ACUTE POTENTIATION ON VERTICAL JUMP PERFORMANCE FOLLOWING ACCENTUATED ECCENTRIC LOADED BACK SQUATS IN MALE HIGH SCHOOL BASKETBALL PLAYERS

by

John Casey Ditch

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy

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ABSTRACT

The purpose of this study was to investigate the acute responses of accentuated eccentric loaded (AEL) back squats to induce a postactivation performance enhancement (PAPE) effect in youth athletes across three jump conditions: countermovement jump (CMJ), squat jump (SJ), and novel propulsive-only jump (POJ). Fifteen participants (age: 15.6 ± 1.1 years; RT experience: 1.3 ± 0.9 years; relative strength: 1.32 ± 0.3) three sessions (one familiarization, two experimental). AEL interventions were performed on each experimental session, (3 sets x 3 repetitions) (ECC: 95%, 105%, 115%: CON: 60% 1RM) with pre- and post-testing (3 min, 6 min, 9 min, 12 min). Using a crossover design, random assignment to either (a) CMJ, (b1) SJ+POJ, or (b2) POJ+SJ, where jump height (JH), net propulsive impulse (NPI) and peak relative propulsive power (PRPP) were assessed for each jump. Three 3x5 repeated measures ANOVAs were used to analyze each dependent variable across jump conditions and time. Results revealed a significant increase in POJ JH performance at 9 min (+12.26% ± 13.65%, $p < 0.05$), whereas CMJ and SJ performance did not show statistically different values from pre-testing for JH, NPI, or PRPP. No significant changes were found for JH, NPI, or PRPP for CMJ or SJ. Although, JH performances peaked at 12 minutes for CMJ (+2.22% ± 7.71%) and SJ (+5.03% ± 12.77%) but did not reach statistical significance. The findings of the study suggest that male high school basketball players may realize superior or unaffected jump performances at 9-12min post-supramaximal AEL back squats. In addition, no significant deficits in performance outcomes were found for any condition from pre- to post-testing. Future research should expand the use of AEL with youth populations, and the practical use of the POJ as a training and performance tool.

Keywords: *accentuated eccentric, propulsive-only jump, post activation, jump performance*

Copyright Page (Optional)

Dedication

To my beautiful wife, **Jenna**, your unwavering patience & love throughout this marathon is beyond what I could have expected. Completion of this program would not have been possible without you by my side. My core motivation for this program was and is to provide a better quality of life for you and our future children.

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1-repetition maximum (1RM)

Accentuated eccentric loading (AEL)

Countermovement Jump (CMJ)

Concentric (CON)

Drop Jump (DJ)

Eccentric (ECC)

Eccentric Overload (EOL)

Electromyography (EMG)

Exercise-induced muscle damage (EIMD)

Flywheel inertial training (FIT)

Jump height (JH)

National Strength & Conditioning Association (NSCA)

Net propulsive impulse (NPI)

Peak relative propulsive power (PRPP)

Post-activation potentiation (PAP)

Post-activation performance enhancement (PAPE)

Plyometric-Accentuated Eccentric Loading (Plyo-AEL)

Propulsive-Only Jump (POJ)

Rate of force development (RFD)

Rate of perceived exertion (RPE)

Squat Jump (SJ)

Stretch-shortening cycle (SCC)

CHAPTER I: INTRODUCTION

Overview

In addition to on-field sport-specific training, resistance training has been identified as an effective tool to increase athletic performance while decreasing the prevalence of injury in team-sport (Suchomel et al., 2016). As a supplemental tool, the determination of the most effective methods to induce acute and chronic adaptations continues to evolve with the inclusion of more research. Specifically, chronic exposure to resistance training is dominantly implemented in the pursuit of increasing muscular strength (Suchomel et al., 2018), muscle hypertrophy (Schoenfeld et al., 2017a), improved cognitive health and function (Chow et al., 2021) and enhancement of sport performance outcomes (Suchomel et al., 2016).

Of the many training methods investigated, accentuated eccentric loading (AEL) has been highlighted for its potential to induce unique acute performance responses at varying degrees when compared to traditional training methods and other eccentric overload (EOL) modalities (Wagle et al., 2017). The following chapter provides an overview of the purpose of this study to gain a deeper understanding, the significance of this study to enable evidence-based decision-making for practitioners, the current issues pertaining to the use of AEL to induce acute performance enhancements, and the research questions leading the investigation.

Background

Accentuated eccentric loading is a training modality that enables dynamic movement patterns to complete the full stretch-shortening (SSC) while providing greater load during the eccentric phase, followed by an immediate reduction in weight with lighter loads during the concentric phase. This load adjustment is designed to complement the SSC while simultaneously providing greater loads to the eccentric phase that is up to 50% stronger than that of the concentric phase (Schoenfeld et al., 2017b). While eccentric muscle contractions display greater force-producing qualities than its concentric and isometric counterparts, it is also accompanied by a lower level of expended energy, greater neural drive using comparable loads, and the highest efficacy of inducing a potentiated response following the movement's conclusion (Douglas et al., 2017 a & b).

AEL's capability of providing increased eccentric load, which would otherwise be limited to concentric abilities in traditional training methods, provides a strong rationale for the use of supramaximal loads (loads greater than 1-repetition maximum [1RM]) to invoke greater eccentric stimulation and the resulting potentiation of subsequent concentric performance (Douglas et al., 2018; Patus, 2021). The resultant concentric potentiation is thought to be a residual effect from physiological and neuromuscular responses accrued from additional eccentric load (Wallace et al., 2018). Responses are assumed through the addition of eccentric strain on the stretch-shortening cycle which contributes to an increase in elastic energy (store and recoil) (Bosco et al., 1981 & 1982 a & b), greater recruitment of motor units to engage muscular tissue (Hudson et al., 2019), and greater neural drive (Wallace et al., 2018).

Although speculative, AEL training has produced compelling evidence as a superior training modality for the improvement of strength and power characteristics as well as acute countermovement jump (CMJ) enhancements than that of traditional resistance methods (Patus, 2021; Wagle et al., 2017). Of the acute responses identified through AEL methods, limited research has been conducted to identify the significance of acute performance enhancements following the intervention itself. More specifically, past research has identified the use of submaximal, maximal, and supramaximal loading procedures with varying results. Past research has uncovered the delicate balance of eccentric-concentric loading prescription (Merrigan et al., 2020), acute physiological responses to increased eccentric strain using AEL modalities (Ojasto & Häkkinen, 2009), as well as loading strategies through cluster sets (Lates et al., 2022; Wagle et al., 2018 a & b). Beyond the variety of potential AEL interventions investigated to this date, there are currently no known articles of research involving AEL interventions in high school male basketball players.

Prior investigations on AEL training and general eccentric overload use have recommended the need for more research to explore its efficacy to stimulate mechanisms that acutely enhance performance following the conclusion of the movement (Merrigan et al., 2022, Patus, 2021). Although these mechanisms have yet to be clearly defined, the enhancement of performance following an activity has been identified by a phenomenon known as post-activation potentiation (PAP) and post-activation performance enhancement (PAPE) (Prieske et al., 2020). Collectively, these phenomena have been interchangeably used at the discretion of identifying any post-activity performance-enhancing qualities due to unsolidified knowledge of their respective mechanisms of influence (Prieske et al., 2020). The majority of research indicating positive PAP and PAPE responses have primarily resulted from traditional training interventions using non-varying loads (Ng et al., 2019; Popp Marin et al., 2021) and eccentric-only protocols (Ong et al., 2015) which also signifies a positive relationship between eccentric loading and post-activation responses (Seitz & Haff, 2016). Beyond PAP and PAPE's theorized properties, potentiated responses hold a strong correlation to the duration and extent of induced fatigue which simultaneously occurs following a conditioning activity, where the potentiated responses are revealed at the dissipation of fatigue (Tillin & Bishop, 2009). Given that the dissipation of fatigue is one of the primary obstacles to the realization of PAP and PAPE qualities, it is theorized that the use of supramaximal AEL training may sufficiently induce an acute potentiating effect at a total decreased mechanical volume than that of current standardized traditional training methods. The decrease in total mechanical volume may lead to a decrease in fatigue duration, a greater window of performance enhancement, and a higher likelihood of a realized potentiated response (Tillin & Bishop, 2009). In light of the theoretical application of utilizing AEL interventions to induce PAPE conditions, minimal research has been directed for its typical use and no research has investigated AEL relating to PAPE in high school-aged athletes (Bright et al., 2023).

Historical Overview

Accentuated eccentric loading methodology has been utilized and documented since the 1960s by renowned Russian scientist, Dr. Verkhoshanksy (Verkhoshanksy & Verkhoshanksy 2011). AEL was first introduced as an adjunct training method to increase athletic performance which accommodated the different strength capabilities between eccentric and concentric actions (Verkhoshanksy & Verkhoshanksy, 2011). In his publication of Special Strength Training (2011), weight releasers (identified as “special suspension devices”) were introduced as a means to achieve a novel stimulus in the development of maximal strength. The utilization of submaximal, maximal, and supramaximal (“super maximal”) loads was prescribed up to 130% of concentric 1RM during the eccentric phase and followed by concentric loads of 70-80% 1RM in the back squat exercise (Verkhoshanksy & Verkhoshanksy, 2011).

It was not until the late 1990s that AEL modalities became of research interest in the United States, where insignificant differences in concentric strength performance were found in a study comparing 10 weeks of AEL and traditional training involving untrained men and women (Godard et al., 1998). In the early 2000s, multiple studies found positive outcomes of acute performance enhancements of maximal strength in the bench press (Doan et al., 2002) and chronic adaptions involving concentric strength in elbow extension (Brandenburg & Docherty, 2002) when compared to traditional methods. This early research using AEL interventions was primarily seeking maximum strength outcomes and acute performance improvements of the subsequent concentric phase.

In the mid-2000s, multiple studies assessed the acute muscular responses to AEL training with findings showing an increased shift of mRNA gene expressions of fast twitch (Type IIx) muscle fibers following eccentric overload training (Friedmann et al., 2004; Friedmann-Bette et al., 2009). This increase in myosin heavy chain (MHC) Type IIx muscle fiber signaling gained considerable attention due to the preferential recruitment and fiber shift changes to that of fast twitch fibers. During this time, acute neuromuscular and hormonal responses were evaluated between AEL and traditional methods, showing individual differences in post-intervention outcomes and the significant variability of responses, determined to be a result of numerous factors such as relative strength, history of training experience, and the respective loading prescribed for each individual (Ojasto & Häkkinen, 2009). Although mixed results were reported from the author's perceptions of fatigue management, significant increases in growth hormone concentrations in the AEL conditions (90% ECC: 70% CON) compared with traditional (70% ECC & CON) ($p < 0.05$) were found (Ojasto & Häkkinen, 2009).

It was not until the late 2000s that AEL research redirected towards acute physiological responses exemplified through ballistic-type movements that closely mimic sporting actions. In 2008, Sheppard and colleagues studied the use of accentuated eccentric loaded countermovement jumps (AEL CMJ) in high-performance volleyball players and found enhanced jump height, peak concentric power, and peak velocity when compared to the traditional (unloaded) CMJ condition (p = 0.00-0.05, d = 1.06-1.97) (Sheppard et al., 2008). A few years later, the use of

AEL on the bench press throw showed greater throw height (displacement) in all submaximal AEL conditions (absolute loading of 60, 70, & 80 kg during eccentric with concentric load constant at 40 kg between participants) when compared to a nonvarying eccentric-concentric coupling of 40 kg (Sheppard & Young, 2010). At the time of research in 2010, AEL had been identified as a suitable means for the enhancement of subsequent concentric power characteristics although the optimal loading procedures and responses pertaining to post-intervention acute potentiation had yet to be evaluated or published.

Over the past ten years, most of the research has been focused on three main topics that include (1) potentiation of the concentric phase(s) (possibly over multiple repetitions) following the eccentrically overloaded phase (Castro et al., 2020; Lates et al., 2022; Merrigan et al., 2020; Munger et al., 2017; Sheppard & Young, 2010; Taber et al., 2023; Wagle et al., 2018a & b), (2) ideal loading procedures pertaining to cluster sets, percentage of concentric 1RM used during the eccentric phase (Lates et al., 2022; Merrigan et al., 2020; Montalvo et al., 2021; Taber et al., 2021; Wagle et al., 2018a & b), and (3) acute physiological, neuromuscular, and hormonal markers of exercise-induced muscle damage (EIMD) (Castro et al., 2020; Merrigan & Jones, 2020; Ojasto & Häkkinen, 2009). To the author’s knowledge, only a singular published article has evaluated supramaximal accentuated eccentric loading to acutely induce a PAPE effect (Tseng et al., 2021).

Theoretical Framework

In the pursuit of acutely enhancing performance using eccentric overload (EOL) modalities, researchers have explored the benefits of inertial based EOL (Flywheel) (Beato et al., 2019 a & b, 2020, 2021; De Keijzer et al., 2020; Maroto-Izquierdo et al., 2017, 2019 & 2020; Timon et al, 2019), plyometric-accentuated AEL (Plyo-AEL) (Aboodarda et al., 2013 & 2014;

Bridgeman et al., 2016 & 2017; Esformes et al., 2010; Godwin et al., 2021; Handford et al., 2021; Hughes et al., 2016; Lloyd et al., 2021), eccentric-only modes (Harden et al., 2018, 2019, 2020; Ong et al., 2015), elastic-variable resistance training (Popp Marin et al., 2021) and accentuated eccentric overloading utilizing weight releasers (Douglas et al., 2018; Lates et al., 2021; Merrigan et al., 2021 & 2022; Merrigan & Jones, 2021; Moore et al., 2007; Munger et al., 2017 & 2022; Ojasto & Häkkinen, 2009; Taber et al., 2021 & 2023; Tseng et al., 2021; Wagle et al., 2018; Walker et al., 2016). Of all of the EOL modalities and respective studies investigating acute lower-body performance, only a handful have focused on the ability to induce post-activation performance enhancement (PAPE) (Beato et al., 2019 a & b; Bridgeman et al., 2016 & 2017; De Keijzer et al., 2020; Esformes et al., 2010; Hughes et al., 2016; Lloyd et al., 2021; Maroto-Izquierdo et al., 2020; Moore et al., 2007; Munger et al., 2022; Ong et al., 2015; Popp Marin et al., 2021; Timon et al, 2019; Tseng et al., 2021) and only one study has evaluated accentuated eccentric loading using weight releasers to induce PAP or PAPE following an AEL conditioning activity (Tseng et al., 2021). Furthermore, it is the purpose of this study to evaluate the potentiating effects of AEL back squats through various vertical jump assessments to fill the gap in the current literature.

The majority of research involving eccentric overload methods as a conditioning activity to induce the phenomenon of PAPE has been explored through inertial loading (flywheel) procedures. Many of these studies uncovered significant evidence showing the potential of eccentric overloading strategies to induce these responses which are explored in this study (Beato et al., 2019b; Timon et al., 2019). With respect to the evidence indicating a positive acute enhancement in performance gained from inertial training, limitations exist regarding its ability to provide a true eccentric overload stimulus to that of AEL using supramaximal loads. It is also of interest to AEL's unique kinematic qualities that allow the attainment of greater concentric velocities, following a greater eccentric stimulation of all other EOL modalities. The ability to provide the greatest amplitude of eccentric stimulation while preserving, or potentiating, the subsequent concentric phase is in parallel with PAPE's most frequently observed potentiated variable of enhanced muscle shortening, or concentric velocity.

Problem Statement

The effect of supramaximal accentuated eccentric loaded back squats on increasing lower body power in the youth population remains unclear. This is particularly true regarding how these exercises influence acute post-activation performance enhancement, as determined through different jump tests. Additionally, PAPE's role in providing enhanced concentric-only power or force has yet to be evaluated under traditional training settings or from the contribution of AEL. A lack of consensus within the literature is evident in the deliverance of AEL modalities to induce acute responses for sports performance (Suchomel et al., 2019 a & b). Several studies have evaluated acute potentiation responses from plyometric-AEL training that would suggest transferable qualities to positively benefit basketball athletes, such as enhancement of jump height in the countermovement jump (Handford et al., 2021; Sheppard et al., 2008), although no studies have been found to date that have assessed this specific population.

Multiple studies have investigated the acute responses to dynamic jumping movements in sport athletes, yielding both positive results (Bridgeman et al., 2017a; Tseng et al., 2021) and non-significant results following a mixture of AEL protocols (Ojasto & Häkkinen, 2009). In prior studies, vertical jump variations commonly utilized countermovement jump (CMJ), drop jump (DJ), and depth jump assessments which utilize the stretch-shortening cycle (SSC) to evaluate lower limb power performance. In addition, the squat jump (SJ) is the only testing measure that disrupts the SSC by including an intentional pause during the amortization phase, with the intent to assess concentric-only performance (Markovic et al., 2004). Although the intent of the SJ is to reduce the influence of potentiated concentric ability gained from the SSC, numerous factors related to contractile elements, neural firing, and preloading of elastic tissues may or may not provide reasonable insight into an individual's ability to produce concentric-only force (Cormie et al., 2010). Supporting evidence to indulge PAP & PAPE's influence on subsequent performance has been validated to increase eccentric-concentric actions and maximal isometric peak force but has yet to be resolved for concentric-only muscular actions (Dobbs et al., 2019; Hortobagyi & Katch, 1990). The first problem is the lack of research on the capabilities of supramaximal AEL training to stimulate PAPE with the intent to enhance subsequent performance in male high school basketball players. The second problem is the unresolved awareness of true dynamic concentric abilities that may or may not be affected by PAPE.

Purpose Statement

The purpose of this study is to investigate the effects of accentuated eccentric loading to induce a post-activation performance enhancement (PAPE) effect on high school male basketball players. The aim of this study is to investigate supramaximal AEL training on acute PAPE across multiple time points. Additionally, the study will examine the significance of PAP and PAPE on concentric-only performance in contrast to traditional eccentric-concentric performance involving the stretch-shortening cycle. Outcomes from this study enable strength and conditioning practitioners to make evidence-based programming decisions with their athletes in the pursuit of increasing athletic performance. These findings may have practical implications when applied to training protocols to acutely enhance athletic performance prior to the start of a competition or in the development of long-term adaptations through chronic exposure.

Conclusions may also expand our understanding of AEL training interventions to potentiate subsequent performance on vertical jump testing variations. The inclusion of a propulsive-only jump (POJ) testing measure in addition to more distinguished jump test variations, such as the countermovement jump (CMJ) and the squat jump (SJ), is intended to gain deeper insight into the effects of PAP and PAPE in the absence of preloading strategies. Comparisons between jump-testing variants are to be assessed in association with influences of PAP and PAPE while evaluating the time effects of any significant performance enhancements that take place.

This investigation involved male high school basketball players who had been free from injury within 6-months and were recruited for participation following the formal acceptance from the Institutional Review Board of Liberty University (Appendix A). In the highly competitive sport of basketball, the intended purpose of this study is to evaluate the potential of supramaximal AEL training interventions to enhance acute jump performance that may carry positive applications onto the court for these athletes.

Significance of the Study

There is a growing body of evidence suggesting that AEL training may provide a more potent stimulus for the improvement of strength and power characteristics when compared to traditional resistance methods (Douglas et al., 2017b; Wagle et al., 2017). Despite this theory, there is still a gap in understanding the relationship between AEL training and PAPE, as well as the optimal AEL loading protocols for eliciting PAPE. The limited knowledge of the underlying mechanisms driving PAPE has led to inconsistent results from prior studies on acute responses of

AEL and perceptions on how to implement with athletes (Hody et al., 2019; McNeil et al., 2019 & 2020; Wagle et al., 2017).

The proposed study aims to address these gaps in knowledge by investigating the capacity of supramaximal AEL back squats to induce an acute post-activation performance enhancement on lower body power through the countermovement jump test. The study will also evaluate the role of PAPE in providing enhanced concentric output using a novel concentric-only jump test to build upon the prior investigation of potentiated jump performances (Aboodarda et al., 2013 & 2014; Bridgeman et al., 2017). The proposed research design, a randomized crossover design with one familiarization and two experimental sessions, provides all participants the opportunity to complete the same testing procedures under the same conditioning stimuli. This research design enabled all the participants to function as their own controls.

The outcomes of this study have the potential to make a significant contribution to the field of exercise science, as it may provide crucial information on the effects of AEL interventions to reveal unequivocal enhancements in performances in the absence of the stretch-shortening cycle, based on current theories in place (Blazevich & Babault, 2019). The findings of this study have the potential to inform the development of training protocols, which may provide strength and conditioning coaches the necessary resources for evidence-based decision-making for the use of AEL within their future training programs, with the expressed need for clarity from researchers in the field (Beato et al., 2021a; Seitz et al., 2014; Seitz & Haff, 2016). Furthermore, the results of this study will contribute to the scientific knowledge base and inform future research in the field of exercise science and athletic performance enhancement.

Research Questions

RQ1: Does exposure to supramaximal accentuated eccentric loaded back squats acutely enhance countermovement jump height to a greater degree than the squat jump and propulsive-only jump?

RQ2: What is the ideal "Potentiation Window" for the enhancement of jump performance following a supramaximal accentuated eccentric loaded back squats in high school male basketball players?

RQ3: Is there a difference in absolute and relative jump performance between the propulsive-only jump and the squat jump in the presence of post-activation performance enhancement following supramaximal accentuated eccentric loaded back squats?

Definitions

1. *AEL* – Accentuated Eccentric Loading: An eccentric overload modality that enables eccentric loading in excess to concentric loads involving a complete stretch-shortening cycle (Wagle et al., 2017).
2. *EOL* – Eccentric Overload: Classification of movements or exercise that places greater emphasis on eccentric contractions (active muscle lengthening) (Vogt & Hoppeler, 2014).
3. *PAP* – Post Activation Potentiation: A phenomenon involving a transient increase of involuntary muscle performance that is induced by a prior conditioning activity (Blazevich & Babault, 2019).
4. *PAPE* – Post Activation Performance Enhancement: A phenomenon involving a transient increase in voluntary muscle performance that is induced by a prior conditioning activity (Blazevich & Babault, 2019).

5. *Weight releasers* – (eccentric hooks) A training tool that hangs from a barbell to provide additional load during the lowering phase of a movement and discards itself from the barbell at a predetermined height (at the end of the eccentric phase) (Suchomel et al., 2019a).
6. *Submaximal* – A load less than an individual's 1-repetition maximum (Diaz et al., 1978).
7. *Maximal* – The greatest load an individual is capable of moving for one repetition (1RM) (Diaz et al., 1978).
8. *Supramaximal* – A load greater than an individual's 1-repetition maximum, completed through a stretch-shortening cycle (Diaz et al., 1978).
9. *SSC* – Stretch-Shortening Cycle: An underpinning phenomenon involving the active lengthening (eccentric) and a subsequent active shortening (concentric) of the muscle-tendon unit, as well as passive neurophysiological reflexes and passive elastic recoil to complete a dynamics movement (Bosco & Rusko, 1983).
10. *Eccentric* – Lengthening of the muscle-tendon unit, commonly seen by the lowering portion of exercises involving free-weights (Petersen, 1960).
11. *Concentric* - Shortening of the muscle-tendon unit, commonly seen during the upward portion of exercises involving free-weights (Petersen, 1960).

CHAPTER II: REVIEW OF LITERATURE

Overview

Accentuated Eccentric Loading (AEL), also known as augmented eccentric loading, has gained significant popularity due to its ability to provide greater eccentric contraction stimulation while avoiding interruption of the stretch-shortening cycle (SSC) (Suchomel et al., 2019a, Wagle et al., 2017). This completion of the stretch-shortening cycle is more commonly seen through traditional training methods where loading magnitude is consistent throughout all phases of the SSC (eccentric, amortization, and concentric phases), described in further detail in the following passages. The capacity of the SSC to potentiate concentric actions is dependent on the loading magnitude during the eccentric phase, which can be blunted when heavy loads cannot be quickly transitioned from the eccentric to the concentric phase, or the magnitude of the eccentric is not sufficient to provide a positive effect (Merrigan et al., 2021). When utilized effectively, this training modality places greater external demand during muscle lengthening (eccentric phase) with an immediate discarding of load to enable potentiated subsequent muscle shortening (concentric phase) and the enhancement of resultant performance. Moreover, greater eccentric stimulation during dynamic movement patterns has displayed unique acute responses to that of other eccentric overload (EOL) and traditional training modalities that have provoked a potentiation in performance following the activity. The purpose of this chapter is to provide contextual information to support the rationale and utilization of AEL through foundational theory and related literature in the areas of eccentric overload modalities, potentiation following a conditioning activity, and the significant relationship of using AEL to induce positive acute changes to increase the probability of success in sporting outcomes.

Eccentric Overload Modalities

Accentuated eccentric loading (AEL) is commonly grouped within a family of training modalities classified as eccentric overload training (EOL) (Suchomel et al., 2019 a & b; Wagle et al., 2017). The most common forms of EOL training involve the use of training tools such as dumbbells, weight releasers (eccentric hooks), bands, inertial (flywheel or cones), or computer-aided tools that are manipulated by either the user, practitioner or discharged automatically at pre-determined heights (Wagle et al., 2017). Each of these EOL tools has its place within an athlete's training cycle, with strengths and limitations presented in each modality exhibited. The propriety of the EOL group is implemented with the common goal of procuring greater loads during the eccentric phase in relation to the successive concentric phase (Douglas et al., 2017). The following sections describe the commonalities of the EOL modalities used to induce acute enhancements and chronic adaptations, as well as the defining characteristics of AEL which separates itself from all other modalities in the pursuit of inducing acute performance enhancement.

Flywheel Inertial Training

Of all EOL modalities, considerable attention has been directed to the flywheel inertial training (FIT) tool to enhance performance and rehabilitative utilization (Franchi & Maffiuletti, 2019). Although a significant amount of attention for eccentric-specific training has spotlighted flywheel training, its effectiveness and reliability as an EOL tool are dependent on the user's ability to generate sufficient concentric force to magnify loading in the subsequent eccentric phase (Suchomel et al., 2019 a). Recent studies on FIT have indicated the modality as an effective method for providing an increase in eccentric stimulation but at the expense of limiting early concentric phase velocity (Cormier et al., 2021). Therefore, the consequence of the user supplying greater magnitudes into the eccentric phase is directly correlated to the limitations to achieve greater concentric velocities in the completion of the SSC (Cormier et al., 2021). In theory, it is possible to induce a novel eccentric stimulus while fulfilling the SSC using FIT, however, it comes at the expense of suppressing the natural potentiated concentric phase which makes the SSC a valuable asset to the athlete.

This inertial modality has shown promising evidence of its ability to enhance subsequent performance in lower limb power shown through tests of the countermovement jump (CMJ) (Beato et al., 2019 b), standing long jump (SLJ) (De Keijzer et al., 2020), squat jump (Timon et al., 2019), and change of direction (COD) performance in physically active men in their early twenties (Chaabene et al., 2022).

Utilizing participants similar to those who participated in the current study, Murton et al (2021) evaluated a 4-week regime of flywheel inertia training (FIT) in comparison to traditional resistance training in high school-aged athletes. The findings of this study indicated that both traditional training and FIT were effective means for improving jump performance in the countermovement jump, drop jump, and squat jump, with no significant differences found between groups ($p > 0.05$) (Murton et al., 2021). Whereas Stojanovic et al (2021) found conflicting findings showing that eight weeks of FIT training displayed superior improvements in CMJ (11.7% vs. 6.8%; $p = 0.006$), change of direction (2.4% vs 1.5%; $p = 0.045$) and 5-meter sprint time (10.3% vs. 5.9%; $p = 0.001$) when compared to traditional weight training in high school aged basketball players.

FIT has shown promise as a sufficient PAP/PAPE stimulus as depicted in the enhancement of lower limb power through vertical jump testing. Potentiation of CMJ and SJ performance following FIT protocols has shown this increase in performance from 4 to 8 minutes following the FIT conditioning activity (Beato et al., 2019 a & b; Timon et al., 2019). A review of 19 studies on the effectiveness of FIT in the team sport setting, by Cormier and colleagues (2021), found that FIT is a promising training modality to use in conjunction with traditional methods. Similarly, Bright et al. (2023) appraised the most current literature surrounding the use of eccentric resistance training in youth athletes, the most commonly used training modalities, and the associated performance-based outcomes. Their review revealed a majority of the research focused on eccentric resistance training and youth athletes is primarily limited to FIT and Nordic hamstring exercises (Bright et al., 2023). The researchers concluded their review by stating that there is a greater need for a larger familiarization window (minimum of three sessions) when working with youth populations. Additionally, they showed that many studies with nonsignificant findings may have been limited by the allocation of time to familiarize themselves prior to testing (Beato et al., 2020; Wilson et al., 2013).

FIT & AEL Comparison

FIT and AEL training are commonly classified within the same genre of eccentric overload modalities (EOL) but are theoretically different when comparing the type of stimulus imposed on the individual. As stated, FIT training is contingent on the ability of the individual to produce sufficient concentric force to overload the following eccentric phase. This limitation may also be compounded by the limitations of FIT to allow for higher velocities during the concentric phase, which may limit the influences stated by Cormier and colleagues (2021) to enhance power production performance. Most importantly, FIT modalities are comparably limited to the same extent as traditional training methods in the ability to provide supramaximal eccentric loads during dynamic movements that complete the SSC, at an unaltered pace, or the separation of segmental contraction phases (Suchomel et al., 2019 a). Although FIT methods have shown positive indications as an effective PAP and PAPE stimulus, the primary attributes of PAP and PAPE to potentiate muscle firing velocity and not the increase of force is the primary justification for the use of AEL over FIT in this study. In theory, utilizing AEL over other EOL modes is based on its ability to provide a supramaximal EOL stimulus with the presence of high-velocity movement in the concentric phase, similar to the proposed outcome characteristics found in the targeted phenomenon of PAPE.

Plyo-Accentuated Eccentric Loading

The utilization of EOL during plyometric-focused movements, also known as plyo-accentuated eccentrics, has shown the ability to enhance subsequent concentric velocity, eccentric and propulsive impulses, and even increases in the rate of force development in many instances (Aboodarda et al., 2014; Lloyd et al., 2021). An assessment of AEL drop jumps using 3 different conditions (percentage of body mass up to 30%) and 3 different heights (up to 50cm) resulted in minor increases of electromyography activity in the quadriceps during lengthening (0.23 > ES > 0.51) with increases in the rate of force development (RFD) ($p < 0.001$) with no detriment to jump height (Aboodarda et al., 2014). Although there were no significant increases seen in jump height by Aboodarda and colleagues, Lloyd and colleagues (2021) found opposing results where jump height was significantly enhanced (ES = 0.47, $p < 0.05$) as well as increases in braking (ES = 0.43, $p < 0.05$) and propulsive impulse (ES = 0.61, $p < 0.05$). The success of the two studies may be indicative of the prescribed load, population utilized, and additional eccentric load provided through different drop jump heights. Llyod and colleagues (2021) studied youth athletes using 15% of body weight during the eccentric phase with drop jump heights of 30 cm. In contrast, Aboodarda and colleagues (2014) studied experienced resistance-trained adult males using up to 30% of body weight and upwards of 50 m in drop jump height. The standalone intensity of the drop jump exercise is considered a high-level form of plyometric training in the absence of additional loading on the eccentric phase (Suchomel et al., 2019 b). Therefore, considerations of appropriate intensity to fit the needs of the population and timing of the periodization plan must be evaluated as the use of these plyo-accentuated modes encompasses the most extreme physiological stressors, as originally postulated in The Shock Method by Dr. Verkhoshansky (Verkhoshanksy & Verkhoshansky, 2011). The Shock Method is a training method that involves exposing the neuromuscular system to high-intensity stressors to promote adaptations in reactive strength, with the drop jump being classified as one of the most stressful modes of implementation (Verkhoshanksy & Verkhoshansky, 2011). Although the prior studies provided useful insight into the potentiation of subsequent concentric performance when greater loading is imposed on the eccentric action, the conditions of the movement are highly intensive where the eccentric portion of the movement is magnified with or without the addition of weight.

Plyo-AEL can also be executed by the addition of elastic bands and has been shown to enhance the eccentric load to enhance jump performance following a conditioning activity. Popp Marin and colleagues (2021) found significant increases in CMJ performance following the addition of eccentric (submaximal) loads with elastic bands (5.8%, $p = 0.02$, ES =1.53) with no changes found in non-varying resistance of comparable workload. The significant increases found in CMJ performance were also accompanied by an increase in peak power ($p = 0.04$, ES = 1.27) approximately 120 seconds following the varying resistance training activity (Popp Marin et al., 2021). Aboodarda and colleagues (2013) displayed similar findings of increased concentric performance during countermovement jumps when manually loaded by elastic bands. The prescription of the load was either 20% or 30% of the individual’s body mass and yielded a

9.52% increase in jump height and a 23.21% increase in concentric power output ($p < 0.05$), respectively.

Although positive findings of plyo-AEL modes using elastic bands have been indicated, the application, monitoring, and analyzation of the loads being utilized are less reliable due to variables of band tension, aging of the band's elastic properties, and the proper execution of the athlete to discard the bands at the appropriate time. Both FIT and plyo-AEL (bands, dumbbells, kettlebells, etc.) are accompanied by the limitations of reliably monitoring the imposed overloaded eccentric phase that is not as limited by the traditional AEL utilizing weight releasers at a predetermined height.

Weight Releasers (Eccentric Hooks)

In the pursuit of implementing supramaximal eccentric loads, the barbell is the most commonly utilized tool with the addition of weight releasers, also known as eccentric hooks. These weight releasers hang from the sleeves of the barbell and naturally disconnect at a predetermined height. This tool has been used in pursuit of strength and power development as early as the 1960s (Verkhoshanksy & Verkhoshansky, 2011), and gained greater popularity in 2002 following a publication by Doan and colleagues (2002) highlighting a significant acute increase in bench press performance by adding supramaximal loads to achieve greater 1RM values ($p = 0.008$) (Doan et al., 2002).

More recently, squat performances (front and back squat variations) have shown enhancement with AEL modalities with the increase of ground reaction forces (GRF), concentric power, and concentric velocity with loads of 120% of a given participant's concentric 1RM during the eccentric portion of the lift (Merrigan et al., 2021; Munger et al., 2017). Many studies using supramaximal loads have attributed the success of potentiated concentric performance to the relationship of the eccentric loads relative to the concentric phase, whereby a larger percentage of load displaced before the concentric phase resulted in greater performances (Harden et al., 2018; Merrigan et al., 2021). Furthermore, the use of AEL has been established as an advanced training modality as a result of controlling excessive loads during the stretch-shortening cycle with no influence or interruption during the release of the eccentric hooks (Suchomel et al., 2019 b). The use of supramaximal loading is accompanied by increased technicality of movement and thus dissuaded many strength and conditioning practitioners (and athletes) for fear of their inability to control the excessive eccentric loading to inherit EOL effects through the possible use of pacing strategies. By the very nature of these imposed limitations, the purpose of this study is to unfold the possible loading prescriptions for high school basketball players to allow and enable discussion of supramaximal loading with younger athletes.

AEL & Traditional Methods

Given that eccentric muscle contractions are up to 50% stronger than concentric and isometric actions (Hody et al., 2019), training styles that encompass non-varying resistance, such as traditional resistance training, are limited by the ability of the concentric contraction (Wagle et al., 2017). With respect to the significant differences in contraction outcomes, eccentric muscle actions are significantly under-stimulated during traditional training methods that do not separate contraction types (eccentric vs concentric) which would consequently interrupt the stretch-shortening cycle. The interruption of the SSC can result in diminished neuromuscular conditioning that would otherwise improve actions attributed to basketball-specific outcomes (Suarez et al., 2019). Successful performance in the sport of basketball can be attributed to many small outcomes that occur throughout a game: a higher percentage of made shots, rebounding over a competitor, deflecting a pass or shot as a defender (Rojas et al., 2000), and the ability move past a defender to attempt a shot closer to the basket (Miller & Bartlett, 1996). Commonalities of all these basketball-specific outcomes are directly attributed to performance characteristics of jumping (Asadi, 2016), change of direction (Čaušević et al., 2021), and acceleration/deceleration qualities found in many team sports (Alemdaroğlu et al., 2012). Furthermore, high school basketball is a highly competitive sport where acute increases in performance may provide an edge over the competition which may influence the outcomes of the game.

Traditional and AEL training methods have been shown to differentiate drastically in both their acute and chronic responses. At the acute intersession level, supramaximal AEL back squats (120% ECC: 65% CON) have resulted in superior peak eccentric velocities (-0.076 ± 0.124 m/s-1; $p = 0.012$), eccentric force, (187.8 ± 284.4 N; $p = 0.007$) and power (peak ECC power: -328.6 ± 93.7 W; $p = 0.002$) (mean ECC power: -145.2 ± 62.0 W; $p = 0.028$) compared to traditionally loaded back squats of the same concentric loads (65%) (Merrigan et al., 2021). These findings show that the magnitude of difference between the (supramaximal) eccentric and concentric loads in relation to each other plays a vital role in the ability of the athlete to effectively complete the full eccentric-concentric coupling when excessive loads are utilized (Merrigan et al., 2021).

Load Prescription

The prescription of supramaximal, maximal, and submaximal eccentric loading procedures has been thoroughly investigated for both acute and chronic responses, with current evidence favoring submaximal loading to acutely potentiate subsequent power and velocity of movements (Wagle et al., 2017). These inclinations to favor submaximal loading prescriptions are sourced primarily due to the balance of the fatigue-potentiation response, as shown to be detrimental to performance following the intervention (Ojasto & Häkkinen, 2009). Balance of the fatigue-potentiation phenomenon is complex due to the interactions of many variables such as the training age of the individual (relative strength & fiber type composition), prescription of load intensity and respective rest time, and prior experience with the training modality (Bright et al., 2023; Wagle et al., 2017). The importance of these variables is further discussed in the following sections.

Implications of supramaximal loading have been found through strenuous loading prescriptions and in some instances shown to result in a decline in overall maximal strength and velocity of subsequent movements (Ojasto & Häkkinen, 2009). The prescription of load used during the eccentric phase must correspond to the magnitude and type of stimuli used with the intent to drive a particular physiological or neurophysiological adaptation. The applied load must also be manipulated to serve the individual athlete’s personal training history, injury history, readiness status, and the type of movement performed (Suchomel et al., 2016).

Harden and colleagues (2018) explored supramaximal loads on the leg press using 110%. 130%, and 150% of individuals 1RM concentric capabilities. Their results provide evidence for greater average force outputs with diminished abilities to control loads during the descent (Harden et al., 2018). The value provided by Harden and colleagues' (2018) study is subject to the nature of the movement used and the subsequent concentric contractions. First, the leg press movement is not dependent on the athlete’s ability to control the load through greater thresholds of motor control and coordination as seen in the back squat modality. Second, the strength-trained subjects had difficulties controlling their weight during the eccentric phase and were not responsible for completing a concentric action (Harden et al., 2018). In the following year, the same researchers acquired evidence depicting the significant task-specific responses to imposed supramaximal eccentric loading on subsequent outcomes (Harden et al., 2019). These findings suggest that the success of the intended outcome (jump) is dependent on the training kinematics that closely replicated the intended subsequent actions (squat to jump, respectively). With respect to these findings, the implementation of AEL back squats provides similar biomechanical demands (Kinematic & Kinetic) found during vertical jumps, such as the CMJ and the SJ (Wallace et al., 2008). The kinematic movement patterns executed in the back squat exercise closely align with the joint angles seen at the hips, knees, and ankles found in the vertical jump variations analyzed. The importance of task-specific movement patterns during the conditioning activity may also imply the contribution of completing the SSC, as opposed to segmenting the eccentric and concentric separately to induce supramaximal eccentric loads, as well as the neuromuscular system's role in the potentiated performance seen following the conditioning activities.

Cluster sets, which include the grouping of repetitions with a smaller rest duration within a given set, have been utilized in back squats (Wagle et al., 2021) and bench press exercises (Lates et al., 2022) with the inclusion of accentuated eccentric loading. Current research has shown uncertainty on the ability of AEL cluster sets to potentiate subsequent concentric power output, velocity, and rate of force development in back squat configurations (Wagle et al., 2018 a & b). Conversely, there is research to support enhanced peak velocities of the subsequent concentric phase when using supramaximal AEL cluster set configurations in the bench press (Taber et al., 2021). Taber and colleagues (2021) stated that their findings were highly dependent on the overall displacement of the bar through its range of motion (ROM) and the intensity of the eccentric load, whereby AEL 110% induced greater results compared to AEL 100%. The prescribed load found to successfully potentiate concentric velocities was beyond each subject's concentric ability but was accompanied by an increased risk of overstimulating the athlete beyond an intended response or adaptation.

With evidence to support the delicacy of the dose-response relationship shown in maximal and supramaximal loading procedures, most (if not all) studies have avoided the use of higher relative loads with youth or recreationally active individuals with moderate to low training ages. The advantage of this study is to provides multiple loads (submaximal, maximal, & supramaximal) to provide insight into the magnitude of responses to this younger population with respect to relative loads used and time effects following training interventions. The following sections provide the physiological and neurophysiological basis by which the body responds and adapts to the demands of eccentric overload training.

Stretch-Shortening Cycle (SSC)

The stretch-shortening cycle (SSC) is a sequence of lengthening and shortening of the muscle-tendon complex (MTC) during most dynamic movement patterns (Bosco & Komi, 1979). The cycle is initiated by the lengthening, or eccentric phase, of the MTC where a pre-stretch and preloading of the muscle (contractile elements) and tendon (elastic elements) occur and is detected by stretch receptors (muscle spindles) before the output of the intended movement (Bosco & Komi, 1980). The rate and magnitude of lengthening detected by the muscle spindles provide sensory feedback as proprioceptor (maintenance of motor control function) and signals to motor neurons to engage greater muscular recruitment by way of the stretch reflex (Kröger & Watkins, 2021).

The eccentric phase is then followed by a brief amortization (or transition) phase, a point between the lengthening and the shortening phase. Preloading that occurs during the lengthening phase has been shown to potentiate the performance of the shortening phase and thus the overall performance of the movement (Aura & Komi, 1986; Bosco et al., 1982 b). The potentiation in concentric performance is believed to be an effect of stored elastic energies observed through the storing and recoil from lengthened tissue, greater attainability for contractile cross-bridge attachment, and increased motor unit recruitment signaling provided during the pre-stretch from muscle spindles (Bosco & Rusko, 1983; Kröger & Watkins, 2021). Therefore, an increase in eccentric pre-loading before a concentric action reveals a higher likelihood of greater performance outcomes than concentric actions in isolation (Hody et al., 2019). During vertical jump movements, the use of the SSC is of great importance whereas the use of the countermovement jump (CMJ) is used to evaluate the ability of individuals to utilize their elastic qualities (Voigt et al., 1995). Conversely, the squat jump (SJ) has traditionally been used to diminish the use of the SSC by elongating the duration of the amortization phase. The intent to cause a delay in the SSC is implemented by the incorporation of an isometric hold in an attempt to inhibit the eccentric-preloading contribution that has been identified to potentiate the subsequent concentric actions as stated prior.

Although the SJ has been extensively used to evaluate lower body power production with the intent to diminish the potentiation of the SSC, the quasi-isometric loading encountered during the pause during the amortization phase may provide greater residual enhancements when evaluating concentric-only performance. Aeles and colleagues (2018) evaluated the MTC characteristics of the medial gastrocnemius tendinous tissue and jump height outcomes of a standard squat jump (SJ) and the inclusion of a squat jump with a hop (PHSJ) leading into the movement. Both squat jump variations involved the standard 3-second pause at the bottom of the movement (amortization phase) whereby the pre-hop variation led to a decrease in fascicle lengthening (muscle fibers) and greater lengthening of the tendinous region (Aeles et al., 2018). The jump heights between groups were not significantly different (PHSJ (m): 0.46 ± .04; SJ: 0.44 ± 0.04, $p = .105$) between conditions but the net work performed using a pre-hop was significantly lower at the ankle ($p < 0.001$) knee ($p = .005$) and hip ($p < .001$), even with the additional pause during the amortization phase (Aeles et al., 2018).

Acute Responses to AEL

Although the specificity of this current study investigates the acute potentiation of AEL, evidence has shown that eccentric-specific training is superior to that of concentric-specific training in relation to the increase of muscle mass (hypertrophy) of preferential Type IIx, fast twitch fibers (Friedmann-Bette, 2010), increase in maximal strength (Montalvo et al., 2021; Walker et al., 2016), and the increase of power output (Merrigan et al., 2022), with all studies primarily emphasizing the acute potentiation of power. Furthermore, the increase of chronic strength and hypertrophic adaptations found in eccentric-specific training is not within the scope of this acute-focused study.

Many studies have compared the acute responses of AEL and traditional training on subsequent concentric performance as well as the comparative ability to enhance sport-specific movements following the respective activity via a potentiation phenomenon, (further discussed in the Post Activation Potentiation section). In the measurement of lower limb power and increased velocity, AEL has been shown to provide a superior stimulus to enhance concentric performance through a variety of potential mechanisms. The conceptual evaluation of concentric performance enhancement by supramaximal AEL training and its ability to provide a superior stimulus for acute potentiation is further discussed in the following segment. The potential mechanisms that define the underlying relationship are classified into contractile elements, elastic elements, and neuromuscular attributes.

Neuromuscular Responses

Eccentric muscle actions are accompanied by significantly different attributes to those seen in concentric and isometric contractions. First, a significant gap in force capabilities exists between contraction types, where the requisite quantity of motor units to achieve a comparable workload is significantly lower in eccentric actions (Linnamo et al., 2006). Furthermore, the recruitment of motor units is oriented through the Size Principle, which states that smaller motor units are recruited prior to larger motor units (Henneman, 1957). These motor units encompass a group of muscle fibers that are recruited and initiated, with the size of the units coinciding with the type of muscle fiber (Morton et al., 2019). Small motor units innervate Type I (slow-twitch) muscle fibers and larger motor units innervate Type II (fast-twitch) muscle fibers (De Luca & Erim, 1994). However, research has found that the utilization of increased eccentric stimuli has challenged the Size Principle through selective recruitment of higher threshold motor units to manage excessive loading (Enoka & Duchateau, 2017). The effects of higher threshold motor unit recruitment can be associated with the expression of Type II (fast twitch) fibers which may or may not enable the rate at which work can be produced, known commonly as an improvement in rate coding (Suchomel et al., 2018). The relationship of specific muscle fiber recruitment has gained interest in the areas of preferential Type II fiber hypertrophy, increased rate of force development (RFD), and the causation of PAP and PAPE to display greater potentiation qualities with individuals of greater relative strength (greater Type II fiber composition) (Tseng et al., 2021).

Within sporting events such as basketball, the ability to generate force as rapidly as possible (rate of force development, RFD) is essential for dynamic actions such as sprinting, jumping, and general motor control (Suchomel et al., 2016). With respect to rapidly producing force in sporting environments, the theorized preferential activation of high threshold motor units instantaneously may increase the probability of success in the occurrence of increased jump performance and increase in the rate of force production in tasks such as change of direction (Taber et al., 2016). The increase in the rate of force production capability may pose as the determining factor when retrieving a rebound over a competitor blocking a shot attempt while on defense. The increased ability to effectively produce controlled movement through motor unit activation is known as neuromuscular efficiency, the relation of initiated movement to display greater force or velocity potential under the same circumstance (Taber et al., 2016). Contributions of accentuated eccentric loads to enforce greater recruitment may reinforce the increase in neuromuscular efficiency to enhance sport performance in actions seen in this study, such as jump performance (Wagle et al., 2017).

Ojasto & Häkkinen (2009) evaluated measures of maximal strength, force, power, and the respective neuromuscular activity through a multitude of loading prescriptions. Their findings indicated a greater magnitude of neuromuscular activation through AEL bench pressing movements, resulting in enhanced concentric performance through increased motor unit recruitment (Ojasto & Häkkinen, 2009). Methods of this study included submaximal loading in the eccentric phase (between 50% and 80%) while a consistent 50% concentric load was used throughout all conditions. On the other hand, a group of national-level powerlifters underwent a four-week supramaximal AEL training program centered on the bench press, resulting in a decrease in neuromuscular (EMG) activity in the same loading protocol (105% ~ 125% ECC &

90% CON) while significantly increasing peak power of their original 1RM (+36.67%: p = 0.036, ES = 0.58) and increasing their 1RM capabilities (p = 0.001) (Montalvo et al., 2021). The significant decrease in EMG activity following AEL protocols coupled with the increase in maximal strength and peak power highlights the holistic enhancement of neuromuscular recruitment during a condensed time duration. Furthermore, increasing the recruitment of muscular action coinciding with the increase of peak power found in Montalvo and colleagues (2021) supports the concept of residual enhancements during muscle shortening through greater contributions of relative activated muscle fibers. With the presence of increased electromyography (EMG) activity, conclusions of the contribution of contractile elements to the enhancement of concentric power may be supported by unknown contributions made by the elastic elements provided during the pre-stretch (Blazevich et al., 2007). Eccentric overload training may therefore increase force production during the concentric phase via increased neural drive and motor unit activation (Aagaard et al., 2002). The effect of greater neurophysiological drivers can prompt an increase in the frequency of motor unit recruitment and firing, further enhancing maximal force generation capacity as well as the rate at which the force is executed (RFD) in the pursuit of performance outcomes (Tøien et al., 2018).

Contractile & Elastic Elements

It is assumed that the involvement of contractile and elastic elements (myosin, actin, titin, and secondary myosin head) are stimulated to optimize muscle lengthening, resulting in the enhancement of concentric performance (Herzog, 2014). During the eccentric phase, both series and parallel elastic components store elastic energy, which can be used during the subsequent concentric phase (Vogt & Hoppeler, 2013). The storing and disbursement of contractile-derived energy are believed to originate from several factors such as calcium sensitivity, titin contribution, and reflexive mechanisms within the muscle (Herzog, 2014; Monroy et al., 2012).

First, calcium sensitivity plays an important role in the initiation of all muscle contractions, where the introduction of calcium from the sarcoplasmic reticulum ignites the action and myosin interaction (MacIntosh, 2003). With greater sensitivity to calcium, the myosin head is prone to execute a greater number of cross-bridge cycles (attachment and re-attachments) with the potential to induce forces at a high rate of production (MacIntosh, 2003). Second, titin is believed to play a critical role in eccentric muscle contractions as a mechanoreceptor that assists in force regulation (active and passive levels of stiffness) when calcium is present, known as the Winding-Filament Theory (Monroy et al., 2012). The combination of increased calcium sensitivity further compliments the role of Titin contribution as a priming factor during the eccentric phase to potentiate the subsequent concentric actions (Herzog, 2014). Lastly, reflexive mechanisms aid in the storing and disbursement of energy by the series elastic components (tendons) providing an elastic rebound of energy (Herzog, 2019).

The optimal lengthening of the muscular tissue is believed to be significant in its capacity to induce a post-activation potentiation effect, with greater ranges of motion providing a more potent stimulus of performance enhancement following the conditioning activity (Esformes & Bampouras, 2013). The incorporation of large ranges of motion invokes a greater lengthening of the muscle-tendon unit (MTU), with a higher likelihood for greater crossbridge-attachment of the myosin head, and increased recruitment of motor units to engage muscular tissue actions (Llyod et al., 2021).

Higher magnitudes imposed on muscle lengthening, using eccentric overloading strategies, may lead to alterations in recruitment strategies. These alterations include decreased motor-evoked potentials (electrical signals produced by the brain to initiate muscular involvement) and H-reflex responses (excitability or sensitivity of motor neurons that induce muscular contractions (Hedayatpour & Falla, 2015). Activation of Type Ia afferent nerves (sensory nerve fiber in muscle spindles that monitor stretch changes of the MTU) through active muscle lengthening of near-maximal loads induces a stretch-reflex, thereby enhancing subsequent concentric contractions (Aagaard et al., 2002). In theory, the resulting stretch-reflex (or myotatic-reflex) itself may play a role in the acknowledgment of the successful eccentric overloading, with greater differences observed between the supramaximal eccentric loads which are followed by submaximal loads less than 80% of the concentric 1RM (Douglas et al., 2018; Merrigan et al., 2021). The inclusion of AEL can provide a unique stimulus, resulting in greater neurophysiological stimuli when compared with traditional loading to improve upon the current contractile and elastic properties in place. This adaptation may transfer favorably to sporting movements that involve rapid countermovement eccentric actions (such as the CMJ) while also investigating the residual effects to potentially enhance concentric-only performance in the absence of the stretch-shortening cycle.

Performance Potentiation

Post Activation Potentiation (PAP)

According to Golas and colleagues, PAP is defined as an acute improvement in muscle performance following a conditioning activity (CA), which is the result of mechanistic changes of contractile elements and neuromuscular interactions that are not fully understood (Golas et al., 2016). Contributing mechanisms can be classified into neural elements (Wallace et al., 2018), contractile elements (Timon et al., 2019), and elastic elements (Seitz & Haff, 2016).

The proposed contractile elements of PAP include increased phosphorylation of myosin light chains, resulting in increased calcium (Ca^{2+}) sensitivity of the myofilaments actin & myosin (Tillin & Bishop, 2009). Neural elements are theorized to include the excitation-coupling of alpha motor neurons (the recruitment of high-threshold motor units) driving fast-twitch muscle fiber (Type II) activation and contribution (Timon et al., 2019). Neural elements are accompanied by the contribution of elastic properties from stretch-reflex and the inclusion of titin stiffness due to Ca2+ saturation (Wallace et al., 2018). Much debate has been centered around the relative contribution of stated mechanisms associated with PAP as literature continues to proclaim findings of PAP without regarding other closely aligned potentiation theories such as PAPE (Blazevich & Babault, 2019). Regulatory assessment of PAP contribution is conducted through twitch-potentiation (TP), which is a measurement of external stimulation classified as non-voluntary, with average dissipation of activity displaying a half-life of only 28 seconds (Blazevich & Babault, 2019).

Post Activation Performance Enhancement (PAPE)

On the other hand, PAPE is defined as an improvement in muscle performance after a pre-conditioning contraction that is specific to the type of contraction performed during the pre-conditioning phase and displayed through voluntary muscle actions (Blazevich & Babault, 2019). According to Prieske and colleagues (2020), PAPE is thought to be mediated by changes in muscle fiber activation, water and fiber content of muscle tissue, and an increase in muscle temperature following the pre-conditioning contraction. Fundamental differences between PAP from PAPE are evident in their durations, with evidence depicting the optimal PAPE window of potentiation between 3 to 7 minutes following conditioning contraction, whereas PAP is limited to less than 60 seconds (Beato et al., 2019 a; Esformes et al., 2010; Krzysztofik et al., 2020; Seitz & Haff, 2016).

The magnitude and duration of potentiation is highly variable between athletes and is dependent on a variety of factors spanning from training age, fiber type composition of the individual, relative strength, mode of exercise, and optimal loading procedures (Seitz & Haff, 2016; Tillin & Bishop, 2009; Blazevich & Babault, 2019). Further evaluations of how these factors are related to the participants involved in the study are discussed in the *Participants and Setting* Section within chapter three. Prior research has focused on optimizing the dose-load threshold of training load to induce PAP/PAPE responses while minimizing the onset of fatigue (Golas et al., 2016). Following the conditioning contraction, it is theorized that both fatigue and -post-activation potentiation characteristics are simultaneously present, with potentiation emerging following the dissipation of fatigue to display enhancement of performance or lack thereof (Whelan et al., 2014).

Eccentric Overload & PAPE

According to Golas and colleagues (2016), eccentric contractions are more effective at inducing PAP and PAPE than concentric contractions in isolation, with the inclusion of supramaximal loads (110-130% of 1RM) eliciting the most promising results. Evidence for eccentric overload (EOL) persists with increased recruitment of higher threshold motor units by utilizing heavier eccentric loads that surpass the individual's ability to complete the full stretch-shortening cycle (SSC) via traditional training methods, at potentially lower total workload volume (De Keijzer et al., 2020; Wagle et al., 2017). Therefore, the use of maximal and supramaximal loads during the eccentric phase provides a rationale for the enhancement of eccentric strain, most suitably implemented through accentuated eccentric loading to induce acute performance-enhancing qualities through PAPE (Suchomel et al., 2016).

As discussed, the "potentiation window" hypothesis suggests a specific timeline following a conditioning contraction during which PAP and PAPE can occur. Therefore, it is important to program and implement AEL training sessions to allow for optimal recovery (fatigue dissipation) and the expression of increased performance in the setting of practice or competition. Examples of muscle performance seen through PAPE have shown an increased rate of force development (RFD) (Aagaard et al., 2002), increased velocity of contraction (Wilson et al., 2013), and increased in performance attributes such as jump (Chiu et al., 2003; Hughes et al., 2016; Kilduff et al., 2007) and sprint performance (Beato et al., 2019 a), all of which are directly indicative of athletic success during explosive team sports such as basketball (Suchomel et al., 2016). Although evidence for the enhancement of sport-specific performance has been present in the literature, there is uncertainty about the PAP and PAPE phenomenon to increase maximum force production (Tillin & Bishop, 2009).

Theoretical Frameworks of AEL & PAPE

The utilization of traditional resistance training as an effective stimulus for the potentiation of subsequent performance is within the consensus in the strength and conditioning community (Tillin & Bishop, 2009). In contrast, the deliberation on AEL training protocols to induce similar or greater potentiation of performance has yet to be established (Douglas et al., 2018). In a study conducted by Tseng and colleagues (2021), collegiate male volleyball athletes were assessed for the effect of PAPE following a single bout of supramaximal (105% 1RM) AEL half squats. Their findings indicated significant enhancements in the rate of force production (RFD) in the isometric-midthigh-pull (IMTP) test, but no significant increases were found for countermovement jump or spike jump from pre- to post-testing (10 min, 24 hrs, 48 hrs) in comparison to the traditional resistance training control group ($p < 0.05$) (Tseng et al., 2021). The absence of significant results found when compared to traditional training procedures reveals key points of focus that may have potentially limited the study's efficacy in inducing potentiated dynamic performance. Methodology to align the first pre-testing measure at 10 mins is not commonly observed in the literature when expressing positive associations of AEL and PAPE. General recommendations emphasize time increments between 3 to 10 minutes due to large variability in each participant's history (Blazevich & Babault, 2019; Kilduff et al., 2007; Seitz & Haff, 2016; Trimble & Harp, 1998). The window of potentiation is also dependent on the temporal profiles of potentiation due to influences of relative strength and training age, the ROM attained during muscle lengthening (Esformes & Bampouras, 2013), and the volume of the pre-conditioning activity (Seitz & Haff, 2016). More notably discussed in the methodology section, different magnitudes of loads, volume, and specificity of movement need to be considered as individuals with lower relative strength may realize their greatest potential following submaximal loads, over many sets with longer rest periods whereas stronger athletes show preferential responses with shorter rest periods and maximal loads with less volume needed (Seitz & Haff, 2016). In the current framework, individuals with greater relative strength (and usually greater training history) may favor supramaximal loading to achieve a PAPE state as it may decrease the total volume of the conditioning activity and the potential of relative fatigue which hinders the duration of realized performance enhancements.

Differing modalities of AEL have shown promising effects on increased CMJ performance, primarily through the grouping of plyometric-accentuated eccentric loading (plyo-AEL) (Bridgeman et al., 2017; Hughes et al., 2016; Patus, 2021). In conjunction with plyo-accentuated findings, Ong and colleagues (2015) found significant increases in performance at 3 and 6 minutes following a pre-conditioning activity involving supramaximal eccentric-only loading on the hip sled (0%, 105%, 125% of CON 1RM). Their results found CMJ maximum vertical displacement (jump height) was significantly greater at 3 min (44.3 ± 8.3 cm) and 6 min (44.7 ± 7.3 cm) in the 125% 1RM group compared to baseline, whereas no significant difference was found for the 0% grouping. Peak power values also aligned with increased jump height values, where the 125% and the 105% grouping displayed similar increases in power (W) from baseline values, whereas no changes were indicated for the 0% condition (Ong et al., 2015). Increases in post-intervention performance were evident in their findings, indicating the significance of the eccentric contraction in isolation, (in the absence of the stretch-shortening cycle) as a viable stimulus to induce a PAPE response. Thus, it can be assumed that the magnitude of the eccentric contraction is of utmost importance in pursuit of PAPE. Through reductional reasoning of responses attained through executing conditioning activity, eccentric-only contractions inducing a similar PAPE response, as seen through traditional training measurements, aid in the rationale to include AEL modalities with the intent to induce acute performance enhancement. The current framework proposes supramaximal AEL as a tactic to impose comparable external stimuli with a lower total volume of load lifted, equating to a greater window of potentiation to display the acute improvements in performance found in the PAPE state.

Propulsive-Only Jump

Potentiation of Concentric Actions

In jumping assessments with a preceding stretch, it is hypothesized the (alpha)-afferent activation via high-velocity loading of intrafusal fibers may increase activation of the muscle and result in greater jump height attainment (Bosco et al., 1982 b). In other words, the addition of eccentric strain through means of increasing velocity, external loading, or a combination of both may increase activation and excitation of the physiological and neurophysiology elements involved in increased jump performance. This increase in activation produces a reflexive response in the transfer from eccentric, amortization, and into the initial stages of the concentric phase. This reflex response is also believed to be influenced or aided in part by series elastic energy gained during the initial loading of the eccentric phase (Bosco et al., 1981). Finally, the potential elastic energy may be evident through the concept of resonance which states that there are optimized rates of stretch and recoil involved in the use of this energy (Walshe et al., 1998).

A study investigating key determinants of the stretch-shortening cycle (SSC) and the influence of isometric preloading on concentric performance found that eccentric preloading enhanced the subsequent concentric performance in the first 300ms of the concentric phase (Walshe et al., 1998). These findings utilized a concentric-only squat which was preceded by an isometric hold of up to 1.5 seconds, which was stated as a potential limitation and may have influenced the results of the findings. The researchers of this study, Walshe and colleagues (1998), hypothesized that the potentiation of contractile elements via stretch-induced mechanisms plays a significant role in the contribution of the potentiation of concentric contractions within the SSC. Concluding remarks signified the high probability of SSC potentiation via contractile element (CE) contribution during longer durations of concentric contraction (>300ms). The results of this study indicate the superior effects of preloading, exhibited in SSC movements when compared to both the isometric and concentric-only squats. Considering greater force abilities attained during the SSC actions, there is consistent evidence separating the contractile differences between concentric-only and isometric preload abilities. (Jensen & Ebben, 2003; Svantessonn et al., 1994; Walshe et al, 1998).

In conclusion, the evidence clearly depicts the enhancement of concentric performance in the presence of the stretch-shortening cycle and is most commonly assessed through CMJ. Current standards of assessing dynamic concentric performance in the absence of SSC contribution are assessed using the squat jump (SJ) assessment. Although the SSC's influence is limited by the increased duration of the amortization phase, which is negatively correlated with concentric potentiation ($r = -0.35$, $p < 0.05$), the presence of preloading still holds value in the isometric preloading phase of three seconds (Bosco et al., 1981; Walshe et al., 1998). With respect to a true assessment of concentric-only performance, the induction of a novel assessment (Propulsive-Only Jump: POJ) may provide a new perspective on the contributions of the SSC and eccentric utilization of the individual (Kozinc et al., 2021 a & b).

Squat Jump Comparison

The squat jump (SJ) assessment is a dynamic lower limb test aimed to evaluate an individual's ability to perform an explosive vertical jump without the positive contributions of the stretch-shortening cycle (SSC) (McCarthy et al., 2012). To complete the SJ assessment, the athlete is instructed to descend into the deepest portion of their jump and perform an isometric hold for 3 seconds before performing the concentric phase of the jump (Walshe, et al., 1998). Under current SJ protocols stated, the isometric loading is still a contributing factor to the elastic and contractile energy that is not seen during concentric-only actions (Walshe, et al., 1998). The limitations of the squat jump are evident in the preloading of the contractile and elastic elements that occur to diminish the stretch-shortening but do not diminish its contribution completely.

Many confounding variables to the performance outcomes of the squat jump have been identified where preloading variables play a significant role in the residual effects normally found with the regular CMJ. McBride and colleagues (2008) found that a comparison of the drop jump and squat jump assessment did not lead to any significant difference in concentric muscle activation of the lower limbs (expressed as mean ± standard deviation in millivolts: SJ = 0.97 ± 0.4; DJ = 1.07 ± 0.37). Unfortunately, pre-activity and eccentric EMG data were not accumulated for the squat jump, and a significant difference in both pre-activity and eccentric activation was found in the DJ over the CMJ ($p < .005$). Moreover, lack of consensus concerning the eccentric phase prior to the isometric hold in the squat jump does foster questions on the contribution and reliability of imposed tests if different strategies of increased eccentric velocities are initiated prior to the isometric hold. Aeles and colleagues (2018) assess the effect of squat jumps with and without a pre-hop squat jump (PHSJ) before the standardized 3-second isometric hold and traditional concentric jump. Their investigation found that the addition of the PHSJ reduced the lengthening of the muscle fascicles and induced greater lengthening of the series elastic elements that contribute to greater elastic energy potential found in the subsequent concentric action (Aeles et al., 2018). These findings indicate that the different length-tension relationships found with PHSJ may provide a more opportunistic muscle-tendon unit (MTU) length to benefit a following concentric action, regardless of the isometric action occurring (Aeles et al., 2018).

Furthermore, the propulsive-only jump aims to eliminate the magnitude of pre-force and pre-loading that occurs during the isometric preloading by initiating the movement from a seated position with similar flexion at the ankles, knees, and hips to that of the squat jump.

Propulsive-Only Jump

The propulsive-only jump (POJ) is a dynamic lower-limb assessment that aims to diminish the magnitude of preloading that occurs during other closely related jump assessments such as the countermovement jump (CMJ) and the squat jump (SJ). Commonalities of the (POJ) are seen in exercise prescription as a plyometric movement termed the “Rocker jump” or “Seated Jump.” The first purpose of the POJ is to gain further insights into the driving mechanisms of eccentric preloading to enhance subsequent concentric contraction abilities. The secondary purpose of the isolated testing measure is to investigate the properties of post-activation potentiation (PAP) and post-activation performance enhancement (PAPE) to enhance concentric-only contractions in a dynamic movement pattern, which utilizes greater motor control and neuromuscular contributions without the aid of prior loading via recruitment at the contractile and elastic level. The pairing of the POJ and SJ with the CMJ is intended to monitor the enhancements of potentiated performance prior to and following the training interventions. Furthermore, the reliable nature of the countermovement jump with no arm swing (CMJ NAS) will function as a measurable action to discern the fluctuations of the POJ as both a control and experimental measure within the study (Heishman, et al., 2020). The inclusion of the CMJ will further aid as a supporting measurement tool to support the determination of PAPE presence to correlate with the measures found in the SJ and POJ.

In the context of investigating the concentric-only outcomes compared to a natural SSC movement, a recent study conducted by Perez-Castilla and colleagues (2020) evaluated two bench press variations including a traditional eccentric-concentric (SSC) and a concentric-only press (no SSC). Although the results of the study indicated an insignificant difference during the early phase of the concentric phase (in the ECC-CON) when compared to the concentric-only group (ES range: 2.87-3.58, $p < 0.001$), the greatest significance of this study is how they chose to conduct the "concentric-only" movement (Perez-Castilla et al., 2020). The researchers utilized a mechanical braking system (held over the chest) to diminish the contribution of preloading prior to performing the explosive concentric bench press.

Propulsive-Only Jump Procedures

The propulsive-only jump involves a box or stable structure that enables the participant to sit with similar degrees of flexion at the ankles, knees, and hips seen in their respective squat jumps. Rather than lowering oneself to the level of the isometric hold, the participant will initiate the upward jump (concentric) movement from the seated position with minimal to no contribution of eccentric loading. During the jump, participants were monitored for prominent eccentric loading. If any downward motion (countermovement) that could affect performance is detected, participants reattempted to eliminate this factor. Detection of the POJ attempts was monitored via live data acquisition, used to indicate if additional eccentric loading or countermovement occurred following initial foot contact. During the familiarization session, participants' seat heights were determined for each individual to control for a starting knee flexion angle of 70 degrees to support consistency across varying anthropometric measures. POJ Seat height adjustment included a simple addition or subtraction of layered increments (see Appendix G & H) layered on top of the seat of the standard weight bench, which was inclined to 85 degrees. The incline of the bench ensued as a fixed point of contact to control excessive anteroposterior rocking. The external rigidness enabled the participant to initiate movement from an explicit starting point (contact point) with the bench (upper back) while maintaining the fixed position (knee flexion at the hips, knees, and ankles) until contact was made with the platform, followed by a strict upward ascent (extension only). Monitoring of concentric (propulsive) only movement was conducted by the researcher to ensure the absence of an excessive loading period, determined by the visual determination of additional hip flexion or preloading found during the first 250 milliseconds, to be assessed by live-data streamed ground-reaction forces (GRF) from the force platforms onto the designated tablet, also identified by duration spent in the eccentric or unweighting phase of the jump via the force plate software (McCarthy et al., 2012).

Potential Limitations

Significant limitations are present in the use of the POJ assessment as concentric-only movement is not evident in any type of movement found in most sports. The inclusion of this assessment is to isolate a component of a complex movement, such as the CMJ, to assess the strengths and weaknesses of the athlete to develop and prescribe personalized measures for performance improvement or preventative measures to avoid injury. The use of any novel testing assessment presents a learning curve which was met with a familiarization session to properly integrate the movement before gaining objective data for analysis. The POJ in training may include the use of the arm swing to align with sport-specific mechanics. For the sake of intersession reliability, the detainment of arm swing was limited with the hand on the hips (akimbo) during the entirety of the movement to preserve the validity of the results (Heishman et al., 2020).

Lastly, restriction of the rocking motion into the concentric motion is of utmost importance. This research limited momentum, preloading, and countermovement upon initial ground contact. In contrast, future training approaches might incorporate some or all of these constraints, as typically observed in exercises like the 'seated jump' or the 'rocker jump.’

Summary

Eccentric overload (EOL) modalities have gained considerable attention for their potential to provide a novel stimulus to induce acute and chronic adaptations (Douglas et al., 2017 a & b; Vogt & Hoppeler, 2014). Within this categorization of emphasized-eccentric focus, accentuated eccentric loading is the only modality that has the capability to provide an absolute overload during the eccentric phase that exceeds an individual 1-repetition maximum (supramaximal), as measured during traditional (non-varying) methods (Suchomel et al., 2019a). With the intent to investigate the potential of acute potentiation following any form of EOL, the majority of research has utilized the flywheel inertial training (FIT) and limited accounts with the use of traditional AEL using weight releasers (Buonsenso et al., 2023). It is assumed that the popularization of the flywheel prompted its emphasis in recent research, in light of traditional AELs' strengths of providing greater eccentric loading while achieving greater concentric velocities (Wagle et al., 2017). This loading ability not only correlates with PAPE's favoritism of greater magnitudes of eccentric loading but commonly revealed itself following the conditioning activity in the form of enhanced concentric velocity rather than force (Hedayatpour & Falla, 2015).

In conclusion, the previous chapter outlines the most relevant literature on the utilization of supramaximal accentuated eccentric loading over other EOL modes to induce unique performance outcomes. Comparison of potentiation forms are evaluated and analyzed to inform the properties of each phenomenon and how it relates to the use of AEL. Lastly, the rationale and protocols for the newly integrated propulsive-only jump (POJ) are introduced to compare the true capabilities of the stretch-shortening cycle in light of post-activation performance enhancement.

CHAPTER III: METHODS

Overview

The purpose of this study was to investigate the acute responses of accentuated eccentric loading (AEL) as a conditioning activity to enhance lower-limb performance in male high school basketball players. An experimental, randomized crossover design was implemented to evaluate multiple jump performance outcomes before and after an AEL experimental intervention. Identical AEL testing interventions were provided to all participants, with intent to evaluate the differences in countermovement jump (CMJ), squat jump (SJ), and the propulsive-only jump (POJ) performances pre- and post-intervention. The dependent variables included jump height, net propulsive impulse, and peak relative propulsive power over three jump variations (CMJ, SJ, & POJ), assessed pre- and post-AEL intervention. Three 3x5 repeated measures ANOVAs were used to evaluate jump variation (CMJ, SJ, and POJ) and time effects (pre-intervention, post-3 min, 6 min, 9 min, 12 min).

The following chapter presents the methodological approach and rationale for the structure and implementation of the investigation. Descriptions and tools for the induction of the novel propulsive-only jump are also provided in greater detail among the more established countermovement jump and squat jump protocols. Procedures for applying interventions, testing protocols, and data collection tools are also expanded upon. Lastly, the population of study and the statistical analyses used are further explored. See Appendix L: Diagram of Methods, for a visual representation of the research design.

Research Design

This experimental, randomized crossover design was used to investigate the acute responses of accentuated eccentric loading (AEL) as a conditioning activity for lower-limb performance enhancements of sport-specific movements. More specifically, the interventions were enacted to stimulate the phenomenon of post activation performance enhancement (PAPE) on subsequently performed countermovement (CMJ), squat (SJ), and propulsive-only jumps (POJ). The framework of this investigation involved a singular familiarization session followed by two experimental sessions, with all sessions separated by 72 hours and conducted at the same time on each occasion to allow recovery between sessions (Heishman et al., 2017). The Procedures Section provides greater detail on the interventions, procedures, timelines, and protocols used during each session involved in the study.

Research Questions

RQ1: Does exposure to supramaximal accentuated eccentric loaded back squats acutely enhance countermovement jump height to a greater degree than the squat jump and propulsive-only jump?

RQ2: What is the ideal “Potentiation Window” for the enhancement of jump performance following a supramaximal accentuated eccentric loaded back squats in high school male basketball players?

RQ3: Is there a difference in absolute and relative jump performance between the propulsive-only jump and the squat jump in the presence of post activation performance enhancement following supramaximal accentuated eccentric loaded back squats?

Null Hypotheses

$H_0$1: There is no statistically significant difference in acute performance enhancement when comparing CMJ performance to SJ and POJ performance following exposure of supramaximal AEL back squats in high school male basketball players.

$H_0$2: There is no statistically significant time course of PAPE in all jump variations following the exposure of supramaximal AEL back squats in high school male basketball players.

$H_0$3: There is no statistically significant difference in absolute and relative jump performance between the propulsive-only jump (POJ) and the squat jump (SJ) in the presence of PAPE following supramaximal AEL back squats.

Participants and Setting

During the fall semester of the 2023-2024 school year, a high school male basketball team (Division 3) located in eastern Iowa was chosen to participate in a study. Participants were selected from a convenience sample, including minors (n = 14) and athletes over 18 years old (n = 1) for a total of 15 athletes. The head basketball coach recruited the adult participant and contacted parents of those under 18 years old via email. All participants were cleared to participate in athletics via sports medicine physical.

To determine the acute potentiation effects of a conditioning activity for this population, this investigation targeted a sample size of at least fourteen or more participants. Similar studies, such as those conducted by Ojasto and Häkkinen (2009), Sheppard et al. (2008), and Tseng et al. (2021), served as the basis for selecting this sample size. The availability of athletes from the small rural town’s basketball roster was also taken into consideration. Successful studies conducted on PAP/PAPE involved 16 participants (8 in AEL condition, 18-25 years of age, volleyball athletes, & 2 years of training experience) (Tseng et al., 2021) and 11 participants (males, 28-37 years of age, relative 1RM strength of 1.2-1.4 x body mass) (Ojasto & Häkkinen, 2009). Sheppard and colleagues (2008) investigated a similarly aged group of athletes (16-27 years of age) with submaximal loading (dumbbells) and high-performance volleyball athletes who had prior training experience with AEL. There is limited research on the effects of AEL and/or PAPE on high school athletes, which highlights the importance of completing this study.

The sample used in this study involved 15 males between of the ages of 14-18 years old, with all minors providing signed parental consent and the singular adult participant signed standard consent. Self-reported years of continuous resistance training experience were 1.3 years (± 0.9) with relative strength outcomes from maximal strength back squat 1RM testing protocols, outlined by McMaster et al. (2014), of 1.32 x body mass (SD = 0.3). None of the participants had prior experience using accentuated eccentric loading with weight releasers, experience with the propulsive-only jump (or seated jump variants), or the squat jump. Participants also reported no prior plyometric or jump-based tasks that were programmed or implemented in training that occurred outside of sport.

Instrumentation

Force Platform System

Countermovement, squat, and propulsive-only jumps were performed on the HD bilateral force plate system (Hawkin Dynamics Inc™., Maine, USA) to collect vertical ground reaction forces and time characteristics at a sampling rate of 1,000 hertz (Appendix E & F). Calibration of the force plate systems were performed to ensure valid readings prior to each experimental session through a two-stage process. First, zeroing of the platform was completed twice with setup occurring at least 30 minutes prior to data collection (Collins et al., 2009). Second, the use of calibrated weights (2 x 10 kg) were integrated to confirm absolute force reading consistency between the bilateral platforms for each experimental session. Data retrieved from this hardware were analyzed through the HD proprietary software™ and exported via csv file in preparation of analysis (Badby et al., 2022). The hardware used in this study had been identified to have a high reliability in the collection of vertical jumping data when compared to current “gold-standard” in-ground force platforms (Badby et al., 2022). The combination of the HD hardware and software has been identified as a reliable combination in the collection and monitoring of vertical jump testing, with less than 3% of error across all tests (Merrigan et al., 2022).

Range of Motion (ROM) Detection Tool

A modified tool using the upright dowels of a Functional Movement Screening (FMS) testing kit (FMS™) was used to monitor and execute the appropriate depth during both the maximal strength test (back squat with 90 degrees of knee flexion) as well as the squat jump assessment (70 degrees of knee flexion). Measurement of the tibial tuberosity was used to identify each individual’s first depth assessment (starting point) and adjusted to meet the anthropometric and kinematics of each subject during the familiarization session. The two upright dowels and (2) elastic cords, normally used during the Hurdle Step Assessment, were anchored in upright positions to a wooden support(s) to enhance stability (Appendix F). The modification of the instrument was indicated due to its accurate labeling in 0.5 in increments, ease of adjustment to meet the needs of each participant and is minimally invasive to the squatting actions performed in the study. Once adjusted to meet the height of the individual, the individual is to squat until they feel the band and either hold the position (squat jump) or continue by executing the concentric movement phase (1RM testing).

Weight Releasers

Steel weight releasers (Rogue Fitness, Ohio, USA) weighing 8 kg per releaser (16 kg total) were utilized during the accentuated eccentric loading intervention (Appendix J). Also known as eccentric hooks, this training tool has a rounded hook connected to an adjustable stem (0.5in increments), that allows the displacement of the hook from the barbell at a predetermined height (90 degrees of knee flexion: center of mas at its lowest point). The base of the releaser is angled in the opposing direction of the hook hanging on the bar, allowing for a swift release when contacting the ground. Additional weight was added to the weight releasers by simply placing weight-plates around the stem. During the initial session, trials were performed to find adjustment heights, determined by the individual reaching 90-degree of knee flexion (also determined by band-depth measurement stated previously), with appropriate displacement from the bar at the end of the eccentric phase. The researcher demonstrated the use of the weight releasers to display the expectations of where the hooks land, the resultant noise expectation when contacting the ground, and the tempo during the eccentric phase. Participants were encouraged to maintain a consistent tempo with their traditionally loaded squats (velocity of movement) during the eccentric phase while maintaining control of the additional load. The participant familiarization process for the weighted releasers included a barbell with the AEL weight releasers and no additional weight to either instrument.

Procedures

Familiarization Session

Prior to any actions taken in this study, approval from the Institutional Review Board of Liberty University was provided to recruit participants and respective permissions (#FY22-23-1976), (Appendix A). Consensual agreements (parental and standard consent documents) and an overview of the study were provided to the parents and the participants of the study, see (Appendix B & C).

The initial familiarization session began with a brief overview of the expectations and tasks related to the day with all participants. The list involved gaining general information from each participant (age, height, demographics), verbal survey of prior weight releaser experience, propulsive-only jump (or seated jump variation), squat jump and countermovement jump experience (Yes/No), anthropometric information related to squat depth, box height needed for POJ trials, maximum strength testing (1RM back squats), the familiarization and identification of weight releaser/ROM Detection tools to find individual adjustment height settings, familiarization and identification of POJ performance standards and individual POJ seat height settings, as well as the standardized procedures for the CMJ, SJ, and POJ.

Active integration of the participants began with a warmup procedure which was performed over all sessions: 10 minutes of cycling at a constant power of 1W per kg of body weight (Beato et al., 2019b). Once warmup was completed, each individual was assessed for the appropriate band height on the ROM Detection tool. The use of a goniometer (Hopkins Medical, Part # 681000: Appendix I) was utilized to confirm degrees of joint flexion at the knee for maximal strength (90 degrees), squat jump (70 degrees) and the propulsive-only jump (70 degrees).

Maximal strength testing of the back squat (1RM) followed the acquisition of individual ROM standards and was executed within the testing procedures provided by the National Strength and Conditioning Association (NSCA) (McMaster et al., 2014). Documentation of maximal strength scores were gathered to confirm the percentage of 1RM loads (eccentric and concentric) used during the following experimental sessions. Weight releaser height settings were confirmed for each individual while using an unloaded barbell (20 kg) and unloaded weight releasers (8 kg each) to ensure the release at the proper squat depth. The final assessment included a familiarization of the propulsive-only jump protocols which is explained in greater detail in the following sections.

Information gained from this initial session (1RM strength values, age, height, experience), seat height for each participant (POJ), band height for squat depth (AEL intervention and SJ), verbal survey of prior experience (Yes/No), and weight releaser setting height was added to each participant's secured profile along with their signed consensual agreements.

Experimental Sessions

The two experimental sessions in this study incorporated identical procedures: warmup protocol, pre-testing of vertical jumps (CMJ, SJ, POJ), AEL training intervention, and post-testing of vertical jumps. All participants completed the AEL intervention with loads derived from maximal back squat 1RM values attained during the familiarization session. Group randomization, jump testing procedures, and training intervention guidelines are further explained below.

Jump Testing Procedures

Following the warmup procedures, all participants were randomly assigned to their respective groups (and subgroups) and instructed to perform two maximal intensity jumps with a brief rest between repetitions. The CMJ group performed two jumps whereas the SJ+POJ or POJ+SJ group completed two jumps for each jump condition for a total of four jumps. Following the AEL intervention, participants were directed to the testing area and completed their assigned jumps for post-testing at 3-min, 6-min, 9-min, and 12-min increments. Participants were provided up to 10 seconds of rest between jump attempts, with the jump attempt with the greatest displacement used for pre- and post-testing analysis. To avoid overflow of participants relative to testing instruments and personnel, participants had staggered start times and remained consistent in time for both experimental sessions. Verbal encouragement during jump tests (pre and post) was implemented to increase motivation and likelihood of achieving the participants' best performances (Pacholek & Zemková, 2022).

The countermovement jump and squat jump have established testing procedures and verbal cues in the execution of their implementation and monitoring (Dobbs et al., 2019; Heishman et al., 2020). In contrast, the use of a propulsive-only jump does not have the same grounding within research, where its primary use can be found in training programs labeled as a "Rocker Jump" or the "Seated Jump." Furthermore, the following are instructions on the protocols of completing the intended propulsive-only jump in the future study.

1.) A singular plyometric box or bench with capability of seat height manipulation is best suited to address the lower-limb lengths and joint angles of the individual.
2.) The use of an adjustable bench with the capability of reaching an 85% incline was used to limit anteroposterior "rocking" prior to start of the jump. The use of customized wooden seat risers with rubber on top enables height increases to meet the needs of the individual.
    a. Optional for future applications in the field: limiting antero-posterior "rocking" by placing box against wall or using an additional object to limit backward rocking motion.
3.) Height of the seat: When the participant is seated with their feet on the force plates/ground, the degree of knee flexion represents an angle of at least 70 degrees

and less than 90 degrees, with 70 degree starting positions producing the most advantageous starting positions of similar jumps (Gheller et al., 2015; Moran & Wallace, 2007).

To account for the individual anthropometrics of each participant, a bench with adjusted incline of 85 degrees (AB-5200 Bench, REP Fitness™) was used to control excessive "rocking" prior to the start of the jump. The seat height of the bench remained parallel and 17.5" above the ground, and approximately 15.5" from the force platforms. To ensure consistent knee flexion starting angles of 70 degrees, the use of seat risers (Appendix G) were implemented to allow for the increase in starting height for 15.5" to 24.5". Four seat risers (1", 1", 2", and 4") enabled 1" increments and greater attainability to control seat height variations needed between participants. A goniometer (Hopkins Medical, Caledonia, MI) was used to gather each participant's seat height during the familiarization phase and recorded for use in the following experimental sessions. Although the participants are instructed to rock backwards prior to the initiation of the jump, the allowable clearance of subject's upper back is minimized to allow the lower extremity the necessary time to create the rigid starting position (flexion of the ankles, knees, and hips) prior to jump's initiation. No arm swing was allowed for any of the jump variations (CMJ, SJ, & POJ). In addition to the verbal instructions provided for the POJ, participants were asked to stand upright and still on the force platforms for one second ("quiet phase") to gain accurate body weight measurements (Heishman et al., 2020).

Visual demonstrations followed by verbal instructions were provided prior to each session:

4.) Verbal Instruction: 1) Once seated on the box, slightly rock backward (until contact is made with the bench) while maintaining the same degree of hip and knee flexion with dorsiflexion at the ankles. Hands are placed on the hips throughout the duration of the movement.
5.) Verbal Instruction: 2) While maintaining a rigid position, allow the momentum to bring you back to the starting position until the feet reconnect with the ground.
6.) Verbal Instruction: 3) At the instant of ground contact, explode upwards into a jump by moving off of the ground as fast as possible.
7.) Supplementary: Instruct the participants to maintain hip flexion position to deter from eccentric loading at the initial contact, by "pressing or punching the ground away." (See Appendix H for visual representation)

Training Interventions

Following the completion of pretest jumps, all participants completed an AEL back squat conditioning activity where each participant was informed of their prescribed loads for each working set. Assigned loads for the eccentric and concentric phases, height settings of the weight releasers, and box were provided before the warmup. Within the randomized groups, participants were paired according to the individual heights to allow for comfortable racking of the barbell. The prescription of loads included three warmup sets of traditionally loaded back squats: (1.) bar-only (6 reps), (2.) 30% 1RM (4 reps), (3.) 50% 1RM (4 reps), and (4.) 70% 1RM (2 reps). Following the intervention warmup, the inclusion of the weight releasers and eccentric overloaded working sets was conducted. The AEL intervention includes a constant concentric load of 60% 1RM through all working sets with a progressive increase of eccentric loads with each working set (95%, 105%, and 115%). Each working set involved the completion of three uninterrupted repetitions, with eccentric overload applied only during the first repetition's eccentric phase (Wagle et al., 2017). Duration of rest between sets were limited to five minutes, to be measured by a stopwatch upon completion of each set. Verbal instruction from the researcher notified 30 seconds & 10 seconds prior to the next set.

Data Analysis

To investigate the contributions of PAPE by jump condition x time interactions, three 3x5 ([CMJ, SJ, POJ]) x [pre-intervention, post 3 min, 6 min, 9 min, and 12 min]) repeated measures analysis of variances (ANOVA) were utilized (Heckstedena et al., 2018). Qualification of statistical significance was indicated with a priori alpha level of $p \leq 0.05$. Significant interactions of time and jump performance were followed by post-hoc (Bonferroni) analysis to determine specific differences between jump performance outcomes which included jump height (cm), net propulsive impulse (Ns) & peak relative propulsive power (W).

Jump Variables

Jump attempts were labeled by participant ID, with the best jump attempt used for analysis (one per jump type at each testing interval). Once all data had been accumulated and stored, it was exported to statistical analysis software (SPSS v28.0™) and assessed for normality and outliers via the Shapiro-Wilks Test. Jump attempts used for analysis were determined by the attempt with the greatest jump height achieved. Homogeneity of variances was assessed using Levene's test and sphericity of the data was assessed using Mauchly's test.

The determination of maximal vertical jump height is grounded in the principles of biomechanics and physics. By applying the impulse-momentum theorem, we can accurately quantify the vertical displacement during a jump (Sayers et al., 1999). This theorem posits that the change in momentum of a body is equal to the impulse applied to it, providing a robust foundation for analyzing jump mechanics. To ascertain the jump height, the athlete's takeoff velocity is pivotal. This velocity is derived from the athlete's mass and the net propulsive impulse exerted during the takeoff phase (Bovee, 2023). Jump height was found using the following equation: peak jump height = $\frac{1}{2} * (v^2 takeoff / g)$

The v^2 takeoff is the takeoff velocity and g is the acceleration due to gravity, 9.81 m/s^2 (Bobbert, 1996). This approach allows for a direct and precise measurement of vertical displacement. Net propulsive impulse (NPI) is a common variable used to assess the athlete’s ability to utilize the stretch-shortening cycle (SSC) through means of elastic energy and positive muscular work (Bovee, 2023). NPI was found at the termination of the (eccentric) braking phase until the final takeoff (force changes x duration) (Bovee, 2023). To calculate, the force gathered between zero velocity and the intersection of forces equivalent to body weight are obtained and displayed as Newtons per second (*N*s). Peak Relative Propulsive Power (PRPP) is a measure of the maximal power output relative to body weight during the propulsive phase. This metric is crucial for understanding an athlete’s ability to express peak force and velocity qualities, where the highest instant (peak) of combined force and velocity is produced external to the relative force of the individuals’ body mass (Sayers et al., 1999).

CHAPTER IV: RESULTS

Overview

The purpose of this study is to investigate the effects of accentuated eccentric loading (AEL) on post-activation performance enhancement (PAPE) on high school male basketball players. Evaluation of acute responses was achieved by force-time data recordings of three jump variations (countermovement, squat, and propulsive-only jumps), occurring prior to and following AEL interventions. Participants were randomly assigned to one of two groups, with one group performing countermovement jumps (CMJ) and the second group performing a combination of squat jumps (SJ) and propulsive-only jumps (POJ). A crossover design allowed both groups to encounter each variation of jump in a different order over two experimental sessions. Jump attempts prior to the AEL interventions (pre-) and post-intervention (3, 6, 9, and 12 minutes) were recorded, whereby the attempt with the greatest jump height at each interval was retained for data analysis. Dependent variables analyzed from each jump included jump height (JH), net propulsive impulse (NPI), and peak relative propulsive power (PRPP). Results from G*Power software revealed a minimum sample size of fifteen participants were required for a 3x5 crossover design, alpha level of 0.05, power level of 0.8, and effect size of 0.70.

The following chapter provides the statistical results and analysis used to assess the hypothesis included. Three separate two-way repeated measures ANOVAs were used to capture the within group x time interactions for each dependent variable. Assumptions testing, analysis of variances (ANOVA) outcomes, and post-hoc analysis are included following significant interaction or main effects. This chapter provides the research questions, null hypotheses, statistical outcomes of the data, and whether the null hypothesis was either rejected or accepted.

Research Questions

RQ1: Does exposure to supramaximal accentuated eccentric loaded back squats acutely enhance countermovement jump height to a greater degree than the squat jump and propulsive-only jump?

RQ2: What is the ideal "Potentiation Window" for the enhancement of jump performance following a supramaximal accentuated eccentric loaded back squats in high school male basketball players?

RQ3: Is there a difference in absolute and relative jump performance between the propulsive-only jump and the squat jump in the presence of post activation performance enhancement following supramaximal accentuated eccentric loaded back squats?

Null Hypotheses

$H_0$1: There is no statistically significant difference in acute performance enhancement when comparing CMJ just height performance to SJ and POJ performance following exposure of supramaximal AEL back squats in high school male basketball players**.**

$H_0$2: There is no statistically significant time course of PAPE in all jump variations following the exposure of supramaximal AEL back squats in high school male basketball players.

$H_0$3: There is no statistically significant difference in absolute and relative jump performance between the propulsive-only jump (POJ) and the squat jump (SJ) in the presence of PAPE following supramaximal AEL back squats.

Descriptive Statistics

Demographics

Participants included in the study were male athletes of a division 3A high school basketball team, located in eastern Iowa (*n* = 15). The average age of the sample group was 15.6 ± 1.1 years of age at the time of the study, with standard and parental consent agreements attained following the approval of Liberty University's Institutional Review Board (#FY22-23-1976). Table 4.1 provides the means and standard deviations of age, height, body mass, relative strength (body mass: 1RM back squat) and resistance training experience. All participants self-reported no prior use of weight, the propulsive-only jump (or seated jump derivatives), or the squat jump prior to this study.

Table 4.1
Population Descriptives and Familiarization Session Outcomes (n = 15)

	Mean	Std. Deviation
Age (yrs)	15.56	1.11
Height (cm)	182.01	7.13
Body Mass (kg)	78.32	19.63
Relative Strength (1RM:BM)	1.32	.30
Training Experience	1.32	.93
Back Squat 1RM (kg)	99.31	23.77

Descriptive Jump Outcomes

Descriptive statistics (Mean ± Standard Deviation) for each jump condition are provided in Table 4.2 – 4.4. Each table is organized by the dependent variable assessed (jump height, net propulsive impulse, and peak relative propulsive power) and the time that the outcome occurred (pre, 3 min, 6 min, 9 min, 12 min).

Table 4.2
Descriptive Statistics: Countermovement Jump (CMJ) Outcomes Over Time.

Variables	Time	Mean	SD
Jump Height (cm)	Pre	33.07	5.44
	3 mins	33.67	6.23
	6 mins	33.44	6.08
	9 mins	33.56	6.84
	12 mins	33.86	6.16
Net Propulsive Impulse (Ns)	Pre	199.68	40.66
	3 mins	200.21	40.26
	6 mins	199.68	39.47
	9 mins	200.19	39.22
	12 mins	200.46	38.38
Peak Relative Propulsive Power (W)	Pre	51.29	6.74
	3 mins	50.45	6.5
	6 mins	49.64	6.98
	9 mins	49.65	6.62
	12 mins	49.87	6.41

Table 4.3
Descriptive Statistics: Squat Jump (SJ) Outcomes Over Time.

Variables	Time	Mean	SD
Jump Height (cm)	Pre	26.21	7.02
	3 mins	25.40	7.28
	6 min	26.85	6.93
	9 min	27.18	7.73
	12 min	27.43	7.66
Net Propulsive Impulse (Ns)	Pre	175.84	38.12
	3 mins	172.54	35.68
	6 min	177.32	37.05
	9 min	177.13	38.0
	12 min	178.99	40.39
Peak Relative Propulsive Power (W)	Pre	46.68	8.60
	3 mins	46.42	8.97
	6 min	46.92	8.6
	9 min	47.02	9.23
	12 min	47.14	9.11

Table 4.4

Descriptive Statistics: Propulsive-Only Jump (POJ) Outcomes Over Time

Variables	Time	Mean	SD
Jump Height (cm)	Pre	31.59	8.64
	3 mins	30.38	8.47
	6 mins	32.75	10.02
	9 mins	35.19	8.75
	12 mins	34.27	8.68
Net Propulsive Impulse (Ns)	Pre	190.95	40.39
	3 mins	187.34	38.29
	6 mins	191.83	38.89
	9 mins	200.53	32.85
	12 mins	196.79	29.25
Peak Relative Propulsive Power (W)	Pre	47.36	9.45
	3 mins	46.22	9.41
	6 mins	47.99	10.39
	9 mins	49.92	8.86
	12 mins	48.96	9.19

Inferential Statistics

Assumption Testing

Countermovement jump (CMJ), squat jump (SJ), and propulsive-only jump (POJ) trial data were assessed through statistical analysis software (SPSS v28.0™) with statistical significance set at $p < 0.05$ for all analyses. Group x time data were gathered and organized by each dependent variable for further statistical analyses (jump height, net propulsive impulse, and peak relative propulsive power). Each dependent variable underwent the Shapiro-Wilks Test, revealing that net propulsive impulse and peak relative propulsive impulse data sets had no significant departures from normality ($p > .05$). However, jump height data did not exhibit any significant departures from normality except for one time interval (3 mins: $p = 0.028$). Given the singular deviation and low sample size ($n = 15$), analysis proceeded with original data using parametric analysis of variance using repeated measures. Levene's test was conducted to assess the assumption of homogeneity of variances across different conditions and time periods. The results of each dependent variable revealed no significant differences in error variances, as all *p*-values were greater than .05. Thus, indicating the assumption of equal error variances was met and unlikely to impact the results of the following analyses.

To assess sphericity of each of the data sets, Mauchley's Test of Sphericity was used to evaluate the following within-subjects effects. For jump height, the assumption of sphericity had not been violated for group (W = .728, $\chi^2_{(2)} = 4.133$, $p = .127$) or time (W = .476, $\chi^2_{(9)} = 9.207$, $p = .422$). The assumption of sphericity for group x time interaction for jump height had been violated (W = .005, $\chi^2_{(35)} = 58.435$, $p = .012$), resulting in the use of the Greenhouse-Geisser correction ($\varepsilon = .411$) to adjust the degrees of freedom for subsequent interpretations (Younsuk, 2015). Similarly, the assumption of sphericity for peak relative propulsive power had not been violated for group (W = .970, $\chi^2_{(2)} = .399$, $p = .819$) or time (W = .450, $\chi^2_{(9)} = 9.915$, $p = .362$), whereas the use of the Greenhouse-Geisser correction for degrees of freedom was used for the violated sphericity of group x time (W = .007, $\chi^2_{(35)} = 56.016$, $p = .020$; Greenhouse-Geisser correction ($\varepsilon = .406$). Net propulsive impulse data met the assumption sphericity for group (W = .728, $\chi^2_{(2)} = 4.132$, $p = .127$), time (W = .305, $\chi^2_{(9)} = 14.731$, $p = .101$), and group x time (W = .013, $\chi^2_{(35)} = 48.273$, $p = .088$). Effect sizes were interpreted using partial eta squared whereby the magnitude of the variances found were defined by a small effect size ($0.01 < \eta_p^2 < 0.06$), moderate effect size ($0.06 < \eta_p^2 < 0.14$), or large effect size ($0.14 < \eta_p^2$) (Richardson, 2011). In the current study with individuals of an average training experience of 1.3 ± .93 years, effects sizes of post-hoc analyses were assessed within the standard of "Recreationally Trained," where effect sizes are subjected as; trivial (< 0.35), small (0.35 – 0.80), moderate (0.80-1.50) and large (> 1.5) under guidelines provided for strength and conditioning research (Rhea, 2004).

$H_0$1: Countermovement Jump versus Squat Jump and Propulsive-Only Jump

The first hypothesis of this study proposed that countermovement jump (CMJ) jump height (cm) would reveal significantly different acute outcomes when compared to squat jump (SJ) and propulsive-only jump (POJ) following supramaximal AEL training intervention(s). Therefore, the null hypothesis states that no significant differences would be found between CMJ and SJ/POJ in the evaluation of jump heights (cm) occurring subsequently to the training interventions when compared to baseline (pre-intervention) values. To address the first hypothesis, a repeated-measures ANOVA to investigate group, time, and group x time variances was conducted to evaluate any significant differences in CMJ jump height when compared to SJ and POJ performance. To reject the null hypothesis, evidence of statistically significant differences must be identified for CMJ in contrast to both SJ and POJ outcomes from baseline, with an alpha level set at .05.

Jump height data underwent a 3x5 (condition x time) repeated-measures ANOVA, revealing a significant main effect for Time (F(4, 56) = 5.19, $p = .001$, $\eta_p^2 = .270$) with a large effect size, and a significant main effect for Condition (F(2, 28) = 24.34, $p < .001$, $\eta_p^2 = .635$) with a large effect size. Using the Greenhouse-Geiser correction, there were no significant Interaction effects (F (3.29, 46.05) = 1.65, $p = .188$, $\eta_p^2 = .105$). Although no significant interaction effects were found ($p = .188$), a moderate effect size was apparent ($\eta_p^2 = .105$) which may have been influenced by the lack of power from the limited sample size ($n = 15$). Post-hoc analysis using Bonferroni Corrections found significant increases in the POJ condition from pre- to post-intervention, the statistical outcomes are further defined by Mean Differences (MD) and Standard Error (SE) with Cohen's *d* effect sizes. Significant findings of potentiated performance for POJ were indicated from pre-intervention at 9 mins (MD) = 3.60, SE = 0.83, $p < 0.001$, d =

.48), as well as 3 mins to 9 mins (MD = 4.81, SE = 1.03, $p < .001$, $d = .64$) and 3 min to 12 min (MD = 2.68, SE = 1.25, $p = .035$, $d = .52$). All significant findings resulted in effect size magnitudes categorized as small. (Rhea, 2004). In similar terms, the propulsive only jump revealed a mean increase of +12.26% (± 13.65%) change from baseline to 9 minutes. Inferential analysis did not find statistically significant differences between 12 mins and pre-testing values for POJ, although an increase of +9.37% (± 17.83%) indicated potentiation may have been realized for only some of the participants. Nonsignificant statistical changes of jump height performance were found for both CMJ and SJ conditions. The first null hypothesis of this study states the absence of significant differences in jump height performance when comparing countermovement jump to squat jump and propulsive-only jump. Due to only one jump condition (propulsive-only jump) revealing potentiated performance following the intervention, the first null hypothesis can be rejected. Table 4.5 provides the mean ± standard deviation for jump height (cm) for each jump condition at each time interval assessed.

Table 4.5

Descriptives (M ± SD): Jump Height (cm) of Jump Conditions Over Time

	Pre	3-min	6-min	9-min	12-min
CMJ	33.07 ± 5.44	33.67 ± 6.23	33.44 ± 6.08	33.56 ± 5.84	33.86 ± 6.16
SJ	26.21 ± 7.02	25.40 ± 7.28	26.85 ± 6.93	27.18 ± 7.73	27.43 ± 7.66
POJ	31.59 ± 8.64	30.38 ± 8.47	32.75 ± 10.02	35.19 ± 8.75	34.27 ± 8.68

Table 4.6

Descriptives (Δ% ± SD)*: Jump Height (cm) Percent Change from Pre-Testing*

	3-min	6-min	9-min	12-min
CMJ	+1.59% (±6.74%)	+0.95% (±7.29%)	+1.49% (±7.62%)	+2.22% (±7.71%)
SJ	-2.68% (±14.53%)	+3.08% (±11.06%)	+3.83% (±12.87%)	+5.03% (±12.77%)
POJ	-3.12% (±13.16%)	+3.65% (±22.78%)	+12.26% (±13.65%)	+9.37% (±17.83%)

$H_0$2: Temporal Significance of Potentiation across Jump Conditions

The second hypothesis of this study states that there will be a significant increase in performance over a duration of time, to be displayed through one or more of the dependent variables (JH, NPI, and PRPP) in one or more jump conditions (CMJ, SJ and POJ) following an AEL intervention. To reject the null hypothesis, significant time or condition x time effects must be found through one or more of the dependent variables stated prior. To investigate the effects of time across all jump conditions, three separate 3x5 (condition x time) repeated-measures ANOVAs were used to evaluate changes in jump performance for each condition over time in relation to baseline (pre-intervention) values.

Jump Height

Jump Height findings are addressed in the prior section ($H_0$1), with a large main effect for time (F (4, 56) = 5.19, p = .001, η_p^2 = .270). Post-hoc analysis for time, with adjustments for multiple comparisons (Bonferroni) revealed a significant increase in overall jump height of the conditions (combined) from pre-intervention testing at 9 min (MD = 1.68, SE = .50, p = .047, d = .22) displaying a trivial effect. Differences from pre-intervention to 12 min were close to meeting statistical significance (MD = 1.56, SE = .58, p = .10) and revealed an effect size similar to that of shown at 9 min (d = .21) Significant differences from 3 min to 9 min (MD = 2.16, SE = .58, p = .022, d =.28) and 3 min to 12 min (MD = 2.03, SE = .58, p = .01, d = .27), likely associated to the acute onset of fatigue directly following the conditioning activity to the later testing intervals. Although, no significant deviations in performance from pre-intervention testing were revealed at 3 min (MD = - 0.47, SE = .49, p = 1.0, d = .06), 6 min (MD = .72, SE = .68, p = 1.0, d = .09). Results from jump height data signify the presence of potentiation occurring at 9 min post-intervention for the averages of all jump conditions when combined, with the propulsive-only jump (POJ) displaying the only significant changes at the individual condition level. See Graph 4.1 in Appendix K for visual representation.

Net Propulsive Impulse

Net propulsive impulse data underwent a 3x5 (condition x time) repeated-measures ANOVA, revealing a significant main effect for Time (F (4, 56) = 3.79, p = .008, = η_p^2 .213) with a large effect size. There was also a significant main effect for condition (F (2, 28) = 14.65, p < .001, η_p^2 = .511) with a large effect size. No significant interaction effects were observed (F (8, 112) = 1.58, p = .140, η_p^2 = .101) although a moderate effect size was presented. Post-hoc comparisons revealed significant mean differences in net propulsive impulse outcomes for the averages of all conditions between time intervals with a trivial effect size: 3 min to 9 min (MD = 5.92, SE = 1.24, p = .003, d = .15). No significant deviations from pre-intervention outcomes were found at 3 min (MD = -2.27, SE = 1.45, p = 1.0), 6 min (MD = .79, SE = 2.53, p = 1.0), 9 min (MD = 3.79, SE = 1.58, p = .31) , or 12 min (MD = 3.39, SE = 1.60, p = 1.0). Although no significant deviations were revealed from pre-intervention testing in the inferential analysis, all jump conditions revealed their greatest values at either 9 min or 12 mins following the intervention, such as CMJ at 12 min (200.46 ± 38.38), SJ at 12 min (178.99 ± 40.39), and POJ at 9 min (200.53 ± 32.85). These values are also be identified by their percentage of mean change (and standard deviation) from pre-testing values, as shown for CMJ at 12 min (+0.65% ± 3.85%), SJ at 12 min (+1.79% ± 6.81%), and POJ at 9 min (+5.69% ± 6.24%) and 12 min (+4.05% ± 8.39%). Table 4.7 provides the mean ± standard deviation of net propulsive impulse for each jump condition at each time interval assessed. See Graph 4.2 in Appendix K for visual representation. Table 4.8 provides the mean percentage change ± standard deviation (Δ% ± SD) from pre-intervention values of net propulsive impulse for each jump condition.

Table 4.7
Descriptives (M ± SD): Net Propulsive Impulse (Ns) of Jumps Conditions Over Time.

	Pre	3-min	6-min	9-min	12-min
CMJ (Ns)	199.68 ± 40.66	200.21 ± 40.26	199.68 ± 39.47	200.19 ± 39.22	200.46 ± 38.38
SJ (Ns)	175.84 ± 38.12	172.54 ± 35.68	177.32 ± 37.05	177.13 ± 38.0	178.99 ± 40.39
POJ (Ns)	190.95 ± 40.39	187.34 ± 38.29	191.83 ± 38.89	200.53 ± 32.85	196.79 ± 29.25

Table 4.8
Descriptives (Δ% ± SD)*: Net Propulsive Impulse (Ns) Percent Change from Pre-Testing.*

	3-min	6-min	9-min	12-min
CMJ	+0.32% (± 3.12%)	+0.13% (± 3.48%)	+0.42% (± 3.76%)	+0.65% (± 3.85%)
SJ	-1.54% (± 5.76%)	+1.22% (± 6.28%)	+0.95% (± 5.25%)	+1.79% (± 6.81%)
POJ	-1.84% (± 7.18%)	+0.97% (± 11.14%)	+5.69% (± 6.24%)	+4.05% (± 8.39%)

Peak Relative Propulsive Power

Peak relative propulsive power data underwent a 3x5 (condition x time) repeated-measures ANOVA, revealing nonsignificant main effects for condition (F (2, 28) – 2.91, p = .071, η_p^2 = .172), and nonsignificant main effects for time (F (4, 56) – 1.236, p = .306, η_p^2 = .081). There was also a nonsignificant condition x time interaction (F (3.25, 45.46) = 1.91, p = .137, η_p^2 = .12). Although no significant deviations were revealed from pre-intervention testing in the inferential analysis, the greatest propulsive power values (Mean ± Standard Deviation) were found at 9 min for POJ (49.92 ± 8.86), and at 12 min for SJ (47.14 ± 9.11), whereas CMJ revealed its best outcomes during pre-testing (51.29 ± 6.74). These values can also be identified by their percentage of mean change (and standard deviation) from pre-testing values, as shown for SJ at 12 min (+0.94% ± 6.35%) and POJ at 9 min (+5.97% ± 8.52%). Table 4.9 provides the mean ± standard deviation for peak relative propulsive power for each jump condition at each time interval. Graph 4.3 (Appendix K) for visual representation. Table 4.10 provides the mean percentage change ± standard deviation (Δ% ± SD) from pre-intervention values of NPI for each jump condition.

Table 4.9
Descriptives (M ± SD): Peak Relative Propulsive Power (W) of Jump Conditions Over Time

	Pre	3-min	6-min	9-min	12-min
CMJ (W)	51.29 ± 6.74	50.45 ± 6.5	49.64 ± 6.98	49.65 ± 6.62	49.87 ± 6.41
SJ (W)	46.68 ± 8.60	46.42 ± 8.97	46.92 ± 8.6	47.02 ± 9.23	47.14 ± 9.11
POJ (W)	47.36 ± 9.45	46.22 ± 9.41	47.99 ± 10.39	49.92 ± 8.86	48.96 ± 9.19

Table 4.10
Descriptives (Δ% ± SD)*: Peak Relative Propulsive Power (W) Percent Change from Pre-Testing*

	3-min	6-min	9-min	12-min
CMJ	-0.49% (±5.92%)	-3.21% (±5.29%)	-3.01% (±7.28%)	-2.68% (±4.37%)
SJ	-0.68% (±4.04%)	+0.61% (±6.82%)	+0.57% (±7.14%)	+0.94% (±6.35%)
POJ	-2.03% (±8.79%)	+1.40% (±12.97%)	+5.97% (±8.52%)	+3.70% (±9.76%)

The findings of the three dependent variables for each jump type over time suggest that CMJ and SJ did not reveal any statistically significant changes in jump performance in respect to jump height, net propulsive impulse or peak relative propulsive power. However, the POJ condition did reveal significant positive enhancements in jump height performance at the 9 min in comparison to pretesting values. Although the POJ condition was the only condition that revealed statistically significant changes, the averages of combined jump conditions at each interval did reveal significant changes from pre-testing to 9 mins for jump height (MD = 2.16 SE = .58, p = .022), at 9 mins for combined net propulsive impulse (MD = 5.92, SE = 1.24, p = .003). As a result of two of the three dependent variables eliciting significant increases in jump height and net propulsive impulse, with significant finding for one of the three conditions at 9 minutes, it is clear that a window of potentiated performance enhancement was realized at 9 minutes and the null hypothesis stating no significant time effects would be presented among the conditions can be rejected.

$H_0$3: Propulsive-Only Jump & Squat Jump Comparison

The third null hypothesis of this study states that no statistically significant differences in performance characteristics (jump height, net propulsive impulse, or peak relative propulsive power) would be evident between the squat jump (SJ) and the propulsive-only jump (POJ). As previously described, POJ was the only jump condition that revealed statistically significant differences in jump height performance following the training intervention. Post-hoc analysis assessing the overall marginal means of each condition found statistically significant differences between POJ and SJ for multiple dependent variables. POJ displayed a higher average jump height (MD = 6.22, SE = 1.09, $p < .001$, d = 0.83) with moderate effect size, higher average net propulsive impulse (MD = 17.12, SE = 4.52, p = .006, d = .44) with a small effect size, but did not significantly differ in peak relative propulsive power (MD = 1.25, SE = 1.29, p = 1.0). Although statistically significant evidence was found between the mean scores for each condition across all time points, the primary focus of the third null hypothesis states non-significant differences between the conditions in the presence of a postactivation performance enhancement (PAPE) effect.

Pairwise comparisons assessing the mean difference (MD) and standard deviations (SD) were conducted using Bonferroni corrections. No significant differences in peak relative propulsive power were observed between the two conditions at pre-intervention testing (MD = .67, SE = 1.71, $p = 1.0$), 3 min (MD = .20, SE = 1.98, $p = 1.0$) , 6 min (MD = 1.08, SE = 1.93, $p = 1.0$), 9 min (MD = 2.90, SE 1.63, $p = .291$), or 12 min (MD = 1.82, SE = 1.81, $p = 1.0$). Net propulsive impulse outcomes did reveal many significant differences between the two conditions where POJ consistency displayed greater values at pre-testing (MD = 15.11, SE = 5.30, $p = .039$), 9 min (MD = 21.47, SE = 3.35, $p < .001$), and 12 min (MD = 17.8, SE = 5.97, $p = .030$). Nonsignificant difference in propulsive impulse values were shown at 3 min (MD = 14.80, SE = 5.82, $p = .07$) and 6 min time interval (MD = 15.51, SE = 6.7, $p = .144$). Jump height outcomes showed significant differences between POJ and SJ at every time interval except at 3 min (MD = 4.99, SE = 1.94, $p = .067$). Differences between the jump conditions were seen at pre-intervention (MD = 5.38, SE =1.71, $p = .02$), 6 min (MD = 5.90, SE = 1.80, $p = .016$, 9 min (MD = 8.01, SE = 1.44, $p < .001$) and 12 min (MD = 6.84, SE = 1.86, $p = .008$), respectively. The overarching evidence reveals significant differences in mean values associated with the squat jump (SJ) and the propulsive-only jump (POJ) across all time intervals for jump height (JH) and net propulsive impulse (NPI). In the context of these differences in average outcomes, there were nonsignificant differences between the two conditions at 3 min and 6 min for net propulsive impulse and insignificant differences found at 3 min for jump height. The absence of significant evidence at these time points likely indicates an onset of acute fatigue followed by a potentiation effect depicted by one condition (POJ) at the 9 min testing interval. Due to the evidence of potentiated performance of the POJ condition and no significant changes found in the SJ condition, the final null hypotheses stating that no significant difference between the POJ and SJ conditions during post-testing can be rejected.

Summary of Findings

Statistical findings to address each of the three research questions were addressed where significant changes from baseline values for the POJ condition (jump height) were evident at 9 min post-intervention from pre-intervention values. Limited deviations from pre-intervention values were found for the CMJ or SJ conditions in the dependent variables analyzed, although mean differences in jump height and net propulsive impulse expressed their highest values during the 12-min testing interval. The addition of percentage change from pre-intervention (Δ%) offered an alternate insight into the changes occurring in the small participant group assessed and the variable capabilities of the individuals within the group. Comparisons between the SJ and POJ conditions indicated consistent statistical mean differences between time intervals except at 3 min and 6 min for jump height and net propulsive impulse. Potentiated jump height outcomes for the POJ condition, coupled with nonsignificant changes in SJ occurring in the initial post-testing intervals (3 min & 6 min) may insinuate that unique characteristics found in the propulsive-only jump were responsible for the incline in performance.

CHAPTER V: CONCLUSIONS

Overview

The research undertaken in this study provides pivotal insights into the effects of accentuated eccentric loading (AEL) on post-activation performance enhancement (PAPE) in high school male basketball players. It particularly focuses on the differential impact of AEL on various jump types: countermovement jump (CMJ), squat jump (SJ), and propulsive-only jump (POJ). This chapter aims to delve deeply into the findings, linking them with existing literature and theoretical frameworks, to draw comprehensive conclusions and implications for sports performance and training.

Discussion

The primary purpose of this dissertation was to investigate the acute effects of accentuated eccentric loading on high school male basketball players, with the intent to induce a post-activation performance enhancement (PAPE) effect through varying jump conditions. The study's crossover design enabled the participants to be assessed for propulsive metrics during the countermovement jump, squat jump, and propulsive-only jump conditions prior to and following the AEL training intervention (pre, 3 min, 6 min, 9 min, and 12 min). Jump performance characteristics for each jump condition were compared for unique changes over time, involving jump height (JH), net propulsive impulse (NPI), and peak relative propulsive power (PRPP).

To the author's knowledge, this is the first study to explore the acute responses to supramaximal accentuated eccentric loading with youth athletes at the high school level. The outcomes of the study revealed modest changes in performance enhancement in the propulsive-only jump (POJ), whereas no statistically significant changes (positive or negative) were found for either the countermovement jump (CMJ) or the squat jump (SJ). Of the three variables assessed for each condition, jump height (JH) was the primary measurement eliciting statistically significant increases from pre-testing, which occurred at 9 mins, as well as 3 min to 9 min for POJ condition only. In the assessment of net propulsive impulse (NPI), significant changes at 9 min compared to 3 min post-intervention were found in the POJ condition as well. Comparison of pre-intervention values to the 3 min time interval for all variables were not statistically different for any of the variables, noting that the changes from 3 min to 9 min (JH and NPI in the POJ condition) was attributed to fatigue from the AEL intervention. In contrast, increased jump height performance found at 9 mins embodies a clear observance of performance enhancement when evaluating changes from baseline values as well as the temporal significances of peak net propulsive impulse and peak relative propulsive power values attained during the same 9 min and subsequent 12 min testing intervals.

Youth Athletes & AEL

The implementation of supramaximal accentuated eccentric loading (AEL) continues to be of large interest for researchers and practitioners within the strength and conditioning field. In the current body of literature, the integration of AEL methods and youth athletes have been limited to the use of submaximal loading prescriptions (Bright et al., 2023; Lloyd et al., 2021), due to reasonable variables such as pacing strategies and potential muscle-activation abilities to ensure the safety of the athlete (Bright et al., 2023; Merrigan et al., 2022). The most common variables believed to contraindicate the use of supramaximal AEL with the youth athletes used in this study is the presence of a low training age, with presumable low level of relative strength to properly perform said modalities due to minimal physiological and neuromuscular development from limited resistance training exposure.

Prior to the study, the level of resistance training experience and relative strength values of this participant sample were unknown to the researcher. In effect, prescribed loading percentages were conservatively adjusted, where the eccentric loads equated to 95%, 105%, and 115% of concentric 1RM values, whereas studies including adult populations commonly use up to 120% during the eccentric phase and 30-90% 1RM during the subsequent concentric phases, respectively (Lates et al., 2022; Merrigan et al., 2020; Taber et al., 2023; Tseng et al., 2021; Wagle et al., 2018). The concentric loads used across all working sets in this investigation were held to 60%, whereas many studies utilized concentric loads of 80% with adult populations (Tseng et al., 2021; Wagle et al., 2018). Situated as the first study exploring supramaximal AEL loading with youth populations, the researcher believed it was in the best interest of the participants to implement a more conservative approach in load management to promote the safest environment. Furthermore, Tseng and colleagues (2021) provide the most similar investigation relating to the use of AEL to induce a post-activation performance enhancement effect. Their study included elite male volleyball players with a an older participant group (age: 18-25 years old) in comparison to the current study (ages: 15-18 years old & only one 18-year-old participant). Their investigation compared a traditional resistance condition (non-varying: 85% of 1RM) and an AEL group undertaking three sets of four repetitions of 105% concentric 1RM during the eccentric followed by 80% on the concentric phase (Tseng et al., 2021). This study also evaluated countermovement jump (CMJ) but found that the AEL group did not improve its performance over their chosen time periods (10 min, 24 hrs, and 48 hrs post-interventions). Most notably, each repetition in the AEL condition (3 sets x 4 reps) utilized the weight releaser and were manually reset onto the barbell for each working repetition performed. Although higher eccentric loading (95%, 105%, & 115% eccentric loading) were used in the current study, only the first repetition of each working set encountered the eccentric overload stimuli whereby the following repetitions were completed with non-varying loads (60% of 1RM for eccentric and concentric phases). The rationale for prescribing higher loading with a reduced overall mechanical volume was aimed at minimizing the total demand from supramaximal loading to reduce or minimize fatigue. This loading approach is supported by evidence indicating that enhanced eccentric and concentric velocities can be observed in subsequent repetitions within the working set following the first AEL repetition (Lates et al., 2022; Wagle et al., 2018). The findings of this study revealed no significant decreases in performance when assessing pre-intervention values to the most immediate – 3 min testing interval. The absence of significant declines in performance may be attributed by a number of factors such as: training intensity (load percentages, number of repetitions encountering the EOL, length of rest times between sets) (Wagle et al., 2017), time duration or tempo control of the eccentric phase during the first AEL repetition (Suchomel et al., 2019a & b), and difficulty of finding significant deviations from lower average values (jump height, impulse, power) found in this population. In conclusion, future research may benefit from increasing the intensity in the form of the concentric loads (from 60% to 70%) or by substituting the first working set (95% of concentric 1RM) to match the second working set of 105%. Future research should also explore similar loading prescription for this population group while controlling for time duration and/or tempo of the eccentric phase during the conditioning activity.

Performance Potentiation

The present study involved two experimental sessions which were identical in loading prescriptions for each individual based upon the maximum strength (1-repetition-maximum for eccentric-concentric loading) values attained during the familiarization session. The initial back squat 1RM values achieved (99.3 ± 27.75 kg) in relation to each individual's body mass (78.32 ± 30.31) revealed an average relative strength ratio of 1.32 ± 0.3.

Contextual understanding of these relative strength levels is particularly important as current evidence indicates that individuals with greater relative strength have a greater likelihood of revealing a PAPE effect and to a greater degree to those with lower strength (Merrigan et al., 2021). Categorical levels of strength, relating the AEL variables and back squat, have been divided into two categories for application measures in a narrative review by Merrigan and colleagues (2022), (weaker = < 2 x BM, stronger = > 2 x BM). The participant sample in this study had a relative strength ratio of 1.32 ± 0.3, placing them in the weaker range of relative strength numbers. This suggested that the recognition or manifestation of potentiation effects might have been less distinct than in those with higher relative strength levels (Seitz et al., 2014) Alongside the clear evidence showing increased probability of more pronounced PAPE effects occurring with stronger individuals, it has also been shown that the efficacy of the concentric phase during the AEL movement (following the overloaded eccentric phase) is dependent on the relative strength in accordance with a potentiation effect on the subsequent concentric phase (Merrigan et al., 2020). These guidelines of relative strength and performance potentiation have been well-established in literature regarding traditional training methods (Seitz et al., 2014, Seitz & Haff, 2016).

Current AEL research narratives have recommended that individuals with lower relative strength levels should primarily use submaximal loading (Merrigan et al., 2021, Suchomel et al., 2019a & b) due to the concept of untrained individuals (athletes who have lower training ages or relative strength) having a lower susceptibility to maximize force production to properly pace the lowering of the additional eccentric loads (Seitz et al., 2014, Merrigan et al., 2020 & 2021). It has been stated that untrained individuals may have the tendency to alter the eccentric pacing strategy by lengthening the duration (slower velocity) to manage the excessive loading that would otherwise aid in the potentiation of subsequent concentric phase (Seitz et al., 2014, Suchomel et al., 2016). In the current study, verbal communication to participants was provided to execute normal temporal eccentric duration to that of their non-varying loads used in preparation of the intervention, although the velocity of the movement was not explicitly gathered or assessed in this current study. Prior to this study, implementing supramaximal accentuated eccentrics was not suggested for the use of the subject population's characteristics (low training age and relative strength), although no prior investigations had been directly conducted to support or deny the use of this modality with the youth athletes. The lack of significant performance decrements following the use of supramaximal loads may revive future conversations for the supplemental use of supramaximal accentuated eccentrics and youth moving forward. Modest evidence for potentiated performance was found in the POJ condition with peak performances for the squat jump and countermovement jump occurring at 12 mins and 9 min, respectively. These findings of potentiation around the 9-12 min post-intervention timeline are within the current guidelines for the relative strength and training age of past research involving other resistance training methods and youth athletes (Beato et al., 2021b, Dobbs et al., 2019).

Flywheel Inertial Training Comparison

In the context of youth athletes and the implementation of eccentric overload resistance training modalities, flywheel inertial training has consistently been at the forefront of research interest with similar findings to those of this study. Beato and colleagues (2021a) conducted a similar study assessing acute potentiation to flywheel inertial training (FIT) using varying FIT training protocols to induce PAPE effects through CMJ performances (*n* = 12). Their findings indicated performance increase in CMJ peak power and jump height at an earlier time range at 3 min and 6 min post intervention. The timeline of potentiation found for their study indicated an earlier and larger window of potentiation at 3 min and 6 min for jump height, whereas this investigation did not reveal potentiation until 9 mins for jump height in only the propulsive-only jump (POJ) condition. Potential reasons for these differences may include the different training intervention acting as the conditioning activity (FIT vs. AEL) and the significant differences in participant biological ages in this study (21 ± 3 years old) which is commonly accompanied with greater relative strength and training experience (not directly stated in the study) to showcase PAP/PAPE responses at an earlier window of potentiation and to a greater magnitude (Merrigan et al., 2020, Seitz et al., 2014).

Similarly, Beato and Colleagues (2019a) compared the effects of traditional loading and flywheel inertial training to induce a PAPE effect in the CMJ, showing that both methods did not significantly differ in the magnitude of potentiation with a window of performance enhancement occurring between 3 min and 7 min. The participants of that study included ten males (age = 22 ± 2 years) with at least four years of heavy resistance training experience at the regional level. In the assessment of a more comparable population to that of this study (age = 20.2 ± 1.4 years), potentiation of CMJ jump height, impulse, and peak power at 3 min, 5 min, 7 min, and 9 min was found following a FIT intervention (Beato et al., 2019b). The inertial training protocols included in three sets of six half squats with maximal effort recorded. The large window of potentiation in CMJ performance, with almost identical jump metrics to that of the current study, promotes the need for further attention directed at the establishment of loading procedures for the youth participant group. Unfortunately, comparisons between the use of the prescribed accentuated eccentric loading cannot be compared with the estimated inertia of 0.0011 $kg \cdot m^{-2}$, as multiple factors of the FIT are contingent on the participants ability to impose concentric output to overload the subsequent eccentric phase in the next repetition. In conclusion, flywheel inertia interventions have been thoroughly evaluated for their efficacy to provide a sufficient stimulus as a conditioning activity for the induction of a PAPE effect. FIT and AEL may be categorized together into the eccentric overload (EOL) categorization but provide significantly different imposed demands. Comparisons found from the host of studies completed by Beato and colleagues (2019, 2021a & b) indicate the significance of the eccentric modalities to induce PAP and PAPE, with most research in the topic area has been directed towards FIT and PAPE.

Propulsive-Only Jump

In the current study, the propulsive only jump (POJ) was the only jump condition revealing a significant change in performance enhancement over a specific time duration, occurring at the 9 min time interval. The evidence of improved jump height in the POJ condition does present the possibility of a PAPE effect. The acute improvement seen in any novel dynamic movement pattern, such as the propulsive-only jump (POJ), should be cautiously analyzed to delineate if enhancements to the activity is due to increase in movement efficiency or if potentiation did occur (Hu et al., 2021). The causal factors for the enhancements cannot be clearly directed by any improvement of motor-skill development or if a potentiation effect did occur from the AEL conditioning activity. In theory, if the increase found in jump height performance had not been a result of a potentiating effect, it could be presumed to be a result of improved movement efficiency or improvement in task strategy (Hu et al., 2021). Within the rationale of increased motor efficiency or coordination of movement, one would expect improvements to be found at the 12 min testing interval as well. However, no significant deviations from pre-testing values were observed outside of the 9 min testing time.

The novel propulsive-only jump (POJ) was not the only newly acquainted jump assessment to this participant group. All participants revealed no prior experience testing or performing the squat jump (SJ) prior to this study. Given the lack of prior experience with both the POJ and the SJ, the observed improvements in the POJ without corresponding changes in the SJ raise additional questions about the differences in their propulsive outputs.

One theory for the enhancement found in POJ and not for CMJ or SJ lies in the absence of the eccentric loading and the preloading that occurs for the CMJ and SJ at different magnitudes. Although the POJ does involve a level of pre-engagement prior to the individual contacting the ground, there is a possibility that the absence of prior eccentric loading found in the CMJ, and isometric holding found in the SJ, may provide the POJ with an energetic advantage due to a reduction of total work performed prior to the concentric actions to deter additional fatigue in showcasing the performance enhancements. One may reason that potentiation dissipated following the 9 min testing interval that revealed a PAPE effect occurring in the small window of time.

The average jump height outcomes for the POJ condition did not significantly differ from either the CMJ (MD = .68 ± 2.57, $p = 1.0$) or the SJ (MD = 6.22 ± 2.57, $p = 0.6$). Whereas the average outcome between CMJ and SJ were notably significant (MD = 6.9 ± 2.57, $p = 0.031$). Jump height outcomes between the POJ and CMJ were remarkably similar in total displacement with the SJ displaying inferior absolute outcomes. Surprisingly, peak displacement outcomes (jump height) attained over all jump conditions with was led by POJ at 9 min (MD = 35.29 ± 1.95), followed by POJ at 12 min (MD = 34.27 ± 1.95), and the CMJ taking the third highest jump at any interval of time for its performance at 12 min (MD = 33.86 ± 1.95). The high-performance markers found with the propulsive-only jump were unexpected, given no pilot studies were performed, as the use of the stretch-shortening cycle to potentiate the concentric performance was unable to be utilized. Due to the novelty of the jump assessment, normative data to comprise further comparisons between this participant group and other populations is still necessary to gain full understanding of the values. However, the potentiation found in the POJ does bring to question the positive contributions associated with the elimination of pre-loading prior to propulsive actions, as seen in the squat jump assessment.

The enhanced performance observed in the POJ condition, specifically the +12.26% increase in jump height at 9 minutes post-AEL intervention, is a significant finding that offers a new perspective on the effects of eccentric loading during resistance training. This result is particularly striking when compared to previous research, where Tseng et al. (2021) reported more modest improvements in other assessments (isometric midthigh pull) following similar training interventions with limited to no apparent changes found in jump performances, specifically the countermovement jump and the spike jump assessment. The pronounced response in our study suggests that the POJ's specific characteristics, notably its minimization of preloading and eccentric contribution, may facilitate a more transparent manifestation of PAPE.

The importance of this finding becomes clearer when contextualized within existing literature. Tseng et al. (2021) and Ojasto & Häkkinen (2009) have both emphasized the time-dependent nature of PAPE within the context of supramaximal eccentric loading procedures. Our results resonate with this concept, suggesting that the effects of AEL are not immediate but emerge significantly after a certain period – in this case, 9 minutes post-intervention. This delay aligns with the physiological mechanisms at play during PAPE, where a balance between fatigue and potentiation determines the optimal time for enhanced performance. Beato et al. (2019b) and Merrigan et al. (2021) have previously observed similar patterns in lower limb power enhancement post eccentric overloading, reinforcing the notion that timing is a critical factor in realizing the acute benefits of eccentric training.

The study's findings also raise interesting questions about the biomechanical and neuromuscular aspects of different jump types and their responses to AEL. The CMJ and SJ, while integral to athletic performance, did not show significant improvements post-AEL intervention in our study. Wallace et al. (2008) noted the complexity of neuromuscular coordination involved in these jumps, which may explain their differing response compared to the POJ. The CMJ, for instance, relies heavily on the stretch-shortening cycle (SSC), where both eccentric and concentric muscle actions are crucial for performance and the resultant increase in propulsive outcomes (Bosco et al., 1982; Komi, 2000). The SJ, similarly, involves a preloading phase that masks or dilutes the potentiation effects observed in a purely concentric movement like the POJ (Aura & Komi, 1986). Potential reasoning for the greater improvements found in the POJ condition could be explained by the developmental limitations of adolescent or youth athletes to utilize the stretch-shortening cycle (SSC) to their full potential when compared to adults (Radnor et al., 2018). The impact of the SSC is evident where the CMJ is capable of performance outcomes to those of the squat jump where an implicit movement-phase segmentation is performed to decrease the contribution of the SSC (Bobbert et al., 1996).

Compelling evidence suggests that the development of musculature and neuromuscular abilities significantly influence young male athletes, particularly in tasks like maximal rebound jumping (Radnor et al., 2021). These physiological and neurophysiological elements are further developed through natural maturation, increased resistance training exposure, and sport-specific stressors. The absence of the SSC encountered in the propulsive-only jump may dispose the limitations of young athletes and help to display the potentiation qualities associated thereafter.

It must be noted that the practicality of a propulsive-only assessment is inherently limited to the absence of the stretch-shortening cycle that is rarely, if ever, found in real-world applications in sport. The utilization of this exercise has been programmed and implemented at all levels of sport-preparations without thorough evaluations for its potential as a suitable stimulus for specified adaptations. Implementation of the findings gained from that the POJ may benefit practitioners in understanding the value of isolating concentric actions with potential to improve movement efficiency and neuromuscular engagement, commonly observed as a hindrance to younger male athletes' abilities to fully utilize their stretch-shortening cycle contributions during jumping actions (Radnor et al., 2021).

Implications

This study's findings not only contribute significantly to the academic understanding of accentuated eccentric loading (AEL) and post-activation performance enhancement (PAPE) but also have profound practical implications for athletic training, especially in youth sports. The unique insights into the effects of AEL on different jump types in high school male basketball players bridge a crucial gap between theoretical knowledge and its application in real-world training scenarios.

Accentuated Eccentrics and Youth Athletes

The study challenges and expands the existing understanding of eccentric loading for youth athletes. The observed effectiveness of AEL in enhancing propulsive metrics, particularly in a concentric-focused task like the POJ, points to the need for a nuanced approach in incorporating eccentric loading techniques in sports training. It emphasizes the potential of specific training exercises and assessments, such as the POJ, to maximize the effects of eccentric loading in improving athletic performance and as use as a tool to evaluate performance or readiness in the field and in research. The practical application of supramaximal loading procurement should be examined and determined with caution. Resistance training for sport performance enhancement is a supplemental tool to induce a novel stimulus. As an advanced tool, the use of supramaximal loading should be implemented with multiple familiarization sessions to ensure the proper adaptations and proper control of the increased load prescription is used appropriately. Therefore, it is suggested that the implementation of AEL with weight releasers would benefit from the use of sub-maximal load (eccentric load > 100%) to gain familiarity, reduce the likelihood of biomechanical changes to the movement pattern, and create a psychological "buy-in" from the athletes.

Temporal PAPE Profile

The time-dependent nature of PAPE observed in this study - notably, the significant enhancement in performance at 9 minutes post-intervention - has important implications for the design of training regimens. Coaches and athletes need to consider the optimal timing for exercise execution following eccentric loading to harness the full benefits of PAPE. This insight is vital for optimizing training schedules and could lead to more effective training strategies that enhance performance on the court or field. As stated previously, the significant increase in dynamic movement (> +10%) can be the deciding factor between player outcomes such as blocking a shot, retrieving a rebound over a defender, or an attempted layup that has the slightest advantage can be the difference between winning and losing a game. Final outcomes of many sporting events are either won or lost in the matter of a few percentages in difference. The potential of increased performance for a jumping activity that is commonly seen in the game of basketball could serve as the differentiator between winning or losing.

Propulsive-Only Jump

The pronounced increase in jump height in the propulsive-only jump (POJ) condition underscores the importance of customizing training approaches to the developmental stage of athletes. The results suggest that young athletes, who may not fully utilize the stretch-shortening cycle (SSC) as effectively as adults, can benefit from training modalities that focus on concentric action, like the POJ. This finding is instrumental for coaches and trainers in designing training programs that are not only effective but also appropriate for the developmental stage of youth athletes. The study's focus on specific jump types and their response to AEL highlights the need to broaden the range of performance metrics used in athletic training. While traditional metrics like the countermovement jump (CMJ) and squat jump (SJ) are integral, incorporating and understanding the impact of different types of jumps can provide a more comprehensive view of an athlete's abilities and the effectiveness of training methods.

Practical Applications

Provisions of a robust framework to practically apply supramaximal AEL with youth athletes may not be sufficiently supported through the outcomes of a singular study. Therefore, the following recommendations should be evaluated on an individual basis to address the desired adaptations and the capabilities of the individual exposed to the stimulus.

Submaximal AEL training with youth athletes have garnered promising evidence in the enhancement of subsequent concentric performances with jumping or plyometric actions (Llyod et al., 2021). It is suggested that the incorporation of AEL training with any population should first be introduced via submaximal loading to gain familiarity and comfort with the unique demands. Familiarization sessions for all EOL loading magnitudes (submaximal, maximal, and supramaximal) are stated to receive the best results (superior concentric performance) when a minimum of three familiarization sessions have been programmed (Bright et al., 2023). As a result, it is suggested to incorporate three familiarization sessions utilizing submaximal eccentric loads with maximal loading to occur once the confidence of the athlete and coaching staff have deemed the athlete's ability to control the eccentric loads without the incorporation of additional pacing strategies. In contrast, future research may need to evaluate longer eccentric durations with AEL, with expectations of diminished subsequent concentric outputs, with intent to induce a PAP/PAPE effect post-exercise.

Due to the dependency of intra-repetition concentric potentiation to be evoked as a result of the concentric loading in comparison to the eccentric loading (Merrigan et al., 2020), it is thereby recommended that maximal and supramaximal eccentric loading should be accompanied by the concentric phase with low to moderate loads (50% - 70% of 1RM) in the quest for improvements in concentric power (Merrigan et al., 2021). The current study progressed eccentric loads up to 115% of concentric 1RM values on the last working set (3 total) and revealed no significant negative deviations from pre-testing values, suggesting that this loading magnitude (115% of 1RM) may be sufficient in this population without significant decline in acute performance following. Due to the higher magnitude of loading and higher potential of delayed onset of muscle soreness (Ojasto & Hakkinen, 2009), strength and conditioning practitioners are encouraged to introduce the initial familiarization period during the off-season training period to ensure proper acclimatization of the novel stimulus can be attained.

Limitations

This study is not without its own limitations. The first limitation of this study is the possibility that the athletes encountered external physiological stressors, in the form of resistance training and/or physical education activities, concurrently throughout the duration of the study. A result of additional resistance training performed outside of the constraints of this study places unknown levels of physiological and neurophysiological fatigue which could hinder the results during testing, including the dissipation of fatigue in order to see potentiation in performance (Blazevich & Babault, 2019). All participants were instructed before the start of the study and at each session to avoid any additional sport-specific or resistance training until the study was completed. Additionally, it must be noted that there were no significant deficits in performance outcomes at and beyond 6 minutes post-intervention. It must also be noted that the implementation of this study occurred approximately 72 hours after the final playoff game of the American football season ended. The timing of this study may or may not have provided sufficient time for recovery for the athletes involved, where twelve of the fifteen participants were on the roster of both the football and basketball teams.

Another limitation is the room temperature at which the intervention and testing occurred. The facility used in this study was unable to provide access to temperature controls in the space provided. Anecdotally speaking, no significant changes in room temperature were observed although there is an absence of evidence to show otherwise. However, an increase in muscle temperature is believed to be a potential contributor in outcomes of potentiated performance (Blazevich & Babault, 2019). Theoretically, an increase or decrease in a temperature-controlled environment could influence the contractile performance at the muscular level (Blazevich & Babault, 2019).

Another potential limitation of this study is the use of a singular familiarization session followed by two experimental sessions. Current literature expresses the need for youth athletes to complete a minimum of three familiarization sessions when using eccentric overload (EOL) modalities such as flywheel inertial training (FIT) & plyometric-accentuated eccentrics (Bright et al., 2023). By association to these modes of training, accentuated eccentric loading may be considered within these guidelines due to the unaccustomed loading imposed on individuals with low training experiences and relative strength measures. Therefore, the use of the singular familiarization session may be seen as a limitation in the present study due to the potential for insufficient skill-development in assessing potentiation qualities while controlling for strategic changes.

Recommendations for Future Research

In the future, research involving accentuated eccentric loading and youth populations should further address loading prescriptions, phase durations, chronic adaptions, and the use of submaximal versus supramaximal eccentric loads to dispel the most advantageous use of this training modality for this population. In prior AEL research, it had been highly suggested that the use of supramaximal loading would not be beneficial for youth populations of lower training ages and/or lower relative strength levels. In agreement with the surrounding literature, the investigator believes that AEL training using supramaximal loading strategies is a highly advanced training method, which is to be implemented with caution to address the needs of the individual athlete. This study provided evidence showing the use of this advanced modality with athletes of minimal training experience and lower relative strength, resulting in no declines in immediate performance outcomes with some evidence indicating acute performance enhancement. It is suggested that future research explores the following areas.

Generalizability and Demographic Specificity

The study's participant pool, confined to high school male basketball players, limits the generalizability of the findings. This demographic specificity raises questions about the applicability of the results to other populations, including female athletes, athletes from other sports, older or younger athletes, and those at different levels of physical conditioning or skill. Future research should consider a more diverse sample, incorporating varying age groups, genders, sports disciplines, and skill levels. This expansion would not only enhance the generalizability of the findings but also provide a deeper understanding of how different populations uniquely respond to AEL.

Longitudinal Impact and Chronic Effects

The scope of this study was restricted to the immediate, short-term effects of AEL. However, the long-term implications of consistent AEL training on athletic performance, skill development, and injury prevention remain unclear. Longitudinal studies, spanning months or even years, are essential to assess the chronic impacts of AEL. Such research could explore adaptations in muscle morphology, changes in neuromuscular efficiency, long-term injury rates, and potential shifts in athletic performance parameters over time. Additionally, examining how AEL integrates into periodized training programs would offer practical insights for coaches and athletes.

Psychological and Subjective Response Analysis

The psychological and subjective responses to AEL training were not addressed in our study. Athletes' perceptions of exertion, training satisfaction, and mental readiness are critical aspects that can influence training outcomes. Future research should consider these subjective measures to understand the holistic impact of AEL on athletes' training experience. This could involve qualitative approaches, such as interviews or focus groups, or the use of standardized questionnaires to assess training load perception, fatigue, and motivation levels.

Control of External Variables

While efforts were made to standardize conditions, external variables such as diet, sleep quality, and daily stress levels, which can significantly impact performance, were not controlled. Subsequent studies could aim to monitor and control these factors more rigorously or at least account for them in the analysis to reduce external noise in the data.

Comparative Studies with Other Training Modalities

The study was limited to AEL as the primary intervention. Comparative studies that juxtapose AEL with other training modalities, such as traditional resistance training, plyometrics, or other forms of eccentric overload training, could yield valuable insights. Such comparative analyses would help in delineating the unique benefits or drawbacks of AEL over other established training methods such as FIT, and submaximal AEL vs supramaximal AEL.

Propulsive-Only Jump

This is the first study to the author’s awareness that includes the use of a seated jump variation with the intent of evaluating performance markers. It is recommended that future research explores the validity and reliability of the propulsive-only jump (POJ) as a training modality and for its potential as a standardized assessment. Also, future insights into the acute and chronic adaptations that may occur with the formalized use within training programs.

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APPENDICES

Appendix A: IRB Approval Letter

LIBERTY UNIVERSITY
INSTITUTIONAL REVIEW BOARD

August 14, 2023

John Ditch
Justin Kilian

Re: IRB Approval - IRB-FY22-23-1476 Acute Potentiation on Vertical Jump Performance Following Accentuated Eccentric Loaded Back Squats in Male High School Basketball Players

Dear John Ditch, Justin Kilian,

We are pleased to inform you that your study has been approved by the Liberty University Institutional Review Board (IRB). This approval is extended to you for one year from the following date: August 14, 2023. If you need to make changes to the methodology as it pertains to human subjects, you must submit a modification to the IRB. Modifications can be completed through your Cayuse IRB account.

Your study falls under the expedited review category (45 CFR 46.110), which is applicable to specific, minimal risk studies and minor changes to approved studies for the following reason(s):

4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)
6. Collection of data from voice, video, digital, or image recordings made for research purposes.

For a PDF of your approval letter, click on your study number in the My Studies card on your Cayuse dashboard. Next, click the Submissions bar beside the Study Details bar on the Study Details page. Finally, click Initial under Submission Type and choose the Letters tab toward the bottom of the Submission Details page. Your stamped consent form(s) and final versions of your study documents can be found on the same page under the Attachments tab. Your stamped consent form(s) should be copied and used to gain the consent of your research participants. If you plan to provide your consent information electronically, the contents of the attached consent document(s) should be made available without alteration.

Thank you for your cooperation with the IRB, and we wish you well with your research project.

Sincerely,

G. Michele Baker, PhD, CIP
Administrative Chair
Research Ethics Office

Appendix B: Parental Consent Form

Parental Consent Form

Title of the Project:
Acute potentiation on vertical jump performance following accentuated eccentric loaded back squats in male high school basketball players.

Principal Investigator:
John C. Ditch, Doctoral Candidate, School of Health Sciences, Liberty University

Invitation to be Part of a Research Study

Your child is invited to participate in a research study. To participate, he must be a member of the men's basketball team at Anamosa High School and cleared for physical activity (physical examination by physician to participate in sports). Taking part in this research project is voluntary.

Please take time to read this entire form and ask questions before deciding whether to allow your child to take part in this research project.

What is the study about and why are we doing it?

The purpose of the study is to investigate the effects of a resistance training method to increase jump performance.

What will participants be asked to do in this study?

If you agree to allow your child to be in this study, I will ask him to do the following:

1. Session #1: Participate in an in-person, resistance training session involving maximum strength testing, an introduction to weight training tools, and jump test variations. This session will be recorded on video and will take no more than 90 minutes.

2. Session #2: Participate in an in-person, resistance training session and randomized into groups to decide what type of jumps will be performed before and after the training session. This session will be recorded on video and will take no more than 90 minutes.

3. Session #3: Participate in an in-person, resistance training session and perform the jumps that were not completed during the prior session #2. This session will be recorded on video and will take no more than 90 minutes.

How could participants or others benefit from this study?

The direct benefits participants should expect to receive from taking part in this study are short-term improvement in vertical leaping ability and gained knowledge on strength and conditioning.

Benefits to society include a greater understanding of cause-and-effect relationships using non-traditional resistance training methods for this population.

What risks might participants experience from being in this study?

The expected risks from participating in this study are minimal, which means they are equal to the risks your child would encounter in everyday life.

I am a mandatory reporter. During this study, if I receive information about child abuse, child neglect, elder abuse, or intent to harm self or others, I will be required to report it to the appropriate authorities.

How will personal information be protected?

The records of this study will be kept private. Published reports will not include any information that will make it possible to identify a subject. Research records will be stored securely, and only the researcher will have access to the records.

Data will be stored on a password-locked computer. After three years, all electronic records will be deleted. Video Recordings will be stored on a password locked computer for three years/until participants have reviewed and confirmed the accuracy of the transcripts and then deleted. The researcher will have access to these recordings.

Is study participation voluntary?

Participation in this study is voluntary. Your decision whether to allow your child to participate will not affect your or his current or future relations with Anamosa High School or Liberty University. If you decide to allow your child to participate, he is free to not answer any question or withdraw at any time without affecting those relationships.

What should be done if a participant wishes to withdraw from the study?

If you choose to withdraw your child from the study or your child chooses to withdraw, please contact the researcher at the email address included in the next paragraph. Should you choose to withdraw your child, or should your child choose to withdraw, data collected from your child will be destroyed immediately and will not be included in this study.

Whom do you contact if you have questions or concerns about the study?

The researcher conducting this study is John C. Ditch. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact him at [redacted]. You may also contact the researcher's faculty sponsor, Dr. Kilian, at [redacted].

Whom do you contact if you have questions about rights as a research participant?

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the IRB. Our physical address is

Institutional Review Board, 1971 University Blvd., Green Hall Ste. 2845, Lynchburg, VA, 24515; our phone number is 434-592-5530, and our email address is irb@liberty.edu.

Disclaimer: The Institutional Review Board (IRB) is tasked with ensuring that human subjects research will be conducted in an ethical manner as defined and required by federal regulations. The topics covered and viewpoints expressed or alluded to by student and faculty researchers are those of the researchers and do not necessarily reflect the official policies or positions of Liberty University.

Your Consent

By signing this document, you are agreeing to allow your child to be in this study. Make sure you understand what the study is about before you sign. You will be given a copy of this document for your records. The researcher will keep a copy of the document with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I have read and understood the above information. I have asked questions and have received answers. I consent to allowing my child to participate in the study.

☐ The researcher has my permission to video-record my child as part of his/her participation in this study.

____
Printed Child's/Student's Name

____
Parent/Guardian's Signature Date

____
Minor's Signature Date

Appendix C: Standard Consent Form

Consent Document

Title of the Project: Acute potentiation on vertical jump performance following accentuated eccentric loaded back squats in collegiate male basketball players.
Principal Investigator:
John C. Ditch, Doctoral Candidate, School of Health Sciences, Liberty University
Co-investigator(s):
Justin Kilian, PhD, Associate Professor of Health Sciences, Liberty University
Jessica Savage, PhD, Adjunct Instructor, Dept. Of Allied Health Professions, Liberty University
Jon Davis, PhD, Adjunct Instructor, Dept. Of Allied Health Professions, Liberty University

Invitation to be Part of a Research Study

You are invited to participate in a research study. To participate, you must be 18 years of age or older, a member of the men's basketball, and cleared for physical activity by medical staff. Taking part in this research project is voluntary.
Please take time to read this entire form and ask questions before deciding whether to take part in this research.

What is the study about and why is it being done?

The purpose of the study is to investigate the effects of a resistance training method to increase jump performance.

What will happen if you take part in this study?

If you agree to be in this study, I will ask you to do the following:

1. Session #1: Participate in an in-person, resistance training session involving maximum strength testing and introduction of weight training tools and jump test variations. This session will be recorded on video and will take no more than 90 minutes.
2. Session #2: Participate in an in-person, resistance training session and randomized into groups to decide what type of jumps will be performed before and after the training session. This session will be recorded on video and will take no more than 90 minutes.
3. Session #3: Participate in an in-person, resistance training session and perform the jumps that were not completed during the prior session #2. This session will be recorded on video and will take no more than 90 minutes.

How could you or others benefit from this study?

The direct benefits participants should expect to receive from taking part in this study include a short-term increase in jump performance and the opportunity to obtain training on the use of new resistance training methods. Expected benefits to the field of strength and conditioning may also indirectly help provide greater understanding to coaches in the field to increase the participants long-term athletic development.

What risks might you experience from being in this study?

The expected risks from participating in this study are minimal, which means they are equal to the risks you would encounter in everyday life. The risks involved in this study include the possibility of physical injury from resistance training and/or jump tests. The risks involved are equal to the risk you would encounter during regularly prescribed training sessions. To reduce risk, the study team will monitor and assist participants during resistance training and jump evaluations.

How will personal information be protected?

The records of this study will be kept private. Published reports will not include any information that will make it possible to identify a subject. Research records will be stored securely, and only the researchers will have access to the records. Participant data will be kept confidential by replacing names with pseudonyms. Data will be stored on a password-locked computer. After seven years, all electronic records will be deleted.

Is study participation voluntary?

Participation in this study is voluntary. Your decision whether to participate will not affect your current or future relations with Liberty University or Liberty Men's Basketball Team. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

What should you do if you decide to withdraw from the study?

If you choose to withdraw from the study, please contact the researchers at the email address/phone number included in the next paragraph. Should you choose to withdraw, data collected from you will be destroyed immediately and will not be included in this study.

Whom do you contact if you have questions or concerns about the study?

The researcher conducting this study is JC Ditch. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact him at [redacted] You may also contact the researcher's faculty sponsor, Dr. Justin Kilian at [redacted]

Whom do you contact if you have questions about your rights as a research participant?

If you have any questions or concerns regarding this study and would like to talk to someone other than the researchers, **you are encouraged** to contact the IRB. Our physical address is Institutional Review Board, 1971 University Blvd., Green Hall Ste. 2845, Lynchburg, VA, 24515; our phone number is 434-592-5530, and our email address is irb@liberty.edu.

Disclaimer: The Institutional Review Board (IRB) is tasked with ensuring that human subjects research will be conducted in an ethical manner as defined and required by federal regulations. The topics covered and viewpoints expressed or alluded to by student and faculty researchers are those of the researchers and do not necessarily reflect the official policies or positions of Liberty University.

Your Consent

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. You will be given a copy of this document for your records. The researchers will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I have read and understood the above information. I have asked questions and have received answers. I consent to participate in the study.

____
Printed Subject Name

____
Signature & Date

Appendix D: Permission Site Approval

City of
Anamosa
Parks and Recreation

Anamosa Parks & Recreation Department
600 E Main St
Anamosa, IA 52205
Ph. 319.462.6181

8/14/2023

John C. Ditch
[redacted] University

Dear John C. Ditch,

After careful review of your research proposal entitled "Acute Potentiation on Vertical Jump Performance Following Accentuated Eccentric Loading in Male High School Athletes.", I have decided to grant you permission to conduct your study at the Lawrence Community Center.

☑ I grant permission for Mr. Ditch to utilize the weight room within the Lawrence Community Center to conduct his research study.

Sincerely,

[redacted]

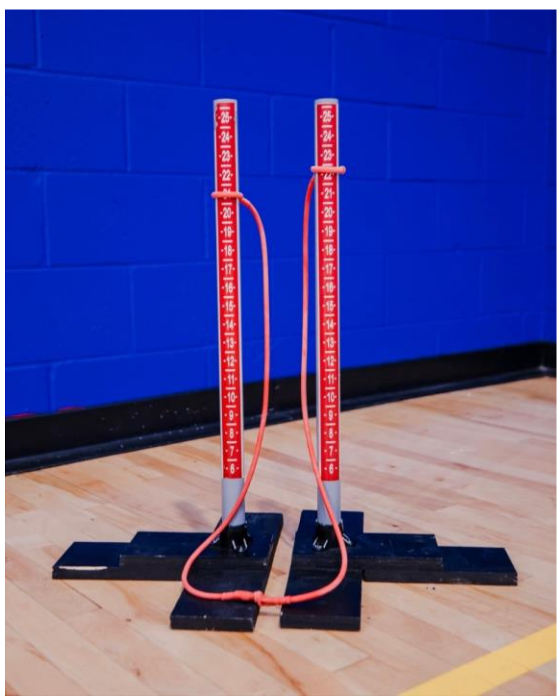
Shelly Carr
Director of Parks & Recreation
Anamosa, IA

Appendix E: Force Plate System

HAWKIN DYNAMICS

(Images provided & approved by Hawkin Dynamics Inc™., Maine, USA)

Appendix F: Modified ROM System

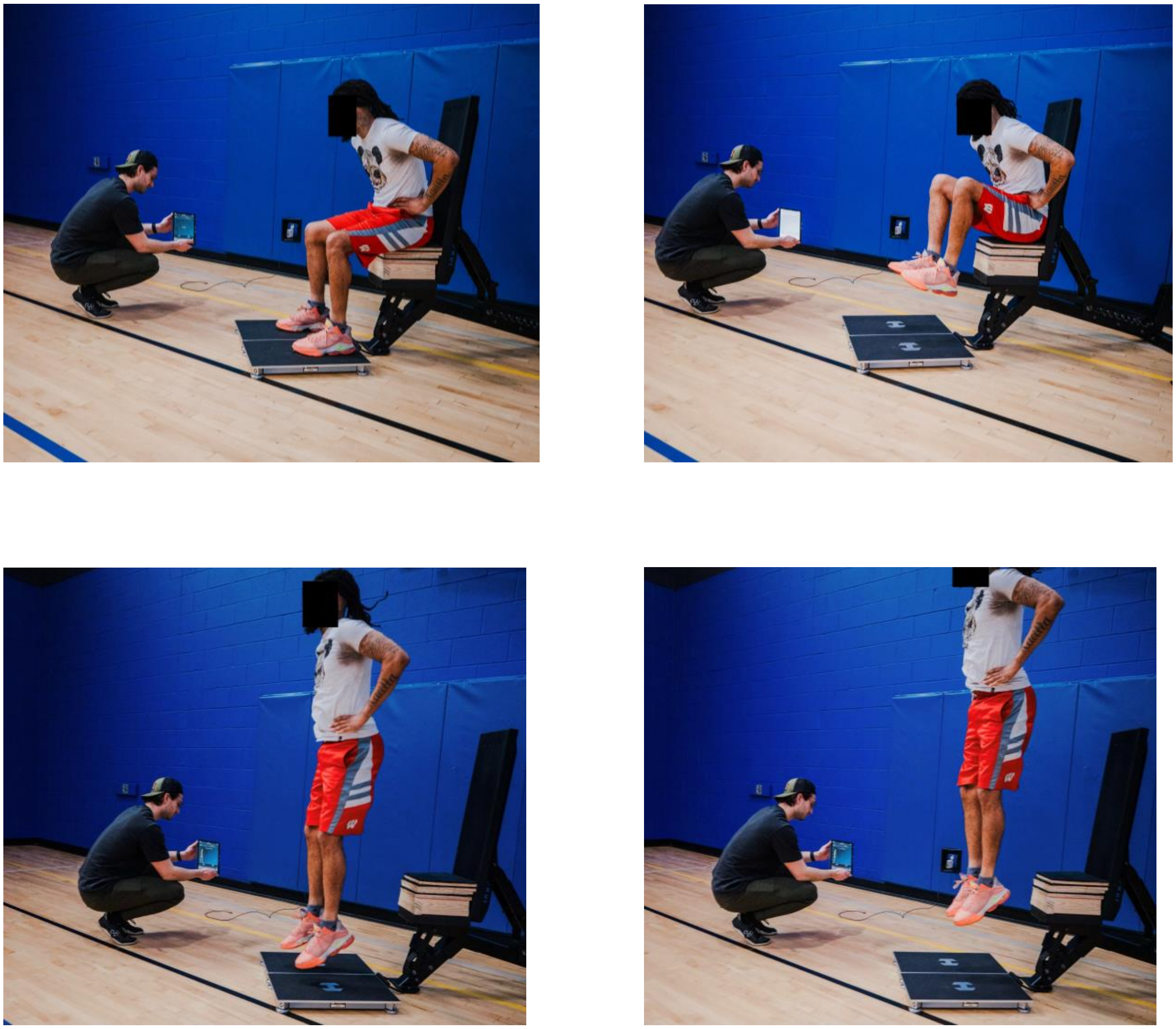


Range of Motion (ROM) System
(Photograph: Dave Martin Studios, 2023)

Appendix G: Propulsive-Only Jump Setup

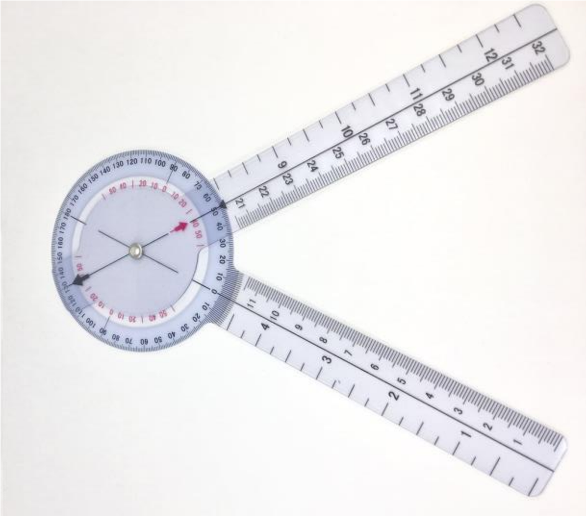
Seat-Risers for the Propulsive-Only Jump
(Photograph: Dave Martin Studios, 2023)

Appendix H: Propulsive-Only Jump in Action



The Propulsive-Only Jump in Action,
(Photograph: Dave Martin Studios, 2023)

Appendix I: Goniometer



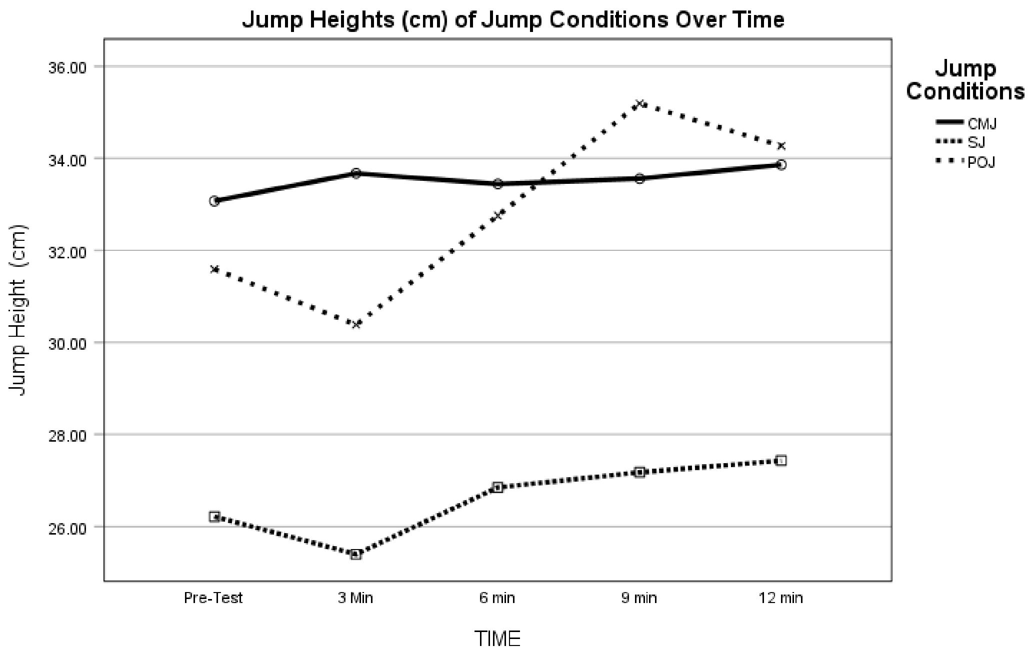
Appendix J: Weight Releasers (Eccentric Hooks)

Weight Releasers from Rogue Fitness™
(Photograph: Dave Martin Studios, 2023)

Appendix K: Chapter 4 Graphs

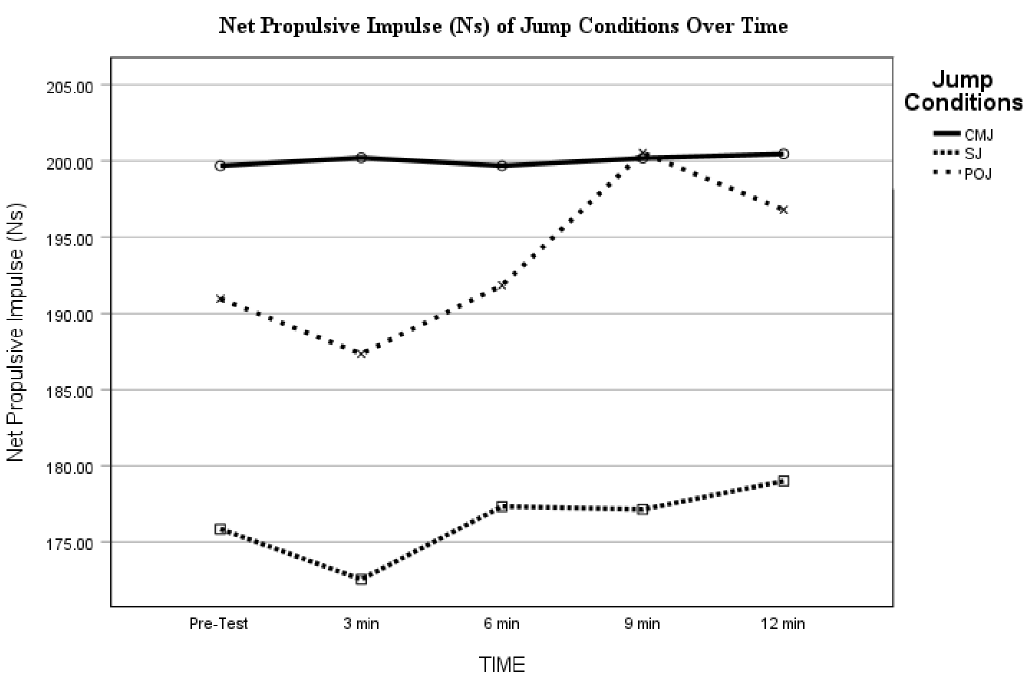
Graph 4.1

Jump Heights (cm) of Jump Conditions Over Time: CMJ, SJ, POJ

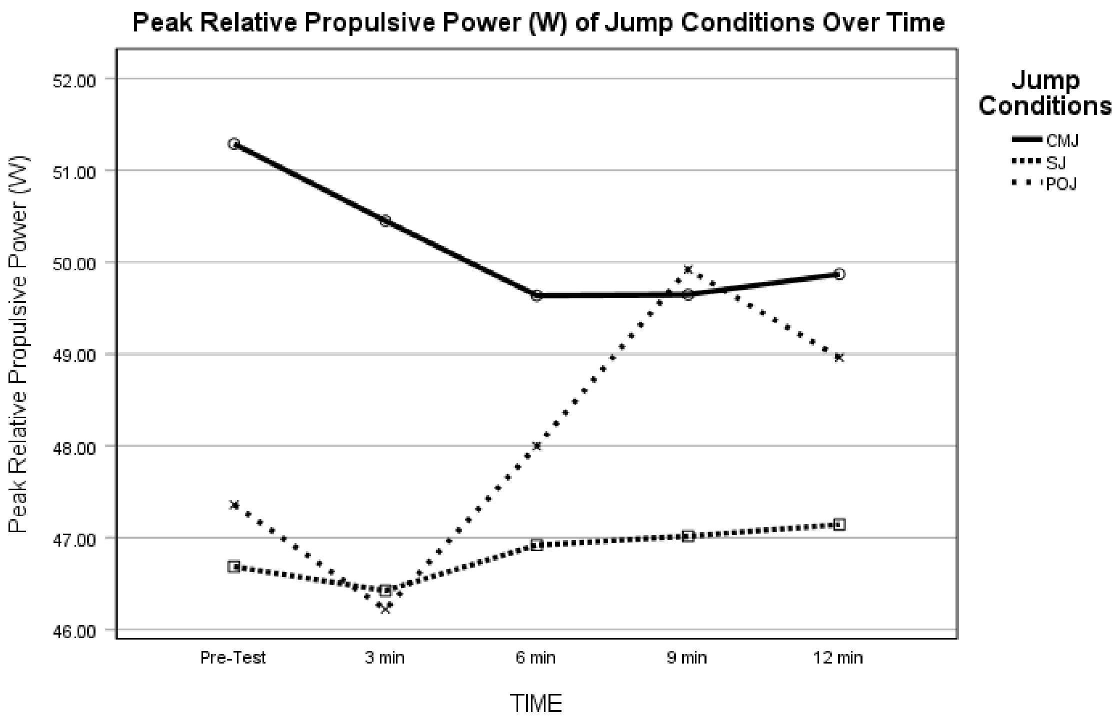


Graph 4.2

Net Propulsive Impulse (Ns) of Jump Conditions Over Time: CMJ, SJ, POJ



Graph 4.3
Peak Relative Propulsive Power (W) of Jump Conditions Over Time: CMJ, SJ, POJ



Appendix L: Diagram of Methodology