research Rationale

The exploration of various aspects related to resistance training and its impact on muscle hypertrophy, athletic performance, and strategic training methods reveals a nuanced understanding of optimising training strategies for diverse outcomes. The multiple factors influencing muscle hypertrophy, including mechanical tension, metabolic stress, and neural adaptations, highlight the importance of deliberate exercise approaches and increased volume resistance training. The core principles of resistance training, from historical development to foundational concepts, provide a solid foundation for understanding the significance of fundamental strength exercises, tailored training programs, and the versatility of compound training approaches.

The impact of resistance training on athletic performance attributes is evident, with a focus on weightlifting exercises, squat variations, the primary movement within this study, and dynamic correspondence. Tailoring training programs to individual weaknesses and incorporating resistance training for specific sports movements emerge as key considerations for achieving superior athletic performance. Delving into strategic training methods, such as ballistic training and optimal load selection, highlights the need for tailored approaches and the integration of variable resistance for monitoring athletic output levels safely.

The significance of variable resistance and exercise considerations is highlighted by control of parameters and personalised approaches. This approach provides valuable insights into biomedical benefits, emphasising its advantages in preserving correct movement patterns and reducing the likelihood of injury. Additionally, optimising effort during the concentric phase promotes the activation of muscle fibres, leading to enhanced athletic performance.

Furthermore, the discussion on increasing strength performance through cluster sets, exercise variations, and testing protocols highlights the importance of a creative and diverse approach to avoid plateaus and optimise muscle adaptation. This comprehensive understanding sets the stage for exploring the practical implementation of precision measurement tools in monitoring athletic performance. The monitoring athletic performance through precision measurement tools, focusing on PFPs and LPTs, acknowledges their revolutionary impact on biomechanical research. However, it also highlights the need for a balanced approach that integrates quantitative and qualitative aspects to gain a comprehensive understanding of an athlete's capabilities.

In essence, this review serves as a foundation for the subsequent research, providing valuable key understandings into the complexities of resistance training and its role in enhancing athletic performance. The primary emphasis is on the importance of attaining optimal results through variable resistance and cluster training approaches. From this standpoint, the study aims to explore the most efficient movement techniques and applied resistance levels to gather the greatest performance outputs, ultimately elevating athletic capabilities. The present study advocates for the combination of cluster set training and accommodating resistance in the form of SLS chains, demonstrating that the cluster method does not impede the benefits of ART.

3.2.0 Research Aims

The primary aim of this research is to investigate the effects of accommodating resistance using chains as part of a cluster set. Specifically, to determine if accommodating resistance can match or improve maximum strength in terms of peak power and rate of force development, whilst reducing peak force required and minimise load at the most biomechanically compromised position, the base of the squat.

Chapter 4 Methodology

This chapter describes the research strategy used in this study, concentrating on the process of performing and monitoring 1RM and ART testing whilst applying a structured resistance back squat exercise. Emphasising participant safety, the methodology details the 1RM Testing and its experimental design, utilising a within-subjects approach to examine individual performance differences under varying loads. The next section presents the chain resistance submaximal back squat, which uses a mixed-model approach to evaluate participants' performance at various chain mass percentages. The data processing procedure is described, including practical implications and output metric parameters, followed by an in-depth examination of the equations used to calculate various output metrics.

4.1.0 Participants

4.1.1 Recruitment

Participants were recruited through Strathclyde Sport, emphasising the inclusion of both male and female athletes with at least six months of experience in structured resistance exercise.

4.1.2 Informed Consent

Prior to participation, all athletes provided written informed consent, acknowledging the nature, purpose, and potential risks of the study. They were informed of their right to withdraw at any time without penalty.

4.1.3 Ethical Considerations

This study adheres to ethical guidelines, ensuring participant safety. Any signs of lower body or spinal injury prompted immediate withdrawal from the research, and confidentiality of participant data is strictly maintained.

All documents within the study underwent approval by the University's Ethics Committee with reference number UEC 22/35. The Ethics Application Form (Appendix 1) and Participant Information Sheet (PIS) (Appendix 2) have been provided in support of this approval.

4.1.4 Inclusion/Exclusion Criteria

Participants were included based on structured resistance exercise experience, while exclusion criteria were assessed through a participant and medical questionnaire.

4.2.0 1 Repetition Maximum Testing

4.2.1 Experimental Design

This research employs a within-subjects experimental design, specifically a repeated measures design. Each participant serves as their control, performing multiple 1RM attempts with varying loads. This design allows for the examination of individual differences in performance under different load conditions.

4.2.2 Independent Variable

The independent variable within this study is the load applied during the 1RM attempts. Loads are categorised into five levels: Light, Medium, Heavy, Near Max, and 1RM Attempt.

4.2.3 Dependent Variable

The dependent variable is the participant's performance during the 1RM attempts, measured as the maximum mass they can lift in a single repetition. Performance is assessed using the percentage of 1RM, Rate of Perceived Exertion (RPE), and form adherence.

4.2.4 Equipment

Platform and weightlifting rack:

The participants carried out their 1RM attempt using the TOTALPOWER™ Lifting Platform (Figure 5) provided by ESP™ Fitness, a division of Elite Performance Technologies Ltd. The movement was performed within the ESP TOTALPOWER™ Rack (Figure 6). Due to the "5 Layer Acoustic Technology," the suitable flooring for the experiment was important. It would reduce noise on the force plates during movement and vibrations created by the chains during squats.

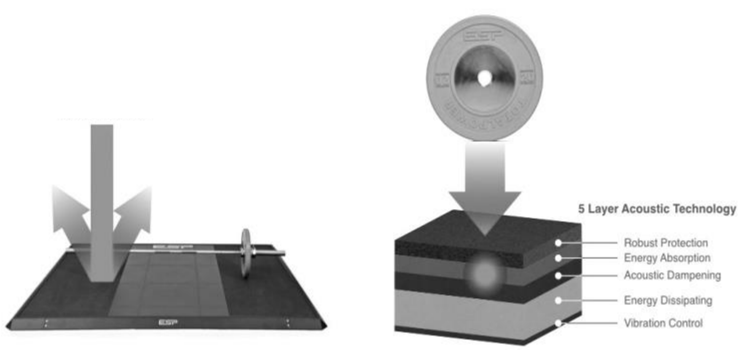

Figure 5. ESP Fitness TOTALPOWER Lifting Platform.

Figure 6. ESP Fitness TOTALPOWER Rack.

Barbell and weighted steel chains:

During the experimental testing, a 20-kilogram Men's Olympic weightlifting barbell adhering to International Weightlifting Federation (IWF) standards was used. Specially designed competitive weightlifting bumper plates, ranging from 0.5 to 25 kilograms, created through a partnership between ESP and Uesaka (UESAKA Barbell Company), provided the barbell's resistance. Olympic spring collars were used to secure the bumper plates firmly to the barbell, preventing any movement during the tests. Participants were permitted to wear IWF standard weightlifting shoes for the assessment.

To measure the barbell-to-floor distance, a single set of chains (GS Products Galvanised Steel Short Link Chain Grade 30 Din 766) (Figure 8) and a a heavy-duty strap (THULE 523 Luggage Strap) (Figure 7) was used. Coloured markers were used to customise strap lengths for each participant, ensuring precise and consistent measurements.

Figure 7. GS Products Galvanised Steele Short Link Chain Grade 30 Din 766.

Figure 8. THULE 523 Luggage Strap.

4.2.5 Experimental Protocol

Before the experiment, anthropometric data on each participant, measuring their height in centimetres with a 'Harpenden' portable stadiometer by Holtain Limited and assessing their body mass in kilograms using a SECA digital stand-on scale.

Participants completed a personalised warm-up known as RAMP (Raise, Activate, Mobilise, and Potentiate) to prepare for 1RM squat testing, aligning with their specific training regimen. The 1RM barbell back squats were conducted under expert supervision and followed the guidelines set by the National Strength and Conditioning Association (NSCA).

During the testing procedure, participants were initially instructed to choose a light load, ranging from 20-40% of their 1RM or a 2-4 RPE (Rate of Perceived Exertion), and perform 5-10 repetitions in the first set. Following a 1–2-minute rest period, the second set involved 3-5 repetitions at a medium load of 40-60% 1RM or a 4-6 RPE, followed by another 2–3-minute rest period. This cycle was repeated until the participant reached a sub-maximal or maximal load.

To meet the criteria for a 1RM barbell squat, the participant's hip and knee joints needed to be at or below parallel. Throughout the procedure, strength and conditioning specialists closely monitored the participants' movements. Table 1 provides a summary of the method for reference.

Table 1. 1 Repetition maximum back squat protocol.

SET	LOAD	REPETITIONS	% 1RM	RPE	REST (MIN.)
1	LIGHT	5-10	20 - 40	2 - 4	1 - 2
2	MEDIUM	3-5	40 - 60	4 - 6	2 - 3
3	HEAVY	2-3	60 - 80	6 - 8	3 - 4
4	NEAR MAX	1-2	80 - 90	8 - 9	4 - 5
5	1RM ATTEMPT	1	100	10	4 - 5

In cases where participants lacked a previous 1RM back squat measurement, they were instructed to use the RPE as a reference for their 1RM attempt. If the individual completed a 1RM, a 5 kg increase was added for subsequent attempts until failure occurred.

If a participant failed to achieve a 1RM, they had the option to repeat the movement or decrease the loaded mass by 5 kg. If the second attempt also failed, the participant was advised to either reduce the loaded mass by 5 kg or stick with the last successful lift.

Each 1RM result was recorded and securely stored in a filing system.

Familiarisation:

Participants in the 1RM session had the opportunity to familiarise themselves with weighted steel chains. They performed 3-5 repetitions using an unloaded barbell and a single set of chains.

Additionally, to ensure proper positioning, the length of the strap holding the steel chains was measured while standing upright with the barbell on the shoulders and neckline, ensuring contact with the ground. A coloured mark was then placed on the strap to indicate the required length for the participant's second session. The setup for both conventional and chain resistance movements can be observed in Figure 9 and Figure 10, respectively.

Figure 10. Set up for a chain resistance back squat when performing the movement on PFPs.

Figure 9. Set up for a traditional back squat when performing the movement on PFPs.

4.3.0 Chain Resistance Submaximal Back Squat

4.3.1 Experimental design

The research design employed a mixed-model design, combining a within-subject and between-subject approach.

Within-Subject Factor: Chain Resistance Percentage:

- Participants experienced four different chain weight percentages (0%, 20%, 25%, 30%)
- Each participant completed squats with all four chain weight percentages

Between-Subject Factor: Order of Chain Resistance Percentage:

- Seven participants completed the squats in a fixed sequence (0%, 20%, 25%, 30%)
- Five participants completed the squats in a random order, preventing order effects

4.3.2. Independent Variable

The independent variable within this study is the load applied during the ART attempts. Loads are categorised into five levels: 0%, 20%, 25%, 30%).

4.3.3. Dependent Variable

The dependent variable is the participant's performance during the ART attempts, measured as the maximum force production (N). Performance is assessed by monitoring participants movement mechanics and producing a valid force reading.

4.3.4 Equipment

The Hawkin Dynamics Wireless Dual Platform (Hawkin Dynamics) is equipped with two platforms, each measuring 605 x 360 x 70 mm and a mass of 13kg. These platforms have a sampling frequency of 1000 Hz. For the experiment, the PFPs were positioned on an ESP Fitness TOTALPOWER Lifting Platform by Elite Performance Technologies Ltd, as shown in Figure 6. The movement execution took place on an ESP TOTALPOWER Rack, depicted in Figure 5.

To collect and display the output data, the researchers used the Hawkin Capture Android Application v7.3.1, which was developed by Google Commerce Ltd. Additionally, to facilitate access to the plates, the HD force plates were accompanied by the ESP™ lowest-level weightlifting blocks from Elite Performance Technologies Ltd.

During the investigation, 20 galvanised SLS chains with varying diameters were used (Table 2 provides detailed specifications). Despite having the same length, each chain set had unique characteristics. Attachment to the barbell was done using heavy-duty straps (THULE 523 Luggage Strap), carabiner clips, and barbell spring collars. Equipment mass breakdown is in Table 3.

Table 2. Galvanised short link steel chain specification.

CHAIN	H (MM)	D (MM)	NO.	MASS (KG)
6MM	8	6	2	0.85
8MM	12	8	2	1.4
10MM	13	10	2	1.9
12MM	15	12	14	3.4

Table 3. Equipment mass index.

EQUIPMENT	NO.	MASS (KG)
BARBELL	1	20
CARABINER CLIP	2	0.41
SPRING COLLAR	2	0.46
THULE STRAP	2	0.26

4.3.5 Protocol

Pre-Experimental Procedure:

Before conducting the submaximal chain back squat, it was necessary to determine the chain mass to bumper plate ratio. The participants' total weight lifted was set at 60% of their 1RM.

For instance, considering a participant with a 100 kg 1RM, Table 4 presents an example of the chain and bumper plate masses used in this experiment. The chain proportion varied within each set to assess its impact.

In this case, set one employed 0% chain mass, set two used 20% chain mass, set three used 25% chain mass, and set four used 30% chain mass. The percentage mass of the chain was determined based on the individual's 1RM.

Table 4. Chain and plate mass configuration of participant with 100kg 1RM.

SET	TOTAL MASS (KG)	CHAIN MASS (KG)	PLATE MASS (KG)
1 (0%)	60	0	60
2 (20%)	60	20	40
3 (25%)	60	25	35
4 (30%)	60	30	30

Incorporating different chain diameters, the configuration for each percentage chain mass was calculated. For instance, if the target was 20kg of chain mass, it could be achieved by using 12mm x 2, 10mm x 2, and 6mm x 2 chains, along with a carabiner clip, spring collar, and Thule strap. The goal was to create chain combinations that closely matched the set percentage mass.

Experimental Protocol:

The participant's mass (kg) was measured using HD portable force plates while they stood still, incorporating selected footwear. As part of their training program, participants underwent a RAMP warm-up to their needs, like the 1RM previous testing. These personalised warm-ups aimed to prepare the participants' bodies for submaximal squats.

After the warm-up, participants engaged in three cluster repetition repeats within each chain percentage set. Cluster sets involve pausing for 15-30 seconds between repetitions, allowing participants to perform each repetition to the best of their abilities. Data from each repeat was recorded during this rest period.

The participants performed three cluster set repetitions of a barbell squat with 0% chain mass at 60% of their 1RM. A rest interval of 3-5 minutes was provided between sets. The chain arrangement was adjusted by connecting the strap between sets and attaching it to the barbell for the next set. The same procedures were followed until the individual completed three repetitions of each percentage chain mass, resulting in a total of 12 repetitions throughout the procedure.

The participants performed chain squats in various orders during each experimental meet. The first seven individuals completed the actions in an assending order, starting with 0% chains and ending with 30% chains. However, the remaining five participants performed the activity in a random sequence of chain percentage mass. Table 5 displays the order in which the participants completed their set setup.

Table 5. Prescribed participant percentage chain mass order.

PARTICIPANT	SET 1	SET 2	SET 3	SET 4
1-7	0%	20%	25%	30%
8	30%	20%	0%	25%
9	20%	30%	25%	0%
10	0%	30%	20%	25%
11	0%	20%	30%	25%
12	30%	25%	20%	0%

4.3.6 Data Processing

Practical Implications:

In the data processing phase, the initial step was to calculate the percentage of chain length lost during the squat. A standard bench with a height of 38cm was used, typically employed for barbell box squat exercises at a parallel or below parallel position. Participants performed the squat on 7cm HD force plates. Figures 11 and 12 indicate that a consistent loss of 55cm of chain length occurred with each attempt. This value was assigned to all participants involved in the movement.

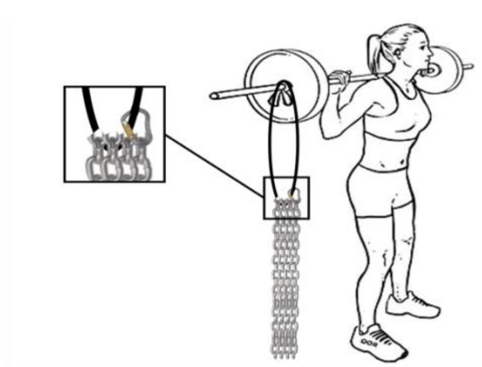

Figure 12. The addition of a carabiner clip for the lost length of chain.

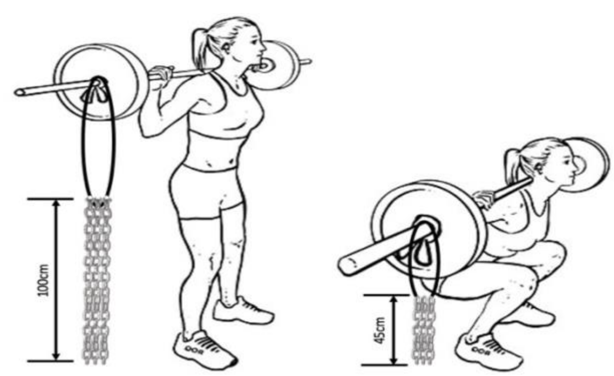

Figure 11. The chain length lost during a barbell back squat.

To address the length shift caused by multiple chains resting higher on the strap, a carabiner clasp was employed on the 6mm chain size. The additional mass of the carabiner clip was accounted for when calculating the overall barbell mass.

Important aspects of the movement will be emphasised, using examples from a randomly selected participant. Each participant performed three repetitions at different percentages of chain mass. The peak value from the three attempts was considered as the significant output measure, presented in the following tables. Participants were sorted in ascending order based on their mass. Mean values were calculated for each participant at each percentage chain mass, providing insights into individual performance across different chain masses.

Output Metric Parameters:

In this study, Peak Power Output (PPO) (W) was chosen as the main independent variable. Other independent variables included peak/minimum force (N), peak velocity (m/s), and peak upwards/downwards acceleration (m/s^2). Peak force output was measured during the ascending phase of the activity, and the maximum force production point was determined by combining the force-time graph with a standard barbell squat action.

As previously mentioned by Newton and Dugan, the highlighted metrics can be grouped as follows: A - Maximum Strength (Peak Force Output and Peak Power Output), B - RFD (Velocity at the point of Peak Force Output), and C - High Load Speed Strength (Peak Acceleration Output).

Peak power output and other secondary independent variables were derived from this point. The Hawkin Dynamics PFPs produce a data point every 0.001 seconds throughout the entirety of the movement. From this selected length of time, a Force (N) output reading is produced. Excel data is produced from the Hawkin Dynamics Cloud with the corresponding movement output. From this, the output data produces a Left and Right force and Combined force from which the following calculations were based.

As the Mass (kg) value was variable without the knowledge of the PFPs, this value had to be calculated within Excel and put in manually within the corresponding force/time stamp. The mass stayed constant until the participant initiated the movement. The loss of chain mass between the top and bottom of the movement was calculated and divided by the time. This rate of change in chain mass differed between the eccentric and concentric phases due to the varied time stamps.

A performance-based rank was determined for each percentage chain mass, indicating the highest output measure achieved. Furthermore, an overall ranking system was established to identify the most effective percentage chain mass across all output metrics.

A percentage change value was calculated by comparing attempts with accommodating resistance to traditional methods. The combined accommodating resistance variations (20%, 25%, 30%) were averaged to establish an overall mean value. This average was then compared to the traditional method (0%), yielding a percentage change figure. Combining the data from all participants produced an overall percentage change value for each output measure.

Equations for Output Metric Calculations:

In this section, the equations used for calculating each output metric will be presented in the order of execution. The Excel equations have been adjusted to display output parameters instead of cell numbers.

Acceleration is defined by the rate of change of velocity with respect to time. The Acceleration (m/s^2) value was calculated using the Force (N) output and Mass (kg) value with the equation shown below:

$$a = \frac{(F - (m \times 9.81)}{m}$$

Equation 1. Acceleration equation derived from force output and mass.

Key: a = Acceleration (m/s^2), F = Force (N), m = Mass (kg)

Velocity can be described as the rate of change of an object relative to its direction of movement. The Velocity (m/s) output was derived from the previous Acceleration (m/s2) against time (s) using the following equation:

$$v2 = \frac{((a2 + a1) \times (t2 - t1))}{2} + v1$$

Equation 2. Velocity equation derived from acceleration output and time.

Key: v2 & v1 = Velocity (m/s), a2 & a1 = Acceleration (m/s^2), t2 & t1 = Time (s)

The main independent variable Power (W) is defined as the rate of work done. The power output was calculated using the following equation that involves Velocity (m/s) and corresponding Force (N):

$$P = F \times v2$$

Equation 3. Power equation derived from force output and velocity output.

Key: P = Power (W), F = Force (N), v2 = Velocity (m/s)

4.4.0 Data Analysis

4.4.1 Statistical Analysis

Statistical analysis will involve within-subjects analysis of variance (ANOVA) to assess the impact of different load conditions on 1RM and ART performance. Post hoc tests, such as paired t-tests, will be used to explore significant differences between specific load conditions.

4.4.2 Significance Level

The significance level is set at $p < 0.05$, indicating statistical significance.

4.4.3 Data Interpretation

Results will be interpreted in the context of load conditions, individual differences, and potential practical implications for resistance training programs. Findings will contribute to understanding optimal load strategies for ART performance in trained athletes.

Chapter 5 Results

5.1.0 Participant Information

In this study, 12 train individuals (N_{male} = 10, N_{female} = 2) participated, with an average height of 178 cm ± 5.9 cm, mass of 83.4 kg ± 14.8 kg, and age of 21.6 years ± 2.6 years. Participants had a minimum of six months of structured resistance exercise experience (training years = 4 ± 1.4 years).

5.2.0 Repetition Maximum Testing Characteristics

Table 6. Repetition Maximum Participant Performance Characteristics (1RM, System Mass, Relative Load).

PARTICIPANT PERFORMANCE CHARACTERISTICS

	1RM (kg)	System Mass (kg)	Relative Load (kg)
N	12	12	12
MEAN	123.67	155.75	1.46
MEDIAN	129.50	160.00	1.48
MODE	170.00	104.00	0.86
STD. DEVIATION	38.97	37.18	0.3
RANGE	110.00	110.00	1.09
MINIMUM	60.00	104.00	0.86
MAXIMUM	170.00	214.00	1.95

Table 6 presents the 1RM test results, indicating an average load of 124 kg with a notable standard deviation of 38.97 kg. When normalised by body mass, the mean 1RM was 1.46, accompanied by a calculated standard deviation of 0.31.

5.3.0 Accommodating Resistance Against Traditional

The relevant stages of the barbell squat exercise are depicted in the figures within the following section, indicating the key positions from which various output metric readings were collected. The data presented illustrate the characteristics of each output measure and how they vary with different percentages of chain mass. The eccentric phase initiates the movement, while the peak concentric phase concludes the lift.

5.3.1 A - Maximal Strength (Peak Force Output)

This section will represent the first attribute, A - Maximal Strength, through Peak Force Output (PFO) and Minimum Force Output (MFO).

Peak Force Output (PFO):

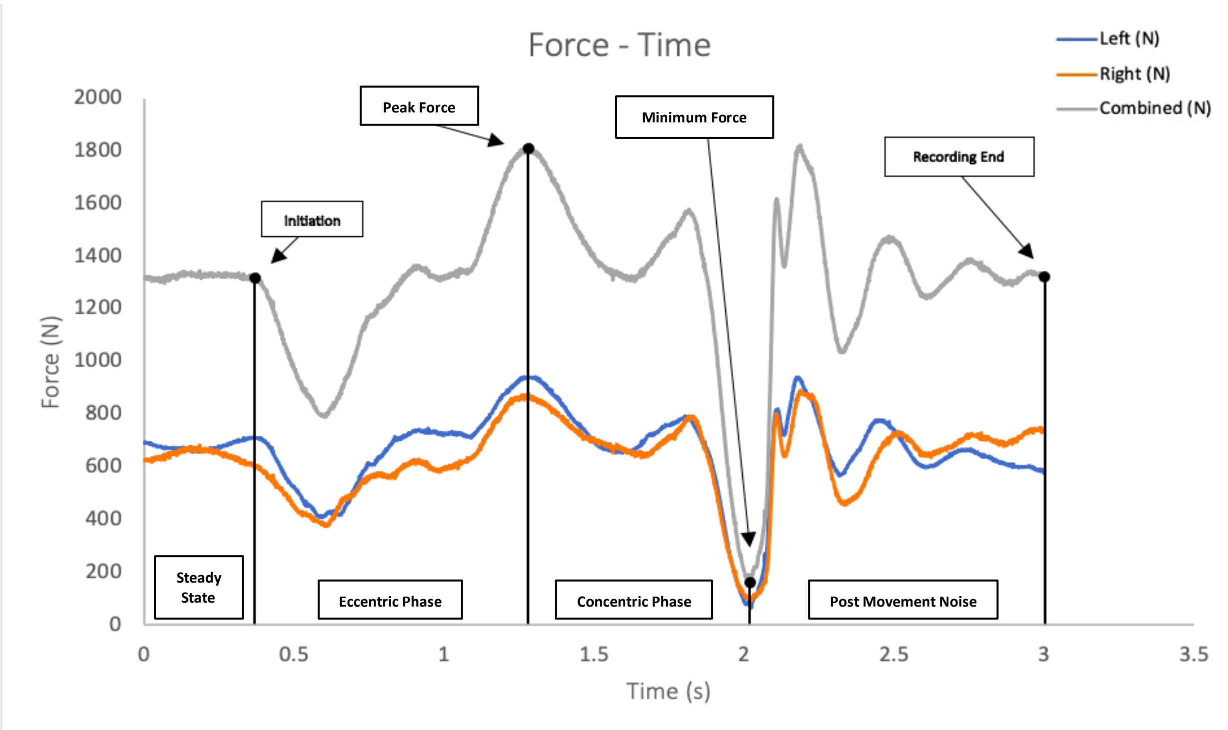

Figure 13. Force - Time characteristics during a barbell squat.

The force-time graph (Figure 13) represents data from Hawkins Dynamic force plates during the movement. Before the eccentric phase, there is a steady state period. The highest force value occurs at the peak eccentric point, while the lowest force value occurs at the peak concentric point during a brief unloading period. Post-movement noise occurs following the attainment of the peak concentric point and before the conclusion of the recording.

Table 7. Peak Force Output across traditional and accommodating resistance barbell squat.

PEAK FORCE (N)

	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	1634	1563	1497	1528	1555.50
66	1341	1289	1296	1263	1297.25
70	1328	1296	1328	1341	1323.25
74	2271	2164	2054	1950	2109.75
76	1979	1946	1770	1820	1878.75
84	2131	2178	2002	2043	2088.50
87	3326	3310	3331	3300	3316.75
88	2370	2318	2239	2254	2295.25
89	3043	2832	2967	2929	2942.75
90	2656	2531	2318	2390	2473.75
103	2566	2520	2449	2557	2523.00
112	3410	3197	3280	3157	3261.00
MEAN	2337.92	2262.00	2210.92	2211.00	
RANK	1	2	4	3	

In the findings displayed within Table 7, the participant with a mass of 87kg generated the highest peak mean force of 3316.75N during the movement, while the participant with a mass of 66kg produced the lowest peak mean force of 1297.25N. The conventional method induced the highest peak mean force (2337.92N) among all participants, whereas the use of 25% chain mass resulted in the lowest peak mean force (2210.92N).

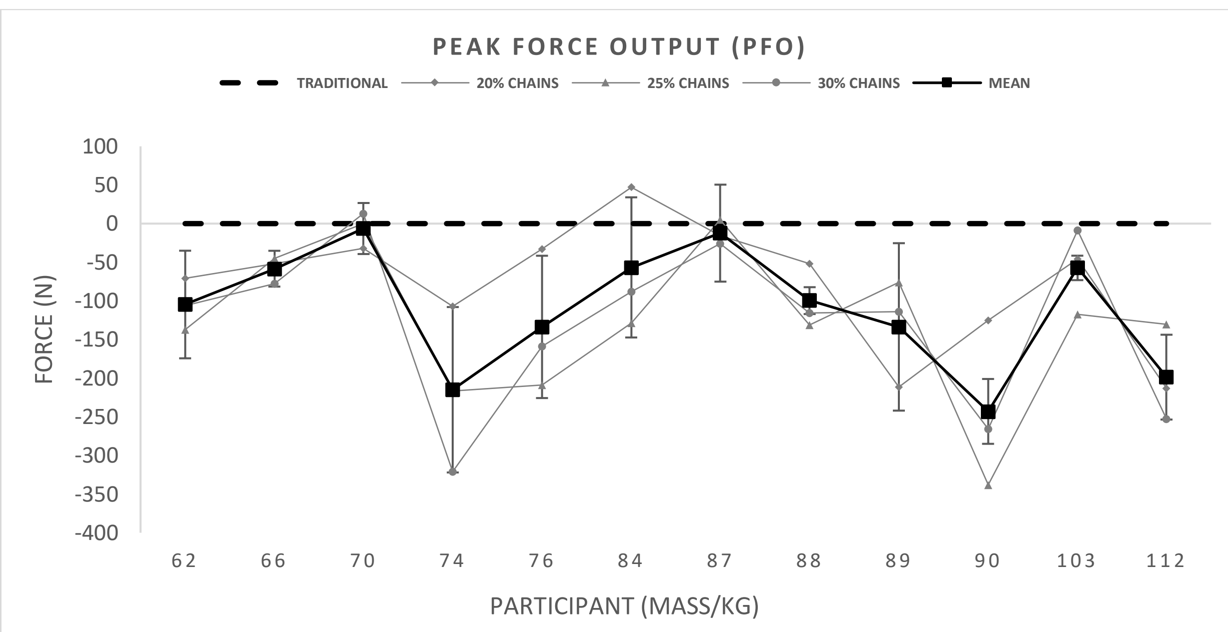

Figure 14. Peak Force Output characteristics showing accommodating resistance based against traditional.

Figure 14 demonstrates the participants Peak Force Output (PFO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that the traditional method created a greater output against all the accommodating resistance attempts. Compared to the traditional method, the participant with a mass of 70kg recorded the nearest peak mean value (-6.33N). Several participants showed a considerable degree of Standard Deviation (SD).

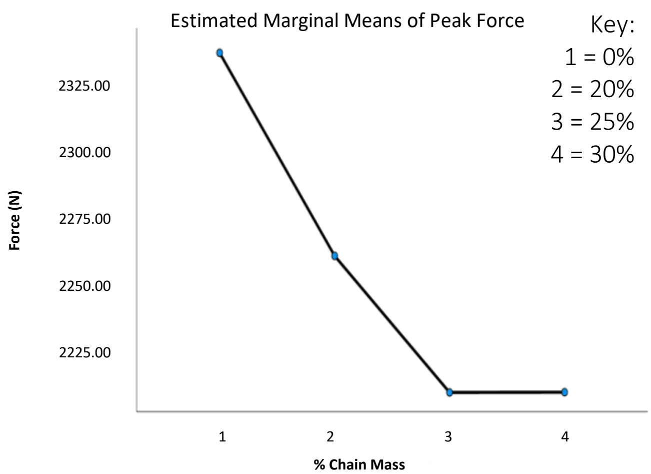

Figure 15. Estimated Marginal Means of Peak Force.

Figure 15 demonstrates that 0% chains had the highest PFO, while 25% and 30% chains had the lowest PFO. PFO measurements, revealing significant mean differences. 0% chains had mean differences of 0.006, 0.001, and 0.002 when compared to 20% chains, 25% chains, and 30% chains, respectively.

Minimum Force Output (MFO):

Table 8. Minimum Force Output across traditional and accommodating resistance barbell squat.

MINIMUM FORCE (N)

	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	221	301	287	283	273
66	101	74	159	189	130.75
70	421	352	240	291	326
74	309	294	318	307	307
76	158	159	188	119	156
84	114	87	154	185	135
87	673	605	655	770	675.75
88	326	312	216	200	263.50
89	271	447	270	265	313.25
90	-10	13	10	10	5.75
103	124	218	251	251	211
112	112	97	108	123	110
MEAN	235	246.58	238	249.42	
RANK	1	3	2	4	

In the findings displayed within Table 8, the participant with a mass of 90kg generated the lowest mean minimum force of 5.75N during the movement, while the participant with a mass of 87kg produced the highest mean minimum force of 675.75N. The range of mean minimum force across all individuals varied greatly from 5.75N to 675.75N, showing a significant discrepancy. The conventional method induced the lowest mean minimum force (235N) among all participants, whereas the use of 30% chain mass resulted in the highest mean minimum force (249.42N).

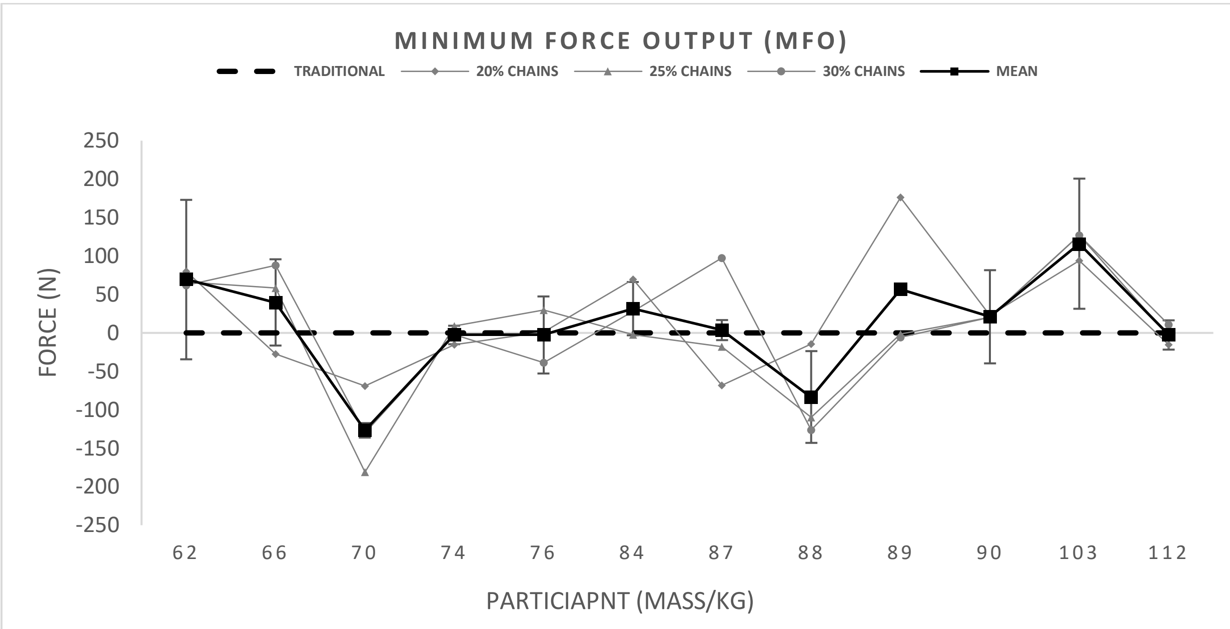

Figure 16. Minimum Force Output characteristics showing accommodating resistance based against traditional.

Figure 16 demonstrates the participants Minimum Force Output (MFO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that there are varied results when comparing accommodating resistance attempts against traditional. Compared to the traditional method, the participants with a mass of 70kg and 88kg recorded the largest decrease in MFO. Several participants showed a considerable degree of Standard Deviation (SD).

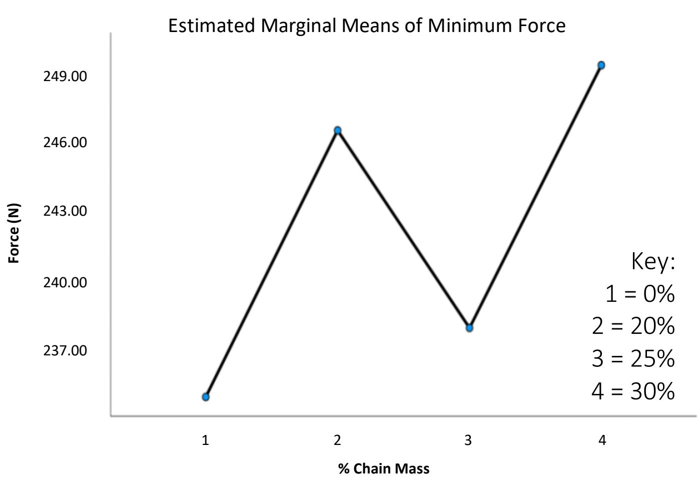

Figure. 17. Estimated Marginal Means of Minimum Force.

Figure 17 can be interpreted in various ways as the lowest output represents the value of interest. In this case, 0% chains yielded the highest minimum output, while 30% accommodating resistance resulted in the lowest minimum output. In contrast to the previous pairwise comparison, minimum force does not show any significant mean difference for each percentage chain mass.

5.3.2 A - Maximal Strength (Power Output Metric)

This section will represent the first attribute, A - Maximal Strength, through Peak Power Output (PPO).

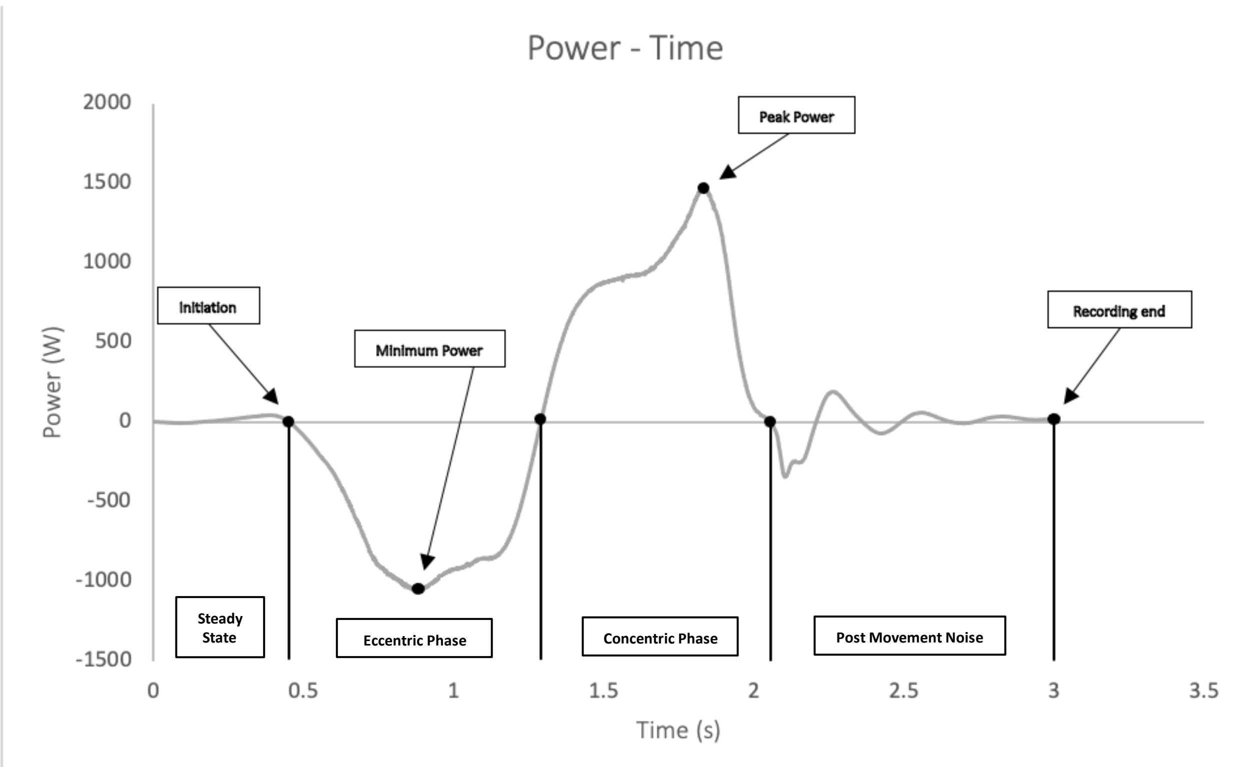

Figure 18. Power - Time characteristics during a barbell squat.

The graph in Figure 18 illustrates power information obtained from the force outputs generated by the Hawkins Dynamic force plates throughout the motion. Before the eccentric phase, there is a steady state period. The minimum power value occurs during the eccentric phase, while the peak power value occurs during the concentric phase. Post-movement noise occurs following the attainment of the peak concentric point and before the conclusion of the recording.

Table 9. Peak Power Output across traditional and accommodating resistance barbell squat.

PEAK POWER (W)

	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	1012.62	1074.40	922.00	779.42	947.11
66	1427.05	1224.59	1589.52	1018.96	1315.03
70	761.32	1146.00	1265.94	783.29	989.14
74	1597.29	1284.87	1307.24	1168.91	1339.58
76	1630.28	1327.86	1407.32	1266.31	1407.94
84	2326.86	1954.09	2348.67	1639.34	2067.24
87	1996.54	1589.99	2249.24	1586.89	1855.67
88	1687.48	1506.44	1517.05	1663.66	1593.66
89	2453.09	2183.82	1950.19	2589.07	2294.04
90	2414.15	2194.42	1947.51	1672.79	2057.22
103	2447.79	1757.78	1767.84	1948.11	1980.38
112	3254.79	2367.84	2802.64	2823.64	2812.23
MEAN	1917.44	1634.34	1756.26	1578.37	
RANK	1	3	2	4	

In the findings displayed within Table 9, the participant with a mass of 112kg generated the highest peak mean power of 2812.23W during the movement, while the participant with a mass of 62kg produced the lowest peak mean power of 1865.12W. The conventional method induced the highest peak mean power (1917.44W) among all participants, whereas the use of 30% chain mass resulted in the lowest peak mean force (1578.37W).

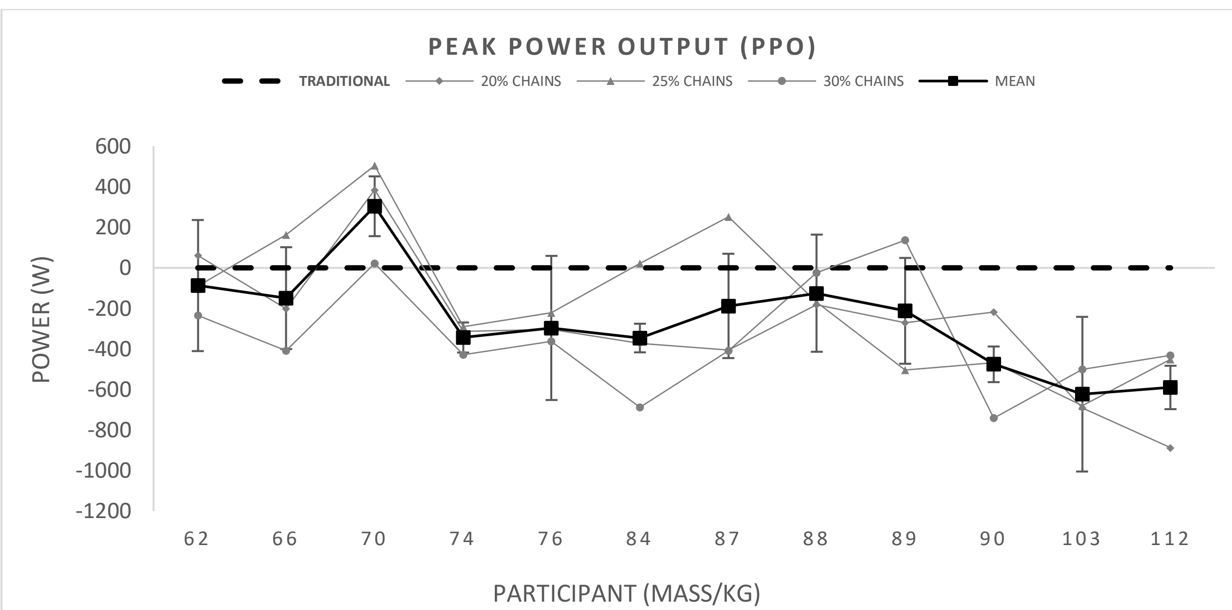

Figure 19. Peak Power Output characteristics showing accommodating resistance based against traditional.

Figure 19 demonstrates the participants Peak Power Output (PPO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that the traditional method created a greater output against the accommodating resistance attempts. Compared to the traditional method, only one participant with a mass of 70kg recorded a greater peak mean value. Several participants showed a considerable degree of Standard Deviation (SD).

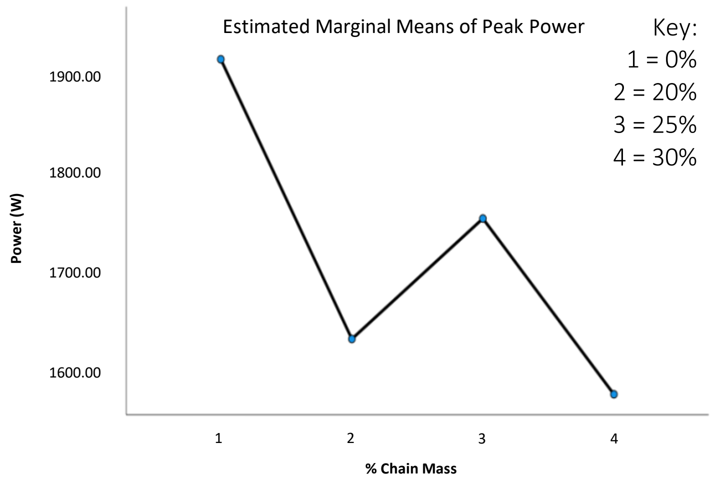

Figure. 20. Estimated Marginal Means of Peak Power.

Figure 20 demonstrates that 0% chains had the highest PPO, while 30% chains had the lowest PPO. PPO measurements, revealing significant mean differences. 0% chains had mean differences of 0.011 and 0.001 with 20% chains and 30% chains, respectively.

5.3.3 B - RFD (Velocity Output Metric)

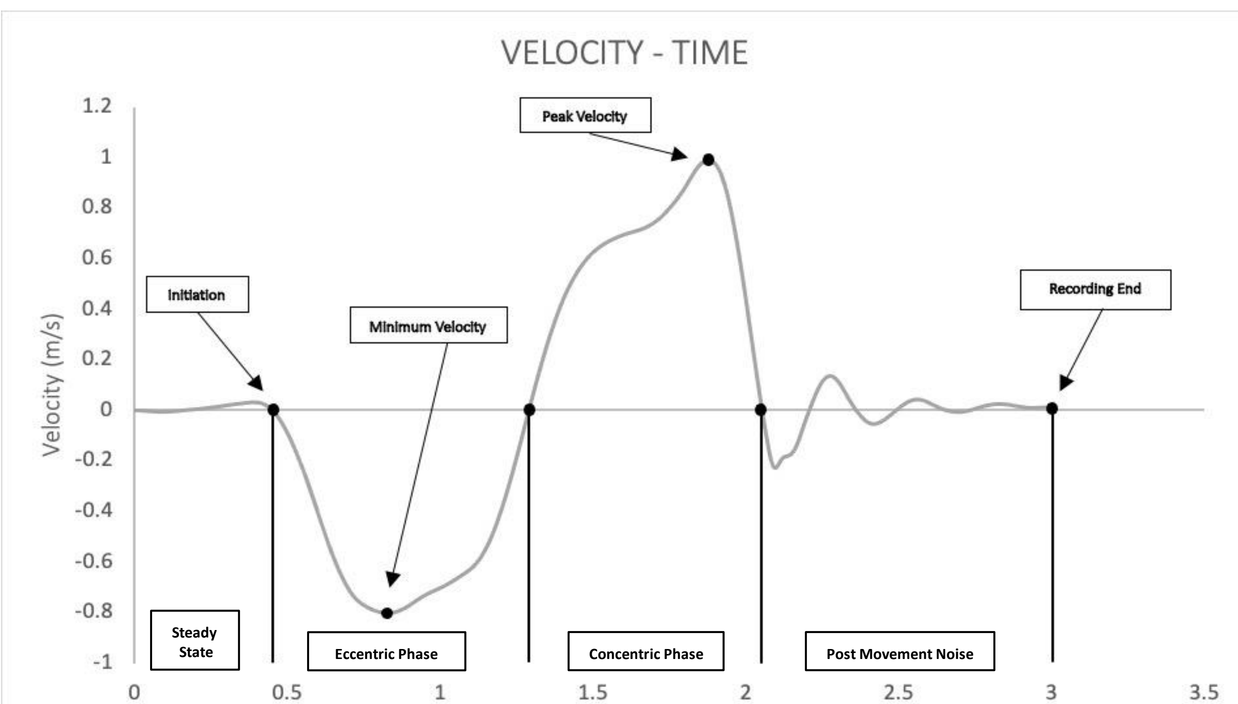

Figure 21. Velocity - Time characteristics during a barbell squat.

This section will represent the first attribute, B - RFD, through Peak Velocity Output (PVO). The graph in Figure 21 illustrates velocity information obtained from the force outputs generated by the Hawkins Dynamic force plates throughout the motion. Before the eccentric phase, there is a steady state period. The minimum velocity value occurs during the eccentric phase, while the peak velocity value occurs during the concentric phase. Post-movement noise occurs following the attainment of the peak concentric point and before the conclusion of the recording.

Table 10. Peak Velocity Output across traditional and accommodating resistance barbell squat.

PEAK VELOCITY (M/S)					
	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	0.87	0.95	0.82	0.73	0.84
66	1.10	1.03	1.35	0.91	1.10
70	0.67	0.98	1.09	0.68	0.85
74	0.97	0.81	0.82	0.75	0.84
76	1.03	0.88	0.92	0.83	0.91
84	1.18	1.05	1.26	0.92	1.10
87	0.98	0.81	1.16	0.84	0.95
88	0.96	0.84	0.88	0.97	0.91
89	1.14	1.09	0.94	1.25	1.10
90	1.21	1.14	1.03	0.9	1.07
103	1.11	0.89	0.86	1.00	0.96
112	1.26	0.97	1.14	1.16	1.13
MEAN	1.04	0.95	1.02	0.91	
RANK	1	3	2	4	

In the findings displayed within Table 10, the participant with a mass of 112kg generated the highest peak mean velocity of 1.13 m/s during the movement, while the participants with masses of 62kg and 74kg produced the lowest peak mean velocity of 0.84 m/s. The conventional method induced the highest peak mean velocity (1.04 m/s) among all participants, whereas the use of 30% chain mass resulted in the lowest peak mean velocity (0.91 m/s).

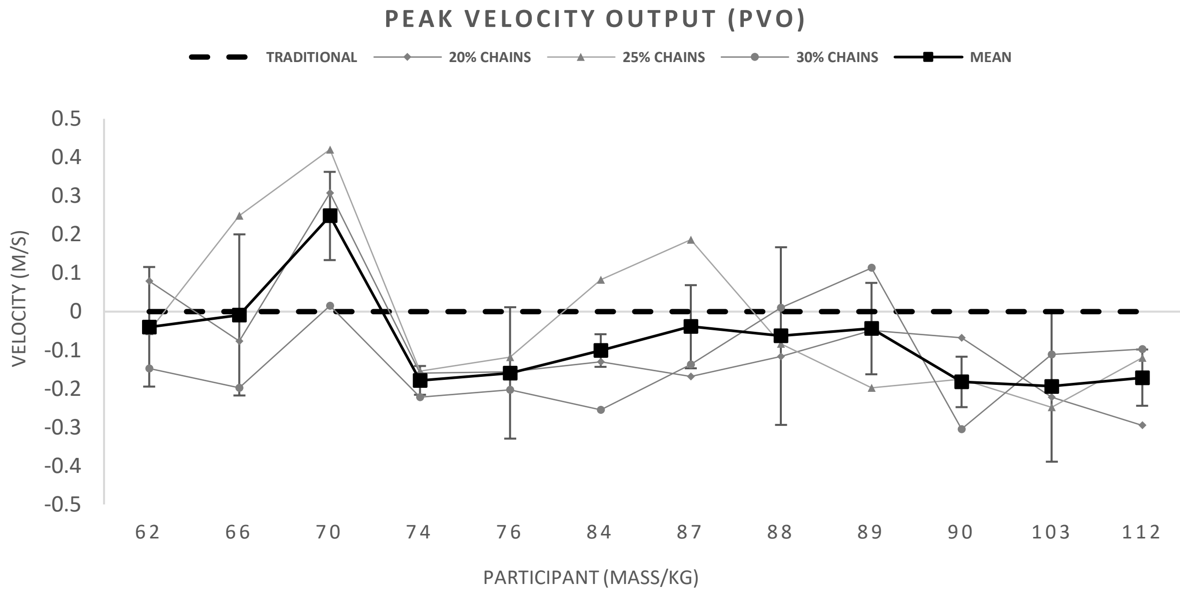

Figure 22. Peak Velocity Output characteristics showing accommodating resistance based against traditional.

Figure 22 demonstrates the participants Peak Velocity Output (PVO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that the traditional method created a greater output against the accommodating resistance attempts. Compared to the traditional method, only one participant with a mass of 70kg recorded a greater peak mean value. Several participants showed a considerable degree of Standard Deviation (SD).

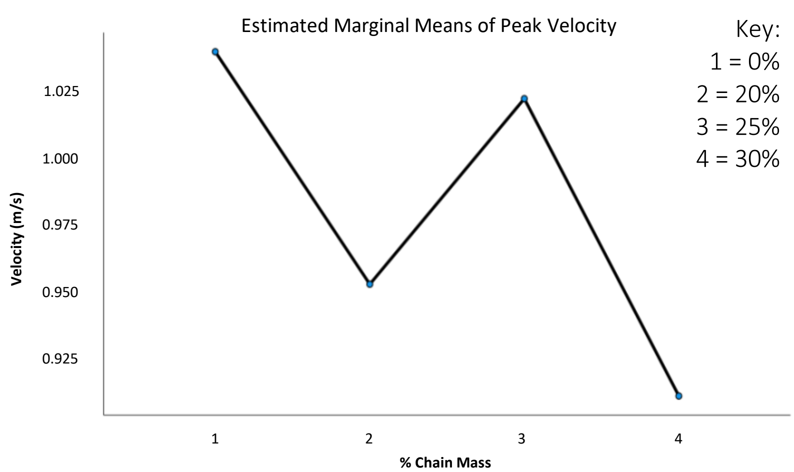

Figure 23. Estimated Marginal Means of Peak Velocity.

Figure 23 demonstrates that 0% chains had the highest PVO, while 30% chains had the lowest PVO. PVO measurements, revealing significant mean differences. 0% chains had mean difference of 0.004 with 30% chains.

5.3.4 C - High Load Speed Strength (Acceleration Output Metric)

This section will represent the first attribute, C – high Load Speed Strength, through Peak Acceleration Output (PAO) and Peak Acceleration Downwards (PADO).

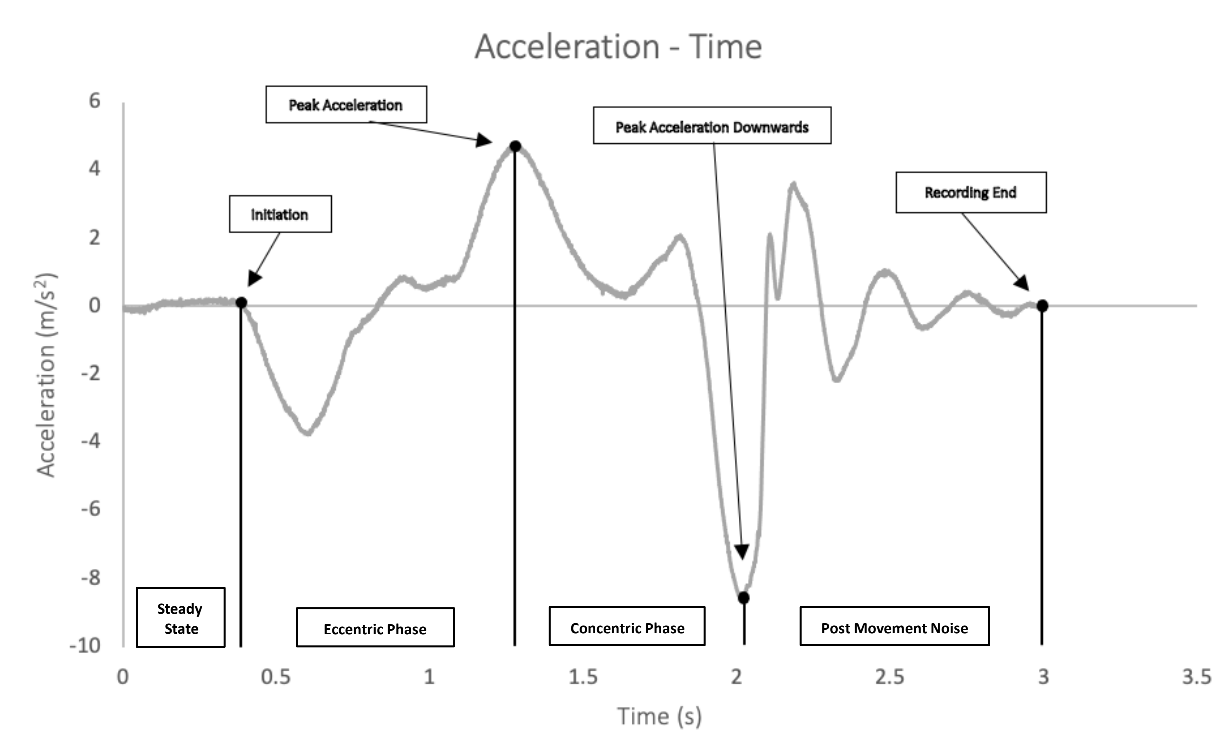

Figure 24. Acceleration - Time characteristics during a barbell squat.

The graph in Figure 24 illustrates acceleration information obtained from the force outputs generated by the Hawkins Dynamic force plates throughout the motion. Before the eccentric phase, there is a steady state period. The highest acceleration value occurs at the peak eccentric point, while the lowest acceleration value occurs at the peak concentric point during a brief unloading period. Post-movement noise occurs following the attainment of the peak concentric point and before the conclusion of the recording.

Table 11. Peak Acceleration Output across traditional and accommodating resistance barbell squat.

PEAK ACCELERATION (M/S²)

	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	5.82	6.48	6.10	6.84	7.12
66	2.92	3.52	3.82	3.80	3.51
70	2.66	3.21	3.89	4.09	3.46
74	5.28	5.91	5.52	5.07	5.44
76	4.70	5.68	4.64	5.36	5.09
84	3.28	4.84	4.12	4.62	4.22
87	7.70	9.49	10.26	10.60	9.51
88	5.12	6.12	6.06	6.54	5.96
89	6.05	6.52	7.81	8.10	7.12
90	6.04	6.73	5.73	6.62	6.28
103	3.81	4.84	4.75	5.81	4.80
112	6.37	6.74	7.34	7.08	6.88
MEAN	4.98	5.84	5.84	6.21	
RANK	4	2	3	1	

In the findings displayed within Table 11, the participant with a mass of 87kg generated the highest peak mean acceleration of 9.51 m/s² during the movement, while the participant with a mass of 70kg produced the lowest peak mean acceleration of 3.46 m/s². The conventional method induced the lowest peak mean acceleration (4.98 m/s²) among all participants, whereas the use of 30% chain mass resulted in the highest peak mean acceleration (6.21 m/s²).

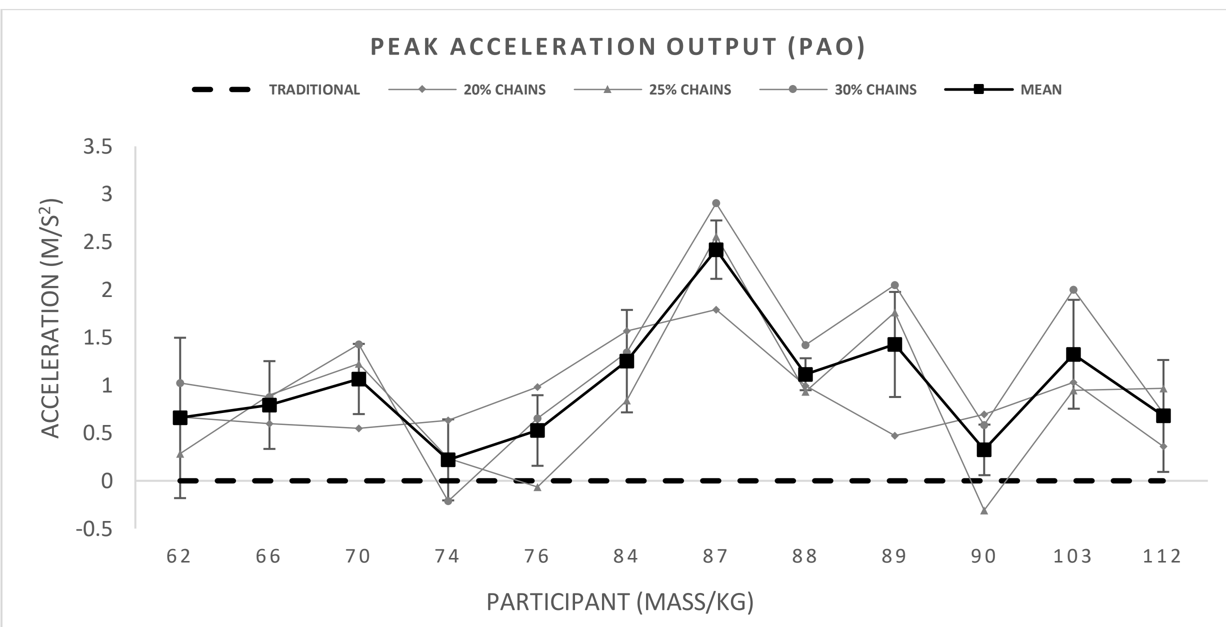

Figure 25. Peak Acceleration characteristics showing accommodating resistance based against traditional.

Figure 25 demonstrates the participants Peak Acceleration Output (PAO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that the traditional method created a lower output against all the accommodating resistance attempts. Compared to the traditional method, the participant with a mass of 87kg recorded the highest peak mean value (2.42 m/s²). Several participants showed a considerable degree of Standard Deviation (SD).

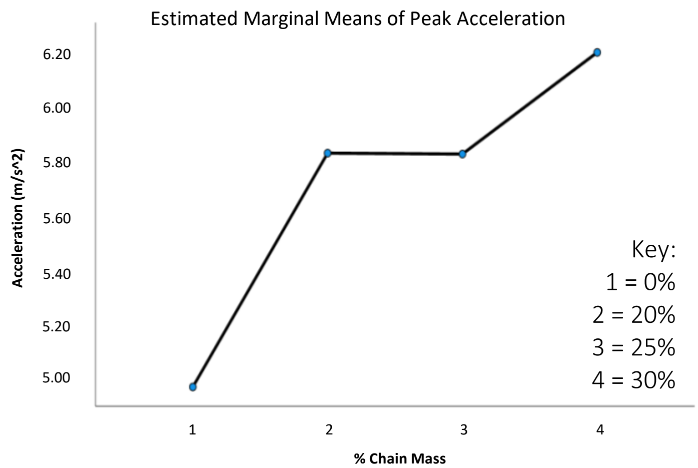

Figure 26. Estimated Marginal Means of Peak Acceleration.

Figure 26 demonstrates that 0% chains had the lowest PAO, while 30% chains had the highest PAO. PAO measurements, revealing significant mean differences. 0% chains had mean differences of <0.001, 0.003, and <0.001 when compared to 20% chains, 25% chains, and 30% chains, respectively.

Peak Acceleration Downwards Output (PADO):

Table 12. Peak Acceleration Downwards Output across traditional and accommodating resistance barbell squat.

PEAK ACCELERATION DOWNWARDS (M/S²)

	% CHAIN MASS				
PARTICIPANT (MASS/KG)	0%	20%	25%	30%	MEAN
62	-7.70	-6.91	-7.06	-7.10	-7.19
66	-8.85	-9.10	-8.31	-8.02	-8.57
70	-5.86	-6.48	-7.53	-7.08	-6.73
74	-7.76	-7.87	-7.70	-7.78	-7.78
76	-8.65	-8.65	-8.43	-8.94	-8.67
84	-9.11	-9.28	-8.86	-8.68	-8.98
87	-6.27	-6.62	-6.34	-5.74	-6.24
88	-7.76	-7.86	-8.45	-8.55	-8.15
89	-8.40	-7.49	-8.40	-8.42	-8.18
90	-9.87	-9.73	-9.75	-9.75	-9.78
103	-9.15	-8.65	-8.48	-8.48	-8.69
112	-9.29	-9.36	-9.30	-9.24	-9.30
MEAN	-8.22	-8.17	-8.22	-8.15	
RANK	1	3	2	4	

In the findings displayed within Table 12, the participant with a mass of 90kg generated the highest peak mean acceleration downwards of -9.78 m/s² during the movement, while the participant with a mass of 87kg produced the lowest peak mean acceleration downwards of -6.24 m/s². The conventional method and 25% accommodating resistance induced the highest peak mean acceleration downwards (-8.22 m/s²) among all participants, whereas the use of 30% chain mass resulted in the lowest peak mean acceleration downwards (-8.15 m/s²).

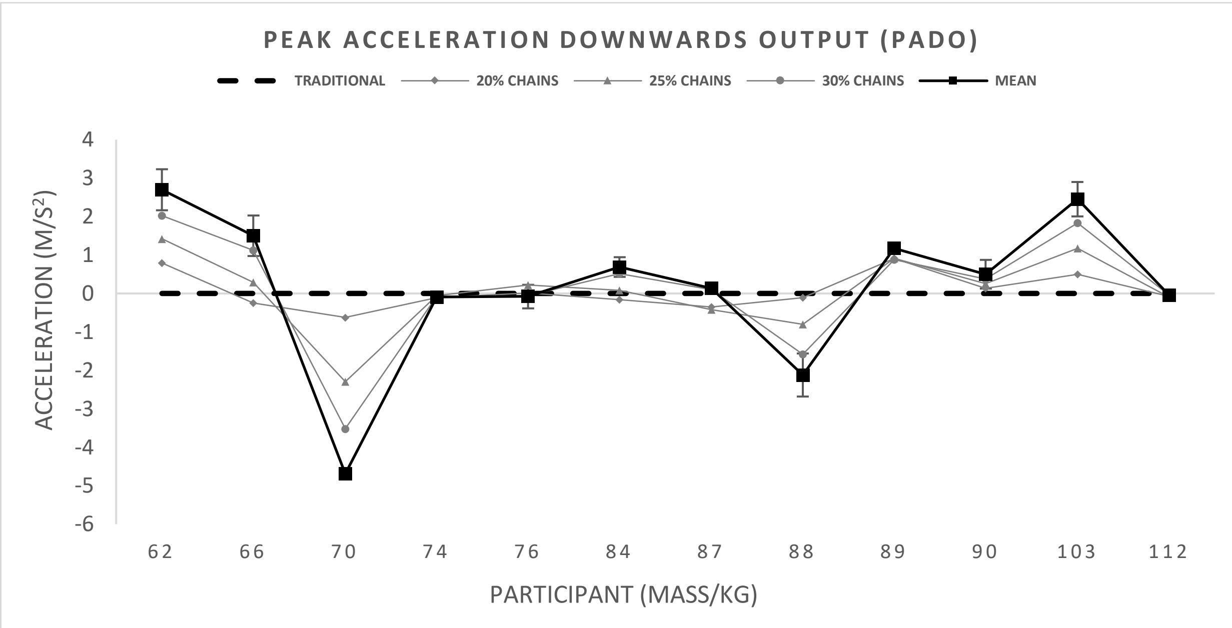

Figure 27. Peak Acceleration Downwards Output characteristics showing accommodating resistance based against traditional.

Figure 27 demonstrates the participants Peak Acceleration Output Downwards (PADO) during an accommodating resistance barbell back squat compared to the traditional movement. It is clear from the figure that the accommodating resistance method created varied outputs against all the traditional method attempts. Compared to the traditional method, the participant with a mass of 70kg recorded the highest peak mean value. Several participants showed a considerable degree of Standard Deviation (SD).

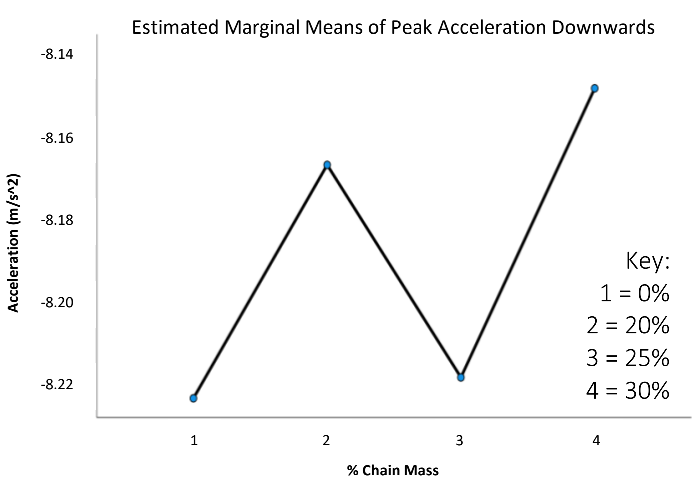

Figure 28. Estimated Marginal Means of Peak Acceleration Downwards.

Figure 28 demonstrates that 0% chains had the highest PADO, while 30% chains had the lowest PADO. PADO measurements, revealing significant mean differences. In contrast to the previous pairwise comparison, PADO didn't show any significant mean difference for each percentage chain mass.

5.3.5 Ranked Output Metrics

Table 13. Peak mean rankings across each output metric.

OVERALL OUTPUT RANK

	% CHAIN MASS			
OUTPUT METRIC	0%	20%	25%	30%
A - MAXIMAL STRENGTH (PFO)	1	2	4	3
A - MAXIMAL STRENGTH (MFO)	1	3	2	4
A - MAXIMAL STRENGTH (PPO)	1	3	2	4
B - RFD (PVO)	1	3	2	4
C - HIGH LOAD SPEED STRENGTH (PAO)	4	2	3	1
C - HIGH LOAD SPEED STRENGTH (PADO)	1	3	2	4
OVERALL RANK	1	3	2	4

In the findings displayed within Table 13, the traditional method with 0% chain mass ranked highest across all the measured outputs, while the 30% accommodating chain mass ranked the lowest. Among these two boundaries of percentage chains, the 25% accommodating chain mass placed second, while the 20% accommodating chain mass placed third.

5.3.6 Percentage Change

Table 14. Percentage Change Values Across Output Metrics.

PERCENTAGE CHANGE OF CHAIN MASS ATTEMPTS AGAINST TRADITIONAL

PARTICIPANT (KG)	A - MAXIMAL STRENGTH (PFO) (%)	A - MAXIMAL STRENGT (MFO) (%)	A - MAXIMAL STRENGTH (PPO) (%)	B - RFD (PVO) (%)	C - HIGH LOAD SPEED STRENGTH (PAO) (%)	C - HIGH LOAD SPEED STRENGTH (PADO) (%)
62	-6	31	-9	-5	11	-9
66	-4	39	-10	-1	27	-4
70	0	-30	40	37	40	20
74	-9	-1	-22	-18	4	0
76	-7	-2	-18	-15	11	0
84	-3	25	-15	-9	38	-2
87	-4	-26	-7	-7	22	7
88	0	1	-9	-4	31	-1
89	-4	21	-9	-4	24	-4
90	-9	-210	-20	-15	5	-1
103	-2	94	-25	-17	35	-7
112	-6	-2	-18	-14	11	0
MEAN	-5	-5	-10	-6	22	0

In the findings displayed within Table 14, multiple values can be emphasised to illustrate the significant contrast between the traditional approach and the accommodating resistance movement. In this case, the emphasised table highlights the percentage differences in output metrics compared to the traditional approach. The participant with a mass of 90kg generated the most substantial negative percentage change (-210%) in A - Maximal Strength (MFO), while the participant with a mass of 70kg attained the highest positive percentage change (40%) in A - Maximal Strength (PPO) and C - High Load Speed Strength (PAO). On average, when considering overall percentage change, C - High Load Speed Strength (PAO) resulted in the highest value (22%), while C - High Load Speed Strength (PADO) showed the lowest value (0%), indicating no change compared to the traditional method. The A - Maximal strength (PFO, MFO, and PPO) and B - RFD (PVO) exhibited percentage decreases against traditional of -5%, -5%, -10%, and -6%, respectively.

Chapter 6 General Discussion

This section delves into analysis of the factors affecting the comparison between accommodating resistance and traditional barbell back squats. The participants' ages, mass, and training years are investigated as necessary considerations for the study. The development and reliability of submaximal attempts and chain mass calculations are explained. The output metric figures and tables will be examined to analyse how performance varies with different accommodating chain masses. Further analysis of ranking and percentage change tables will offer insights into the notable impact of accommodating resistance, revealing both positive and negative effects on performance.

6.1.0 Experimental Data Analysis

6.1.1 Participant Metric for Data Collection

The study included 10 male participants and 2 female participants, indicating an uneven gender distribution. Ideally, an equal representation of genders would have facilitated more meaningful comparisons between the two groups. Nevertheless, insights can still be made regarding how different genders might respond to this type of testing. Previous research, such as the work of Lin, C. Y. et al. in 2018, has identified gender disparities in sports injuries. However, Lin, C. Y. et al. also emphasised the challenge of clarify the influence of sex and gender on sports injuries, as these factors are often interconnected. This aligns with findings by Huebner, M. et al., highlighting the importance for weightlifting athletes, coaches, to be conscious of injury patterns and gender distinctions when implementing effective prevention strategies. In this study, efforts were made to consider these factors and prevent injuries across genders.

The participants' ages, with a mean age of 21.6 years ± 2.6 years, played a crucial role, as age can influence their understanding of S&C. It was essential to consider this factor to ensure that participants possessed the necessary background knowledge and cognitive maturity to comprehend and follow the provided instructions. In contrast, Chodzko-Zajko W. J. et al. have noted variations in how individuals age and respond to exercise programs. Despite participants having experience in movement, precautions were deemed necessary across all testing methods. The inclusion of experienced athletes proved effective in preventing injuries and enhancing understanding of movement.

Measuring the participants' mass (83.4 kg ± 14.8 kg) was essential due to its sensitivity in the data analysis, which was done using PFPs and a scale. This ensures comprehensive data collection by accounting for the gravitational forces acting on the participants (mass). According to the prior findings of Bonafiglia J. T. et al., there is no indication of variations in individual trainability based on body mass and body composition parameters. This knowledge enabled participants to follow a consistent protocol, ensuring that differences in body mass did not potentially influence the overall outcomes.

The participants' documented training years (training years = 4 ± 1.4 years) provided insight into their level of skill in S&C training, which could impact their performance in complex exercises like the barbell squat. This information helped establish a baseline understanding of their experience and preparedness for such exercises. Despite this study only including experienced athletes, Oliver, J. M. et al. discovered that individuals with no prior resistance training history had comparable kinetics and kinematics to those with experience in S&C (Oliver, J. M. et al. 2016). The rationale behind choosing experienced athletes for this research stemmed from the nature of 1RM testing, which carries a risk of injury as highlighted by Braith et al., Dohoney et al., urging the inclusion of individuals with prior experience. Additionally, to adhere to ethical standards, it was clear that the athletes possessed a background in the specific back squat movement.

6.1.2 Metric for Strength Assessment and Performance Objectives

The development of submaximal attempts and chain mass relied on 1RM; a choice justified by its widely successful role in strength assessment by multiple sources (Faigenbaum et al., 2003, 2012; English et al., 2008; Bezerra et al., 2013; Seo et al., 2012; Ribeiro et al., 2014; Urquhart et al., 2015; Levinger et al., 2007). The decision to use a 1RM test, as opposed to a 3RM or 5RM test, was established in its ability to provide a precise measure of participants' maximal effort, facilitating the calculation of chain percentage mass. Using a higher RM test would involve estimating a perceived 1RM, introducing potential inaccuracies. Furthermore, this study contributes to the existing understanding, confirming that the 1RM testing protocol is a reliable and safe method for determining an athlete's maximum intensity in a specific movement.

6.1.3 Analysis of Output Metrics and Performance Measures

Pairwise comparisons and estimated marginal means for each output measure revealed significant mean differences ($p > 0.05$) for individual percentage chain masses, but this significance is limited to the specific mass under consideration and doesn't apply to the overall subject. These calculated marginal means support the ranking scheme discussed in the preceding section for each percentage chain mass.

This study compared the impact of accommodating resistance on barbell back squats with traditional squats. The results indicate that according to the ranking system, the traditional approach, which features a consistent barbell mass and a higher average load than when utilising chains, may provide greater advantages. However, upon closer examination of the percentage change in outputs relative to the traditional approach, it was discovered that the advantages of this method were only marginal.

A - Maximal Strength (PFO):

Analysing performance across various accommodating chain masses provides valuable insights, as demonstrated by this A - Maximal Strength (PFO). The participant with a mass of 87kg demonstrated noteworthy characteristics, showing both the highest minimum and peak mean force. This observation suggests a deliberate deceleration at the conclusion of the lift. Conversely, the 90kg participant displayed a negative minimum peak force, potentially indicating unloading during maximal effort. The traditional approach exhibited greater PFO compared to variations incorporating accommodating resistance. In this instance, incorporating a 20% accommodating mass contribution resulted in the most significant change against tradition when measuring PFO. Examining all participants, all attempts utilising accommodating resistance showed a decreased output in peak mean compared to the traditional method. Furthermore, these results contradict the Swinton et al. study, which reported an enhancement in peak force with the use of accommodating resistance. This contributes additional support to the idea that alterations in the type of movement can impact the observed variations in output metrics. The fundamental concept of Newton's Second Law is exemplified in this case. This law states that when a force is exerted on an object, it will undergo acceleration in the direction of that force. The acceleration is directly proportional to the applied force, and inversely proportional to the mass of the object. In this scenario, the PFO was identified at the peak eccentric point, occurring during the accommodating resistance repetition when the mass was at its minimum. This led to a decrease in PFO compared to the traditional variation. However, the analysis revealed that the decrease in percentage change was 5% when contrasting the accommodating resistance approach with the traditional method. It could be contended that this modest decrease is insufficient to result in a notable disparity in performance, particularly considering the advantageous performance characteristics offered by accommodating resistance.

A - Maximal Strength (PPO):

Analysing performance across various accommodating chain masses provides valuable insights, as demonstrated by this A - Maximal Strength (PPO). The findings revealed that the participant with the highest body mass produced the greatest PPO, while the participant with the lowest body mass generated the lowest PPO. This significant trend might stem from the influence of mass on PPO, as suggested by the power equation. Specifically, when mass increases while velocity remains constant, PPO is expected to rise accordingly. Only one participant with a mass of 70kg produced a greater output across chain percentage attempts against traditional. In this case, this outlier could have been caused with inaccuracies around the 1RM testing which in turn affected the proscribed chain percentage. This study has shown that incorporating a 25% accommodating mass contribution resulted in the most significant change against tradition when measuring PPO. Significant differences were observed across each chain percentage mass, reinforcing these findings. However, the reduction in PPO is supported in a study by Swinton et al. (2011), where they compared traditional resistance training with accommodating resistance and found that chains substantially decreased PPO. Swinton et. al. directed their attention to the deadlift exercise, and the results obtained in this study may indicate biomechanical parallels between the deadlift and squat movements, as evidenced by the observed metric outcomes in both investigations. While examining this output, the PPO was found during the concentric phase of the movement. Consequently, there was a decline in PPO when compared to the traditional method, attributable to the diminished accommodating mass contrasted with a constant mass. Furthermore, the analysis revealed that the decrease in percentage change was 10% when contrasting the accommodating resistance approach with the traditional method. Unlike PFO, it could be contended that this decrease is sufficient to result in a notable disparity in performance, particularly considering the support from previous literature. This intern suggests that for enhancing PPO, utilising the traditional method would be the best approach in this scenario.

B - RFD (PVO):

Analysing performance across various accommodating chain masses provides valuable insights, as demonstrated by this B - RFD (PVO). Like the results observed in PPO, the results for this output indicated that the participant with the highest body mass exhibited the greatest PVO, whereas the participant with the lowest body mass created the lowest PVO. However, the same theory around the power equation can’t be applied in this instance as a participant with a mass of 74kg also induced a minimal value. Unlike PPO, which varied according to force and mass outputs, previous ideas indicated that RFD is based on the intention to with maximal intent rather than actual velocity (Behm, D.G. and Sale, D.G. 1993). Conversely, some claim that increasing bar velocity is critical for enhancing RFD and high-speed capabilities (McBride, J.M. et al. 2002; Morrissey, M.C. et al. 1998). As previously stated, Swinton et al. (Swinton, P.A. et al. 2011) observed a decrease in bar velocity and RFD when chains were added to the deadlift exercise, confirming the notion that real bar velocity is a key role in RFD. Like PPO, only one participant with a mass of 70kg exhibited a higher output in accommodating resistance attempts across chain masses compared to traditional methods. This outlier is likely due to inaccuracies in the 1RM testing, impacting the prescribed chain percentages. The study demonstrates that integrating a 25% accommodating resistance mass leads to the most significant enhancement against traditional methods when assessing PVO. Additionally, the analysis indicates a mere 6% decrease in percentage change when comparing accommodating resistance to traditional methods. It can be argued that this slight decrease isn't substantial enough to significantly affect performance, especially considering the benefits of accommodating resistance. This suggests that in practical S&C sessions, if accommodating resistance is preferred over traditional methods, the accommodating chain mass should be set at 25%. The determining aspect regarding PVO involves executing movements with maximum intent to generate the highest PVO results, whether utilising traditional methods or ART.

C - High Load Speed Strength (PAO):

Analysing performance across various accommodating chain masses provides valuable insights, as demonstrated by this C – high load speed strength (PAO). The participants identified in the previous section exhibit distinctive traits when examining PAO. Among them, the individual with a mass of 87 kg demonstrated the highest PAO output with the use of accommodating resistance in contrast to traditional methods. Given the reasoning discussed about the acceleration according to Newton's Second Law when analysing PFO, similar predictions can be drawn regarding the improvements in PAO. The participant with a mass of 70 kg, who was an outlier among the participants, generated the least PAO. This result is understandable given the earlier noted discrepancies in prescribing movement mass. Accommodating resistance created significant benefits, resulting in increased PAO compared to traditional method. The increase in barbell mass during the lift's ascending phase corresponds to increased acceleration. The analysis indicated a significant 22% increase in percentage change when comparing accommodating resistance to traditional methods. The study also demonstrates that integrating a 20% accommodating resistance mass leads to the most significant enhancement against traditional methods when assessing PVO. As previously discussed, utilising ART helps mitigate the need for active deceleration, thus enabling the preservation or even enhancement of barbell acceleration during the critical final phase of the exercise (Swinton et al., 2011; Baker & Newton, 2005; Simmons, 1999). This notion is supported by the findings within this study which displays participants producing a greater chain induced output against traditional. Notably, the highest acceleration occurs during the peak eccentric phase, contrary to prior studies. This due to the concentric change in mass the participant is forced to continuously accelerate for an increased period in comparison to the traditional method. This further solidifies the concept of executing movements with maximum intent which has also created a practical justification for the heightened acceleration. This suggests that in practical S&C sessions, if accommodating resistance is preferred over traditional methods, the accommodating chain mass should be set at 20%.

6.1.4 Experimental Data Analysis Overview

In summary, the experimental data analysis conducted in this study provides a multifaceted understanding of the implications of incorporating accommodating resistance into barbell back squats, particularly in comparison to traditional methods. Despite the initial challenge posed by an uneven gender distribution among participants, the study's methodology was carefully crafted to account for potential gender disparities in sports injuries and to implement prevention strategies effectively. By considering various factors such as age, mass, and training experience, the research ensured a comprehensive assessment of participants' capabilities while minimising the risk of injury.

The decision to employ the 1RM testing protocol was justified by its established efficacy in accurately assessing maximal effort, thereby contributing to the existing body of knowledge on strength assessment methods. Through detailed analysis of output metrics, including A -maximal strength (PFO, PPO), B - RFD (PVO), and C - high load speed strength (PAO), this study has analysed the differences between accommodating resistance and traditional approaches. While accommodating resistance demonstrated certain advantages, particularly in terms of enhancing PAO, the observed differences compared to traditional methods were often subtle.

It could be contended that this modest decrease is insufficient to result in a notable disparity in performance, particularly considering the advantageous performance characteristics offered by accommodating resistance. To optimise performance characteristics through the integration of ART into S&C sessions, it is strongly advised to incorporate a 25% accommodating resistance mass contribution for maximum benefit. These findings further highlight the complexity of optimising performance in resistance exercises and emphasise the importance of tailoring training approaches to individual characteristics and performance objectives.

6.2.0 Experimental Limitations

6.2.1 Mass Errors and Sensitivities in Experimental Analysis

Throughout the investigation, there were recurring issues related to mass errors and sensitivities. One notable example involved the calculation of the percentage chain mass based on participants' 1RM, which closely resembled the recommended mass for the squat movement. In this case, the prescribed chain configurations were adhered to as closely as possible during the movement, but the fixed mass of individual chains posed a challenge that could not be addressed during the experimental procedure. For future research in this area, it is recommended to acknowledge and address mass fluctuations at the early stages of the experiment to enable comparative analysis or minimise their impact.

6.2.2 Mass Consistency in Experimental Procedures

To minimise errors arising from fluctuations in mass, alternative approaches could have been implemented. For instance, during the familiarisation stage, assessing squat depth with an unloaded barbell, as recommended, could have been employed. This assessment could have utilised a simple measuring tape or a wire with a tension mechanism within an inactive LPT. Considering this perspective, it would have been possible to integrate personalised squat heights based on the same calculation used in the current study, rather than employing a uniform squat height for all participants.

Additionally, the challenge of estimating mass was intensified by the presence of multiple chain sizes with varying mass displacements simultaneously. To enhance the mass estimation process in future research, employing chains of uniform length and mass distribution could prove beneficial, reducing variability in different chain percentage mass attempts if the study were replicated. After the experimental procedure, it was suggested that a mathematical formula could replace the manual mass calculation used in this study, particularly when individual squat height is unknown. Implementing such a variable mass estimation method would be recommended for future experimental procedures, as it minimises human errors associated with squat height estimation and mass fluctuations.

6.2.3 Contact Stability and Minimising Unloading Variability

Mistakes in establishing contact with the chains, particularly during instances where participants exerted significant force, resulted in a loss of contact and swinging during the final phases of the lift. The initial methods did not specify the frequency of unloading among participants; this assumption is based on the characteristics of the data observed in the 90kg participant. The impact of sporadic unloading on the key outcomes of the study remains uncertain. To address this issue, securing the lowest chain link to the ground could minimise movement and sway. If this proves impractical in future research, participants should be instructed to consistently maintain control over the chains while still exerting maximal force.

6.2.4 Biomechanical Advantages and Safety Considerations

Previous studies show that using chains in training improves an athlete's biomechanical advantages at the "sticking point" during workouts such as the barbell squat (Elliott et al., 1989). This idea of the “sticking point” would be more apparent within a study that analyses movements closer to a participant’s maximum. As the participants within this study completed the barbell squat at 60% of their 1RM, this notion wasn’t so noticeable during movement monitoring. If a greater percentage ART was used, the analysis would further rely on tracking attempts, assessing Rate of Perceived Exertion (RPE), and gathering movement feedback. If this is carried out within an S&C setting effective feedback is required with a strong athlete-coach relationship.

The goal of the current study wasn’t to directly measure the improved safety of using chains in a biomechanically weaker position. However, both the use of 1RM testing and ART provide to be a viable methodology with regards to participant safety as all participants successfully completed the movements without any injuries caused. This notion is supported by the concept that ART depends on input from athletes and their strategic incorporation of chains to gain biomechanical benefits. If chains can reduce the barbell mass at the least biomechanical advantageous stage of the lift, it could further enhance safety and facilitate the movement for the athlete.

6.2.5 Considerations and Limitations in Participant Selection

Recruiting for the research was limited to experienced athletes in both 1RM and ART testing due to the complexity of the barbell squat, reducing the potential participant pool due to safety and ethical concerns. There are several aspects which can be explored which lead to the external validity and generalisation of the findings. To begin with, the outcomes of the experiment may not readily apply to individuals who are not experienced athletes. Individuals categorised as novices or intermediates, along with those possessing diverse levels of fitness, could exhibit distinct responses under the conditions examined.

Furthermore, the decision to exclude novice participants constrains the potential external relevance of the study to everyday S&C scenarios where individuals with varying experience levels might participate in barbell squat exercises. Lastly, the conclusions drawn may not precisely reflect the wider population engaging in barbell squat routines. This becomes particularly relevant if the understandings from this study aim to guide training programs for a diverse group of athletes. Within the context of this study, the movements analysed would likely be found in a high-performance S&C group as it provides an increased degree of feedback across outputs for the athletes.

6.3.0 Future Research

6.3.1 Insights and Implications of Original Aims

The primary objective of this study was to assess the influence of accommodating resistance, specifically using chains, on forces during the squat motion. The findings indicate that, in terms of forces, the conventional approach resulted in a greater peak force output across all participants. While exploring the effects of incorporating chains in resistance training, the study observed various additional outputs. Participants exhibited greater peak velocity, minimum force, peak acceleration downwards, and peak power when executing the traditional squat method. Notably, peak acceleration was the only parameter that showed higher values in the ART group. This reinforces the notion that, in this context, the traditional method is considered the optimal approach over ART. The implications for future training methods suggest that integrating traditional squat movements can yield the most significant benefits in terms of multiple outputs.

A secondary objective aimed to recognise differences in the most effective barbell loads based on prior research and to understand their implications for training intensity. Previous studies revealed that a 60% total barbell load resulted in the highest benefits for specific peak power outputs. While this investigation did not directly examine the impact of varying total barbell mass on power outputs, it is recommended that this percentage mass be considered in future research. Additionally, the study sought to determine the ideal load for achieving peak power output during ART exercises, particularly focusing on squat variations. The findings indicated that a 25% contribution from chain mass produced the highest mean peak power values across all participants. If ART methods are incorporated for training diversity, it is advised to use a 25% ART prescription to optimise power outputs.

The tertiary objective aimed to investigate the advantages of incorporating the cluster technique into the resistance movement. The findings of this study reveal that employing cluster set repetitions can have a favourable effect on the method of data collection. This training approach proved beneficial for data collection by facilitating notetaking between each attempt, providing brief rest intervals for participants, enabling maximal effort in each attempt. Isolating repetitions also minimised the impact of errors during data collection, as only one repetition needed to be repeated instead of potentially three in consecutive repetitions. Consequently, this study recommends the utilisation of cluster style repetitions in this type of data collection to enhance its efficiency. While the direct impact of cluster set training on measured outputs wasn't explicitly measured, it is suggested that it optimised each individual attempt, allowing participants to execute with maximum intent. This highlights the positive impact of cluster sets in this style of data collection and advocates their use in future S&C experiments.

Alongside these findings, this study also uncovered several essential concepts out with the initial aims that contribute significantly to future understanding of the research. These key takeaways can be summarised as follows:

1. The utilisation of chains in training introduces diversity to exercises, preventing performance plateaus. When used in combination with a barbell back squat, chains lighten the eccentric phase, reducing the effects of delayed onset muscle soreness (DOMS) and enabling quicker recovery, thus facilitating more frequent high-intensity training sessions.
2. Cluster set training is beneficial for maintaining proper movement patterns and lowering the risk of injury.
3. Maximising effort during concentric movements encourages the activation of type II muscle fibres, resulting in improved athletic performance in explosive activities such as sprinting and jumping.

6.3.2 Optimising Study Design and Future Research Directions

The following section will highlight alterations that can be made to this study and future research to enhance the significance of adaptations around accommodating resistance within athletes' training regimes.

One way to improve the study's findings is to simply expand the sample size and include a more diverse pool of athletes with varying athletic abilities. By doing so, the statistical significance of the results can be strengthened, and unique insights may arise using between-group experimental designs. Another aspect to consider is tailoring training regimens to specific athletes based on their strength categories. This personalised approach could potentially lead to more effective training programs, optimising each athlete's performance and progress. Incorporating a LPT alongside HD force plates can offer valuable benefits in the assessment of performance, velocity-based training, and power monitoring. By using both technologies, researchers can make meaningful comparisons between the LPT's direct output, and the force measurements obtained from HD force plates. Furthermore, the LPT can serve as a useful measuring device to determine the height lost during barbell back squat efforts when it is turned off. This capability can provide additional data on the impact of accommodating resistance on squat performance and help in understanding the effectiveness of different training methods.

By considering these factors and conducting further research in these areas, future studies can advance our understanding of accommodating resistance in S&C training and contribute to more effective and tailored training approaches for athletes of all levels.

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Appendix

Appendix 1:

Ethics Application Form

Please answer all questions

1. Title of the investigation
The impact of using accommodating resistance as part of a cluster set to enhance acute lower body power.
Please state the title on the PIS and Consent Form, if different: N/A

2. Chief Investigator (must be at least a Grade 7 member of staff or equivalent)
Name: Craig Childs Teaching Fellow Department: Biomedical Engineering Telephone: 01415482228 E-mail: craig.childs@strath.ac.uk

3. Other Strathclyde investigator(s)
Name: Peter Steele Status: Postgraduate Student Department: Biomedical Engineering Telephone: 07501462668 E-mail: p.steele@strath.ac.uk Name: Dave Sykes Status: Performance Sport Manager Department: Strathclyde Sport Telephone: 01415483822 E-mail: dave.sykes@strath.ac.uk

4. Non-Strathclyde collaborating investigator(s) (where applicable)

Name: N/A Status (e.g. lecturer, post-/undergraduate): Department/Institution: If student(s), name of supervisor: Telephone: E-mail: Please provide details for all investigators involved in the study:

5. Overseas Supervisor(s) (where applicable)
Name(s): N/A Status: Department/Institution: Telephone: Email: I can confirm that the local supervisor has obtained a copy of the Code of Practice: Yes ☐ No ☐ Please provide details for all supervisors involved in the study:

6. Location of the investigation
At what place(s) will the investigation be conducted Strathclyde Sport
If this is not on University of Strathclyde premises, how have you satisfied yourself that adequate Health and Safety arrangements are in place to prevent injury or harm? N/A

7. Duration of the investigation
Duration(years/months) : 6 months Start date (expected): 06 / May / 2022 Completion date (expected): 20 / Oct / 2022

8. Sponsor
Please note that this is not the funder; refer to Section C and Annexes 1 and 3 of the Code of Practice for a definition and the key responsibilities of the sponsor.
Will the sponsor be the University of Strathclyde: Yes If not, please specify who is the sponsor:

9. Funding body or proposed funding body (if applicable)
Name of funding body: N/A Status of proposal – if seeking funding (please click appropriate box): ☐ In preparation ☐ Submitted ☐ Accepted Date of submission of proposal: / / Date of start of funding: / /

10. Ethical issues
Describe the main ethical issues and how you propose to address them: All participants will complete a health screening and strength and conditioning questionnaire prior to testing see "5_MEDICAL_QUESTIONNAIRE_FOR_PHYSIOLOGICAL_TESTING and 6_STRENGTH_AND_CONDITIONING_QUESTIONNAIRE" Subjects will only take part in testing if their form has been cleared and signed off by the researcher. All participants will undergo maximal physical exercise throughout the data collection. During maximal squat testing there is potential for risk of injury or harm which is highlighted within "8_SU_RA_5926_2022-03-22". Mitigating factors within the inclusion criteria have been highlighted to lessen the potential risk. The participant must be either a current Scholar performance athlete or part of a FOCUSport performance team. Both scholar and FOCUSport athletes undergo regular 1 repetition maximum testing throughout the year over a variety of movements including the barbell back squat. Data collection includes a medical questionnaire for physiological testing, strength & conditioning questionnaire, participant consent form and data created by the 1 repetition maximum testing and accommodating resistance testing. Only the named investigators will be present during this initial screening session. All the data sets collected throughout the study will be kept strictly confidential,

stored in a locked cabinet in the Wolfson Building (room WC601d which requires ID pass to access pass) and stored indefinitely. All data will be handled in accordance with the Departmental Data Management Plan. Only the named study investigators within this ethics application will have access to the consent forms and screening questionnaires. The participants won't be identified or identifiable to a specific data set within any report that is published.

11. Objectives of investigation (including the academic rationale and justification for the investigation) Please use plain English.

In general, resistance training (also known as weight training or strength training) is implemented in an athlete's training program to increase muscular strength, endurance and power production. The main adopted form of resistance training found commonly today is described as compound training, which involves strength-based and power-based movements performed on different days : strength training with increased resistance (70-90% 1 repetition maximum) in one session and speed training with decreased resistance (30% 1 repetition maximum) in the following session. The maximum weight an athlete can lift is the 1 repetiton maximum and is a key outcome measure which needs to be regularly assessed to monitor an athletes progression. Peak power may be a more convenient measure.

An alternative to compound training is the use of cluster sets, which include short rests intervals (15-30s) in-between each repetition. This recovery should reduce fatigue whilst maximising the overall load the athlete lifts in the session.

Rigid weights (Olympic style bumper plates) on a barbell offer the same resistance to motion whatever position the athlete is in. However, the force-length relationship of muscles means that an athlete's ability to lift a given load will vary through the motion. Chains can be included in the weight to create a load that will vary depending on how much of the chain is in contact with the ground at each point in the motion. In a squat, the chains 'accommodate' the athletes ability to produce lift at the weaker position (more chain is on the floor at the bottom of the lift) whilst maximising the load at the top (fewest chain links on the floor on returning to upright).

It is believed that towards the upper section of a back squat movement, the athlete needs to reduce their force production and actively decelerate the barbell (i.e reduce barbell speed) to stay in control of the lift. The use of an accommodating weight in the form of chains may retain, or even increase, the force production and barbell decceleration in the upper section of the lift. This is not yet known. This study aims to measure the force during squat lifts performed by trained athletes for different ratios of rigid and accommodating weights using a cluster set. The athletes will perform the squat whilst on a forceplate which will record the force produced throught the lift. From this force/time data the power can be derived. The peak force output gathered from the participants will allow for a peak power production value to be created. The peak power production can be used in future training prgrams to closely analyse the benefits of resistance training. It will allow strengh and conditioning coaches to implement power based testing movements within sessions to monitor progression as the athlete increases their performance.

12. Participants

Please detail the nature of the participants:

Summarise the number and age (range) of each group of participants:

Number: 12 Age (range) >18

Please detail any inclusion/exclusion criteria and any further screening procedures to be used:

Athletes must be able to self-report the following inclusion/exclusion to be able to part within the study:

Inclusion

- Able-bodied
- Normal lower limb function
- A current Scholar performance athlete or FOCUSport team athlete
- [FOCUSport are University targeted sports clubs receive strength and conditioning support from the performance department]
- Technically proficient in barbell back squat.
- Participants must provide a negative lateral flow test before attending the testing

Exclusion

- Musculoskeletal lower or upper limb injury impairing gym performance at the time of trial
- Neurological trauma to the brain, spine, or nerves
- Difficulties with their balance due to either musculoskeletal or neurological injuries

- COVID-19 symptoms in 14 days before each experimental trial day (N.B. this will be asked before every session)
- Known to be pregnant
- Spinal injury
- Those who have any injury/disease which presents as a contraindication to exercise

The medical questionnaire will be used as a final screening to highlight any exclusions that the participants have not identified as being included in the list above. In particular questions surrounding heart defects and shortness of breath including asthma. The document will be used as a form of medical consent with the participant stating that all the information that they have provided is true. The strength and conditioning questionnaire will be used to draw similarities or differences across participants' ability and how this may affect results. Conclusions can then be made from this with the data that is collected.

To be technically proficient within the barbell movement, the participant must be able to perform the following:

- Safely load the barbell from the squat rack onto your shoulders (trapezius muscles). With knees slightly bent stand with feet shoulder-width apart, feet pointing slightly outward, core raised and chest up.
- To initiate the squat movement, the hips need to be pushed back and the knees bend outwards. Sink into the movement until the thighs become parallel with the floor
- Push through the floor once the parallel mark has been made to return to the starting position.

Given their training programmes, scholar performance athletes and FOCUSport team athletes will be very familiar with this action.

13. Nature of the participants

Please note that investigations governed by the Code of Practice that involve any of the types of participants listed in B1(b) must be submitted to the University Ethics Committee (UEC) rather than DEC/SEC for approval.

Do any of the participants fall into a category listed in Section B1(b) (participant considerations) applicable in this investigation?: ~~Yes~~ ☐ **No** ☒

If yes, please detail which category (and submit this application to the UEC):

N/A

14. Method of recruitment

Describe the method of recruitment (see section B4 of the Code of Practice), providing information on any payments, expenses, or other incentives.

Trial information will be sent via Strathclyde Sport's Union official club accounts, which is likely the club captain. In the case of non-club Strathclyde performance scholar-athlete, the advertisement will be circulated via the senior performance coach, Adam Crook. Within the advertisement, contact details (email) will be provided for the aspiring participants to request the participant information sheet (PIS) and to ask any questions or queries they may have about the study.

People responding to the advert will be sent an email with 2_PARTICIPANT_INFORMATION_SHEET_(PIS), 5_MEDICAL_QUESTIONNAIRE_FOR_PHYSIOLOGICAL_TESTING and 6_STRENGTH_AND_CONDITIONING_QUESTIONNAIRE.

Potential participants will be asked to read through the documents, ask any questions and if interested contact the lead researcher via email. The medical questionnaire and strength and conditioning questionnaire will be provided within the participant recruitment letter so that participants can preview the documents before attending the first testing day. This will allow participants to highlight any criteria that will exclude them from the experiment.

Once the questionnaires have been completed and signed by the participant, the researchers will screen the answers provided before commencing with the testing.

See 2_PARTICPANT_INFORMATION_SHEET_(PIS), 4_PARTICIPANT_RECRUITMENT, 5_MEDICAL_QUESTIONNAIRE_FOR_PHYSIOLOGICAL_TESTING and 6_STRENGTH_AND_CONDITIONING_QUESTIONNAIRE for reference.

15. Participant consent

Please state the groups from whom consent/assent will be sought (please refer to the Guidance Document). The PIS and Consent Form(s) to be used should be attached to this application form.

Consent will be sought from all participants:

Participants will be given the opportunity to get in contact with the research group prior to attending, once they have previewed the documents stated below.

See 2_PARTICIPANT_INFORMATION_SHEET_(PIS), 3_PARTICIPANT_CONCENT_FORM and 5_MEDICAL_QUESTIONNAIRE_FOR_PHYSIOLOGICAL_TESTING, 6_STRENGTH_AND_CONDITIONING_QUESTIONNAIRE

16. Methodology

Investigations governed by the Code of Practice which involve any of the types of projects listed in B1(a) must be submitted to the University Ethics Committee rather than DEC/SEC for approval.

Are any of the categories mentioned in the Code of Practice Section B1(a) (project considerations) applicable in this investigation? No

If 'yes' please detail:

Describe the research methodology and procedure, providing a timeline of activities where possible. Please use plain English.

The determined hypothesis will be tested with a within-group experimental design.

The participants will attend Strathclyde Sport over two separate days. On arrival of each of the testing days the participants height and weight will be measured with the use of a Harpenden Portable Stadiometer and standing analogue scale. Height measure will be used to set chain length to ensure correct number of chain-links will be in contact with the ground at the top and bottom of the lift. Participants weight value will be used during the analysis for measuring differences in bar and system (body weight + bar weight) outputs. The participants will complete a standard warm-up and cool down at the beginning and end of each testing day. The warm-up and cool down will involve dynamic stretches and static stretches respectively. Each testing day will require approximately 45 minutes of commitment from the participant.

Day 1 – Each participant will complete back squat[1] testing to determine the maximum weight they can lift (1 repetition maximum load). The protocol for this testing will follow NSCA guidelines[2]. The load used in Day 2 will be 60% of this maximum load. Day 1 loads will all be rigid Olympic style bumper plates. Day 2 loads will consist of different proportions of Olympic style bumper plates and weighted steel chains. The participant height measured on Day 1 will be used to set chain length to ensure correct number of chain-links will be in contact with the ground at the top and bottom of the lift.

The protocol for maximum load testing is based on participants estimated or previously recorded 1 repetition maximum:

- 10-minute welcome/explanation/questionnaire completion/consent
- 5-minute warm up
- 3-5 repetitions at 30%-40% of estimated/previous maximum load
- 3-minute rest
- 3-5 repetitions at 40%-60% of estimated/previous maximum load
- 3-minute rest
- 1-3 repetitions at 60%-70% of estimated/previous maximum load
- 3-minute rest
- 1-2 repetitions at 70%-95% of estimated/previous maximum load
- 3-minute rest
- 1 repetition at maximum load
- 5-minute cool down/debrief

During the testing the participant will go through 10-18 repetitions in total with the added extra attempts after they have completed their first 1 repetition maximum attempt. If the first attempt is successful, the process is repeated with 2.5kg increments until a new maximum is met.

There will be a minimum of 48 hours between the first and second session.

Day 2 – During the 10-minute welcome and explanation period on day two, participants will be asked to confirm if that have picked up any injuries between testing days. If an injury has occurred, the participant will be removed from the experimental process with all previously gathered questionnaires and data discarded.

Each participant will complete four cluster sets of three repetitions with a maximum barbell load of 60% of the 1 repetition maximum determined on Day 1. The contribution to the overall weight from the rigid Olympic Bumper Plates and Chains for each of the sets is shown in Table 1, where set A is the control condition. The set order will be randomised for each participant.

Table 1 contribution to overall weight				
	A	B	C	D
Olympic Bumper Plates	60%	40%	35%	30%
Chains	0%	20%	25%	30%

The day 2 protocol is:

- 10-minute welcome/explanation
- 5-minute warm up
- 3 cluster repetitions Set 1
- 3-minute rest
- 3 cluster repetitions Set 2
- 3-minute rest
- 3 cluster repetitions Set 3
- 3-minute rest
- 3 cluster repetitions Set 4
- 5-minute cool down/debrief

On day 2 the participants will undergo 12 squat repetitions in total. Hawkins force plates will be used to measure the force throughout each squat. From this power will be derived to analyse differences in system (bodyweight + barbell load) peak force output across the accommodating resistance variables.

All sessions will adhere to Strathclyde Sport's "Clean Use Clean" COVID-19 policy.

What specific techniques will be employed and what exactly is asked of the participants? Please identify any non-validated scale or measure and include any scale and measures charts as an Appendix to this application. Please include questionnaires, interview schedules or any other non-standardised method of data collection as appendices to this application.

Resistance training is based on three key weight lifting movements; the barbell back squat, barbell bench press and barbell deadlift. The main movement within this study is the barbell back squat which is carried out by an athlete carrying out the following:

(1) Squat

- Safely load the barbell onto your traps and shoulders, from the squat rack. With knees slightly bent stand with feet shoulder-width apart, feet pointing slightly outward, core raised and chest up.
- To initiate the squat movement, the hips need to be pushed back and the knees bend outwards. Sink into the movement until the thighs become parallel with the floor
- Push through the floor once the parallel mark has been made to return to the starting position.

(2) https://www.nsca.com/globalassets/education/nsca_strength_and_conditioning_professional_standards_and_guidelines.pdf

Where an independent reviewer is not used, then the UEC, DEC or SEC reserves the right to scrutinise the methodology. Has this methodology been subject to independent scrutiny? Yes ☐ No ☒
If yes, please provide the name and contact details of the independent reviewer:

17. Previous experience of the investigator(s) with the procedures involved. Experience should demonstrate an ability to carry out the proposed research in accordance with the written methodology.
Dr Craig Childs manages the CAREN virtual reality motion analysis laboratory at the University of Strathclyde. He is a registered Clinical Scientist, who has worked in motion analysis over many years for a range of conditions, including managing drop foot in stroke survivors and assessing children with cerebral palsy for potential surgery. Craig will be active in a research role, not as a coach. Dr Dave Sykes is currently Performance Sport Manager at the University of Strathclyde. Dave holds an applied PhD which was sponsored by a professional rugby league club and has published on a range of sports science topics periodically over the past decade. In addition, Dave has supervised both undergraduate and postgraduate dissertations from several leading UK-based Universities and is formerly an Associate Lecturer on the MSc in Strength and Conditioning at the University of Edinburgh. Dave has expertise within strength & conditioning and experimental analysis, he will be active in a research role and supervise data collection and analysis Peter Steele is currently an MPhil student within the Biomedical Engineering Department whilst specialising within S&C. Peter has graduated with a Second-Class Upper Division BEng in Sports Engineering and has completed a final year project within the same field. Peter holds a UKSCA Foundation Coaching award and a UKSCA membership. Peter will be the main investigator during the experimental procedure and analysis, whilst being the lead strength and conditioning practitioner during the testing days.

18. Data collection, storage and security
How and where are data handled? Please specify whether it will be fully anonymous (i.e. the identity unknown even to the researchers) or pseudo-anonymised (i.e. the raw data is anonymised and given a code name, with the key for code names being stored in a separate location from the raw data) - if neither please justify. All data will be handled in accordance with the Departmental Data Management Plan. Data will become fully anonymous once the pseudo-anonymisation code is deleted. The main data types have been highlighted below: Pseudoanonymous data:

- 1 repetition maximum value (stored within the University OneDrive, only accessible to investigators, will be stored until study is completed)
- Force data created by Hawkins force plates (stored within the University OneDrive, only accessible to investigators, will be central to the final thesis)

All pseudoanonymous data will become anonymous once the identification key is deleted, thus making the data anonymous and it will be kept indefinitely.

Personal Identifiable Data:

- Medical questionnaire
- Strength and conditioning questionnaire
- Consent form

All the data sets collected throughout the study will be kept strictly confidential. The participants won't be identified or identifiable to a specific data set within any report that is published. All paper-based documents will be kept within a locked cabinet in the Wolfson Building (room WC601d which requires ID pass to access pass). These will only be accessible to the research team and will be stored indefinitely.

See "3_PARTICIPANT_CONSENT_FORM and 5_MEDICAL_QUESTIONNAIRE_FOR_PHYSIOLOGICAL_TESTING, 6_STRENGTH_AND_CONDITIONING_QUESTIONNAIRE"

Explain how and where it will be stored, who has access to it, how long it will be stored and whether it will be securely destroyed after use:

All personal contact details will be deleted at the end of the study along with the pseudo-anonymisation key; thus all remaining data will be anonymous. All anonymous experimental data will be kept indefinitely. All data will be handled in accordance with the Departmental Data Management Plan.

Will anyone other than the named investigators have access to the data? Yes

If 'yes' please explain:

Yes, anonymised data will be available for future researchers. Once the pseudo anonymisation code file is deleted the data will become anonymous and stored indefinitely on the University's PURE repository.

19. Potential risks or hazards

Briefly describe the potential Occupational Health and Safety (OHS) hazards and risks associated with the investigation:

All participants will undergo maximal physical exercise throughout the data collection. During maximal squat testing there is potential for risk of injury or harm which is highlighted within "8_SU_RA_5926_2022-03-22". Mitigating factors within the inclusion criteria have been highlighted to lessen the potential risk.

Within the inclusion criteria, the participant must be either a current Scholar performance athlete or part of a FOCUSport performance team. Both scholar and FOCUSport athletes undergo regular 1 repetition maximum testing throughout the year over a variety of movements including the barbell back squat.

As the athletes have undergone multiple maximal barbell squat testing attempts, they are well attuned to the correct squat depth to justify technical proficiency. In this instance, the squat depth needed to technically perform a barbell squat correctly is on or below parallel.

If the participant doesn't hit the required depth on their 1 repetition maximum attempt, the lift will be decarded from the testing data collection. At this point, the participant will either be allowed to reattempt the lift or use their 1 repetition maximum from the previous attempt.

During the 1 repetition maximum barbell squat testing the participant will either perform the movement within a secure squat rack with safety pins or with the assistance of a spotter (one of the research team). The participant will decide if they would rather squat inside the rack with the use of safety pins or outside with the assistance of a spotter.

COVID-19 transmission risk will be reduced by testing procedures following Strathclyde Sport's COVID-19 "Clean Use Clean" policy.

Please attach a completed eRisk Assessment for the research. Further Guidance on Risk Assessment and Form can be obtained on Occupational Health, Safety and Wellbeing's webpages

List of all risk docs...

If requested, a summary of the results taken from the testing will be shared via email.

21. How will the outcomes of the study be disseminated (e.g. will you seek to publish the results and, if relevant, how will you protect the identities of your participants in said dissemination)?
The outcomes found within the experiments will be used for a MPhil thesis and scientific publication in an international peer-reviewed journal. During publishing, only the anonymous data will be included in the report.

Checklist	**Enclosed**	**N/A**
Participant Information Sheet(s)	X	☐
Consent Form(s)	X	☐
Sample questionnaire(s)	☐	X
Sample interview format(s)	☐	X
Sample advertisement(s)	X	☐
OHS Risk Assessment (S20)	X	
Any other documents (please specify below)	X	☐
Strength And Conditioning Questionnaire	X	☐
Medical Questionnaire for Physiological Testing	X	☐
COVID-19 Risk Assessment	X	☐
	☐	☐

22. Chief Investigator and Head of Department Declaration

Please note that unsigned applications will not be accepted and both signatures are required

I have read the University's Code of Practice on Investigations involving Human Beings and have completed this application accordingly. By signing below, I acknowledge that I am aware of and accept my responsibilities as Chief Investigator under Clauses 3.11 – 3.13 of the Research Governance Framework and that this investigation cannot proceed before all approvals required have been obtained.

Signature of Chief Investigator: Craig R Childs

Please also type name here: Dr Craig Childs

I confirm I have read this application, I am happy that the study is consistent with departmental strategy, that the staff and/or students involved have the appropriate expertise to undertake the study and that adequate arrangements are in place to supervise any students that might be acting as investigators, that the study has access to the resources needed to conduct the proposed research successfully, and that there are no other departmental-specific issues relating to the study of which I am aware.

Signature of Head of Department

Please also type name here

Date: / /

23. Only for University sponsored projects under the remit of the DEC/SEC, with no external funding and no NHS involvement

Head of Department statement on Sponsorship

This application requires the University to sponsor the investigation. This is done by the Head of Department for all DEC applications with exception of those that are externally funded and those which are connected to the NHS (those exceptions should be submitted to R&KES). I am aware of the implications of University sponsorship of the investigation and have assessed this investigation with respect to sponsorship and management risk. As this particular investigation is within the remit of the DEC and has no external funding and no NHS involvement, I agree on behalf of the University that the University is the appropriate sponsor of the investigation and there are no management risks posed by the investigation.

If not applicable, tick here ☐

Signature of Head of Department

Please also type name here

Date:	/ /

For applications to the University Ethics Committee, the completed form should be sent to ethics@strath.ac.uk with the relevant electronic signatures.

24. Insurance
The questionnaire below must be completed and included in your submission to the UEC/DEC/SEC:

Is the proposed research an investigation or series of investigations conducted on any person for a Medicinal Purpose? Medicinal Purpose means: ▪ treating or preventing disease or diagnosing disease or ▪ ascertaining the existence degree of or extent of a physiological condition or ▪ assisting with or altering in any way the process of conception or ▪ investigating or participating in methods of contraception or ▪ inducing anaesthesia or ▪ otherwise preventing or interfering with the normal operation of a physiological function or ▪ altering the administration of prescribed medication.	No

If "**Yes**" please go to **Section A (Clinical Trials)** – all questions must be completed
If "**No**" please go to **Section B (Public Liability)** – all questions must be completed

Section A (Clinical Trials)

Does the proposed research involve subjects who are either: i. under the age of 5 years at the time of the trial; ii. known to be pregnant at the time of the trial	No

*If "**Yes**" the UEC should refer to Finance*

Is the proposed research limited to: iii. Questionnaires, interviews, psychological activity including CBT; iv. Venepuncture (withdrawal of blood); v. Muscle biopsy; vi. Measurements or monitoring of physiological processes including scanning; vii. Collections of body secretions by non-invasive methods; viii. Intake of foods or nutrients or variation of diet (excluding administration of drugs).	Yes / No

*If "**No**" the UEC should refer to Finance*

Will the proposed research take place within the UK?	Yes

*If "**No**" the UEC should refer to Finance*

Title of Research		
Chief Investigator		
Sponsoring Organisation		
Does the proposed research involve:		
a)	investigating or participating in methods of contraception?	No
b)	assisting with or altering the process of conception?	No
c)	the use of drugs?	No
d)	the use of surgery (other than biopsy)?	No
e)	genetic engineering?	No
f)	participants under 5 years of age(other than activities i-vi above)?	No
g)	participants known to be pregnant (other than activities i-vi above)?	No
h)	pharmaceutical product/appliance designed or manufactured by the institution?	No
i)	work outside the United Kingdom?	No

If **"YES"** to **any** of the questions a-i please also complete the **Employee Activity Form** (attached).
If **"YES"** to **any** of the questions a-i, and this is a follow-on phase, please provide details of SUSARs on a separate sheet.

*If "**Yes**" to any of the questions a-i then the UEC/DEC/SEC should refer to Finance (*insurance-services@strath.ac.uk*).*

Section B (Public Liability)

Does the proposed research involve :		
a)	aircraft or any aerial device	No
b)	hovercraft or any water borne craft	No
c)	ionising radiation	No
d)	asbestos	No
e)	participants under 5 years of age	No
f)	participants known to be pregnant	No
g)	pharmaceutical product/appliance designed or manufactured by the institution?	No
h)	work outside the United Kingdom?	No

*If **"YES"** to any of the questions the UEC/DEC/SEC should refer to Finance (*insurance-services@strath.ac.uk*).*

For NHS applications only - Employee Activity Form

Has NHS Indemnity been provided?	No
Are Medical Practitioners involved in the project?	No
If YES, will Medical Practitioners be covered by the MDU or other body?	No

This section aims to identify the staff involved, their employment contract and the extent of their involvement in the research (in some cases it may be more appropriate to refer to a group of persons rather than individuals).

Chief Investigator		
Name	**Employer**	**NHS Honorary Contract?**
		Yes / No
Others		
Name	**Employer**	**NHS Honorary Contract?**
		Yes / No
		Yes / No
		Yes / No
		Yes / No

Please provide any further relevant information here:

Appendix 2:

Participant Information Sheet (PIS)

Name of department: Biomedical Engineering

Title of the study: The impact of using accommodating resistance as part of a cluster set to enhance acute lower body power.

Introduction
The researcher is a current Peter Steele, a current postgraduate student. Peter has an undergraduate BEng (Hons) degree in Sports Engineering and this research is being conducted through his MPhil studies in Biomedical Engineering. Peter's University of Strathclyde contact email address is p.steele@strath.ac.uk. The project supervisor contact details are as follows: Dr Dave Sykes (dave.sykes@strath.ac.uk) and Dr Craig Childs (craig.childs@strath.ac.uk).

What is the purpose of this research?
The aim of this research is to study if there are differences in biomechanics when lifting the same overall load, but in different forms. Within the squat movement the weight of the chains 'accommodates' (i.e gets heavier or lighter) alongside the participants ability to produce force during a stronger or weaker position. The use of cluster sets will be included within the movement to analysis its beneficial adaptations on minimising fatigue and maximising power output during the set. A cluster set comprises of a short rest period between each repetition lasting around 15-30 seconds. During the barbell back squat different percentage ratios of weighted bumper plates and accommodating resistance will be used to analysis

changes in power production. The accommodating resistance will come in the form of weighted steel chains.

Do you have to take part?
It is completely your decision to whether you take part in the research or not. On agreeing to participate, you will be asked to complete a consent, health questionnaire and strength and conditioning questionnaire which will all be signed and dated. This can happen at the first session. You can withdraw from the study at any point without providing a reason. Withdrawal will not affect your standing with the university in any way.

What will you do in the project?
Participants will attend two practical sessions within Strathclyde Sports strength & conditioning suit. Each of the experimental sessions will have a duration of around 45 minutes, meaning the total project commitment time needed from the participants will be 1 hour and 30 minutes. Both 45-minute sessions will start with dynamic warm up and end with a cool down led by Peter Steele, a current strength and conditioning practitioner. The testing sessions will be further overlooked by Dave Sykes, who is the head of the performance department within Strathlcyde Sport. . As the practical investigation revolves around a barbell squat, a fully body warm-up tailored to the movement will take place. The first session will comprise of a height and weight data collection, 1 repetition maximum back squat testing and familiarisation of using accommodating resistance. The second session will involve three different variations of a submaximal accommodating resistance back squat. There will be a minimum of 48 hours between the first and second session. As you are a high-level an athlete who is involved in in strength and conditioning sessions multiple times a week, 48 hours is enough time between testing days. The testing days which you currently participate in throughout the year have more than one movement within the session. During your participation within this study, you are only required to carry out one specific movement which has a moderately low volume.

Why have you been invited to take part?
You have been chosen for this study as you currently perform strength and conditioning within a performance sport environment, either as a scholar athlete or as part of a FOCUSport team. This has given you the building blocks to perform the proposed experiment correctly and efficiently. To participate within this research experiment, you should be capable of performing a loaded barbell back squat at the required depth. The required depth in this case is either below or parallel. You should have no injuries or medical concerns that should prevent you from participating within the study. All participants will review and complete a medical and strength & conditioning questionnaire prior to the testing. Participants will be given the opportunity to raise any questions, they may have. The questionnaires and consent form will be signed in person with researcher and coaching staff present. The main inclusion and exclusion criteria are as follows:

Inclusion

- Able-bodied
- Normal lower limb function
- A current Scholar performance athlete or FOCUSport team athlete
- [FOCUSport are University targeted sports clubs receive strength and conditioning support from the performance department]
- Technically proficient in barbell back squat.
- Participants must provide a negative lateral flow test before attending the testing

Exclusion

- Musculoskeletal lower or upper limb injury impairing gym performance at the time of trial
- Neurological trauma to the brain, spine, or nerves

- Difficulties with their balance due to either musculoskeletal or neurological injuries
- COVID-19 symptoms in 14 days before each experimental trial day (N.B. this will be asked before every session)
- Known to be pregnant
- Spinal injury
- Those who have any injury/disease which presents as a contraindication to exercise

What are the potential risks to you in taking part?
Participating within the study is not anticipated to cause any distress or discomfort. The potential for any physical harm or injury will be the same as experienced in previous strength and conditioning sessions and 1 repetition maximum testing days. To minimise the risk of injury, a sufficient warm up and cool down will be provided along with adequate rest periods between working sets.

What information is being collected in the project?
Information includes a medical questionnaire for physiological testing, strength & conditioning questionnaire, participant consent form and data created by the 1 repetition maximum testing and accommodating resistance testing. All the data sets collected throughout the study will be kept strictly confidential. The participants won't be identified or identifiable to a specific data set within any report that is published.

Who will have access to the information?
Only the project researcher and affiliated academic supervisors of the study, (Dr Dave Sykes and Dr Craig Childs), will have access to the unpublished data. All published data created will be anonymised from personal and contact details. The data linked with the participant can be removed up to the point of anonymisation which will occur soon after the testing is complete.

Where will the information be stored and how long will it be kept for?
The data collected will be stored on Microsoft OneDrive and Teams within separate folders. Both the OneDrive and Teams are locally encrypted, and data can be shared with the relative project supervisor if needed. Experimental data will be given approved long-term open access to other researchers on this topic.

What happens next?
If participants wish to take part in the research or have any queries over the participation information sheets provided, they should email the researcher All participants must sign a consent form to confirm their involvement within the study. If a participant does not wish to take part within the study, I thank them for their attention. Once the data has been collected, participants may receive a summary of overall results and project findings sent via email upon request. The results will not be published once the study has been published.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

Please also read our Privacy Notice for Research Participants

Researcher(s) contact details:
Peter Steele
MPhil Student
Biomedical Engineering, University of Strathclyde, Glasgow
p.steele@strath.ac.uk
Chief Investigator details:
Craig Childs
Teaching Fellow
Biomedical Engineering, University of Strathclyde, Glasgow

craig.childs@strath.ac.uk.

Supervisor:
Dr Dave Sykes
Performance Sport Manager
Strathclyde Sport, Glasgow
dave.sykes@strath.ac.uk

If you have any questions/concerns, during or after the research, or wish to contact an independent person to whom any questions may be directed or further information may be sought from, please contact:

Secretary to the University Ethics Committee
Research & Knowledge Exchange Services
University of Strathclyde
Graham Hills Building
50 George Street
Glasgow
G1 1QE
Telephone: 0141 548 3707
Email: ethics@strath.ac.uk