8-2024

Strength and Endocrine Adaptations from the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength Endurance Training Block

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A dissertation

presented to

the faculty of the Department of Sport, Exercise, Recreation, and Kinesiology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Performance

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by

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August 2024

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Keywords: accentuated eccentric loading, resistance training, block periodization, endocrine system, strength

ABSTRACT

Strength and Endocrine Adaptations from the Combine Use of Accentuated Eccentric Loading and Cluster Sets During a Strength Endurance Training Block

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The purpose of this study was to investigate the chronic effects of accentuated eccentric loading (AEL) paired with cluster sets (CS) on dynamic and maximal strength, the endocrine system, and body composition. Seventeen recreationally active subjects (male = 11, females = 6, age = 23.05 ± 4.07, height = 172.09 ± 9.98, body mass = 81.29 ± 22.18, back squat to body mass ratio = 1.55 ± 0.33, bench press to body mass ratio = 1.06 ± 0.28) participated in one familiarization week, 2 weeks of testing, and 4 weeks of training. A strength-endurance block (4 wks) was used for training in which the target load consisted of 3 sets of 10 repetitions. The AEL group performed 3 sets of 10 repetitions for the squat and bench press using AEL every other repetition (5 AEL repetitions per set). Because of this protocol, CS were also performed as one AEL repetition plus one traditional repetition followed by 15 s rest. Weight releasers were attached during the rest between clusters. Resistance training was performed three days a week, sprint and agility work were performed two days a week. Maximum dynamic strength (1 RM squat, 1RM bench press), isometric maximum strength (Isometric midthigh pull) and rate of force development (RFD) were tested before and after the training protocol. Additionally, Testosterone (T), Cortisol (C), and Creatinine (CREA), fat mass (FM) and fat free mass (FFM) were assessed pre and post-test in 16 of the subjects as blood was unable to be collected from one of the subjects post test. Although maximum strength increased over time (n= 17), no statistically significant differences in strength occurred between the AEL and TRAD protocols after 4 weeks of training. No

statistically significant differences in resting blood variables or body composition occurred between the AEL and TRAD protocols after 4 weeks of training.

DEDICATION

I would like to dedicate this dissertation to my wife and my best friend, Lindsey Nicole Brown. Thank you for your unwavering support and persistent grace that has pushed me to better at everything I do in life.

ACKNOWLEDGEMENTS

I would like to acknowledge the following:

Dr. Michael Stone for his consistent efforts to help me grow as a professional and a person. I have learned much as your student and my life has been changed even more. I only hope that I have a fraction of the impact you have had on others.

Dr. Satoshi Mizuguchi for his consistent willingness and patience with me as his pupil. I have been challenged by your tutelage in a variety of ways, and your expectations of excellence have allowed me to develop into a better researcher and practitioner than I could have without your guidance.

My classmates and fellow investigators, without whom this would have been impossible and futile. I have both enjoyed the process far more with you all than I would have without, and you all have taught me a significant deal not only during this dissertation process, but throughout the entirety of the PhD program.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1. Introduction

It has been established that resistance training yields adaptations that enhance performance variables (Deschenes & Kraemer, 2002; Stone et al., 1991). One training method that has garnered the attention of investigators is accentuated eccentric loading (AEL). The premise behind AEL is to take advantage of the additional force production capabilities apparent during the eccentric contractions of resistance training. AEL is characterized by greater loading during the eccentric portion of a movement and removal of some of the load for the concentric portion. The greater eccentric loading during AEL may provide greater adaptation through two primary mechanisms: first is the potential benefits of the greater forces, which may better target type II fibers and second, it may potentiate the subsequent concentric contraction via the greater eccentric loading again potentially increasing adaptation (Wagle et al., 2017). The methods used to overload the eccentric movement range from a handful of different implements such as bands (Aboodarda et al., 2014), flywheels (Maroto-Izquierdo et al., 2021), and weight releasers which are the most common method noted in the literature (Montalvo et al., 2021; Walker et al., 2017).

Although not all (Godard et al., 1998; Munger et al., 2022; Ojasto & Hakkinnen, 2009), several findings suggest that AEL elicits superior strength improvements when compared to traditional resistance training (TRAD) (Brandenburg & Docherty, 2002; Chakshuraksha & Apanukul, 2021; Doan et al., 2002; Douglas et al., 2018; English et al., 2014; Friedmann et al., 2004; Helland et al., 2017; Montalvo et al., 2021; Walker et al., 2016; Walker et al., 2020). For example, Chakshuraksha and Apanukul (2021) found greater 1 RM back squat strength gains in an AEL training group compared to TRAD training group. Additionally, Douglas et al. (2018) reported greater increases in the back squat 1 RM compared to TRAD in the first half of their training study. Friedmann et al. (2004) suggests that AEL results in a shift of muscle fiber types towards a greater concentration of type II fibers, allowing for greater force production capabilities. This literature tends to support the greater efficacy of AEL compared to traditional training methods.

Evidence indicates that alterations in performance (i.e. strength, power, HIEE etc.) are often accompanied by endocrine alterations. Although evidence tends to support the notion that AEL produces favorable performance responses, the literature is inconclusive on the endocrine response. Acute studies have shown similar or superior endocrine responses between AEL and TRAD (Merrigan & Jones, 2021; Walker et al., 2017; Yarrow et al., 2007). Merrigan and Jones reported similar post training cortisol levels and inflammatory responses between TRAD and AEL, suggesting similar recovery capabilities between the two training modalities. Additionally, Walker et al. (2017), among strength trained subjects, reported elevated resting testosterone and growth hormone concentrations in response to an AEL exercise session, but not in TRAD, potentially favoring greater adaptations of strength and hypertrophy via overloaded eccentrics.

While the body of research on AEL has grown over the last decade, it is not clear as to exactly how to integrate AEL into the training process. One possibility is that AEL may be beneficial during block periodization (BP) programs. BP consists of three basic periodization blocks: Accumulation, Transmutation (transition), and Realization (Stone et al., 2021). Each block has a specific emphasis. Typically, Accumulation is used to build capacities, Transmutation is used to initiate a transfer to more sport specific aspects, and Realization uses very specific methods to bring preparedness and performance higher levels, often peaking when necessary. While it is possible that AEL could be used in any of the three periodization blocks, this study deals with the Accumulation block and how it effects various parameters resulting from and integrated sprint and resistance training program mimicking a strength-power sport such as sprinters would use (Carroll et al., 2019). Typically, for strength power sports an Accumulation periodization block is made up of two fitness blocks, strength-endurance (SE) and basic strength each lasting about 4 weeks (Stone et al., 2021). The resistance training during the SE block is typically high volume often with higher repetitions per set (~ 10). This block (SE) is believed to enhance high intensity endurance and recovery which may potentiate increased strength and power gains later in the periodized process (i.e. Transmutation and Realization). However, among advanced strength power athletes this training paradigm often reduces explosiveness (rate of force development (RFD) and power output and creates considerable fatigue. As the literature suggests, AEL may enhance these aspects, then its use during SE may help preserve RFD and power. Preserving parameters may be advantageous as 1) this might mean even greater potentiation later in the process and 2) for some sports with competition occurring early in the season preservation may enhance performance. Furthermore, as AEL, using weight releasers, has to be performed using cluster (rest pause) sets, the overall fatigue from performing higher repetitions per set may be less compared to traditional training (Chae et al., 2023). However, this aspect has not been studied.

To the author’s knowledge, there has not been a study that has investigated a block periodized approach with AEL and the adaptations that could result from the acquired training stimulus. Therefore, the purpose of this study is to compare the strength and endocrine responses of two training programs using TRAD and AEL during a typical Accumulation block consisting of a 4 wk strength endurance concentrated load (Stone et al., 2021).

Dissertation Purposes

1. The initial purpose of the current investigation was to examine the strength response to eccentric overload during a strength endurance block of training.
2. The secondary purpose of this investigation was to observe selected metabolic alterations, associated with recovery and protein anabolism, in relation to the combined use of eccentric overload and cluster sets during a strength-endurance training block.
3. The tertiary purpose of this investigation was to provide rational for further investigation of the possible potentiation of greater strength gains experienced in strength blocks of training following the use of eccentric overload performed during a strength endurance training block.

Chapter 2. Review of the Literature

Introduction

Resistance training has been investigated and has been shown to improve fitness characteristics such as force production (Aagaard et al., 2002; Hakkinen et al., 1988; Kraemer & Ratamess, 2004; Kraemer et al., 2002). Currently, the most common resistance training method is the traditional loading scheme (TRAD) used for decades, where the weight being moved is consistent between the eccentric and concentric movements (McMaster et al., 2009). However, it has been observed that the eccentric contraction in skeletal muscle is able to generate substantially greater amounts of force in comparison to the concentric contraction (Dudley et al., 1991; Hortobagyi & Katch, 1990; Jorgensen, 1976; Katz, 1939; Lindsted et al., 2001; Prilutsky, 2000; Suchomel et al., 2019; Wagle et al., 2018; Westing et al., 1988). Because of this, the loading scheme for traditional resistance training programming is limited by the maximal force production of concentric contractions. Furthermore, an eccentric contraction immediately preceding a concentric (stretch shortening cycle) can result in enhancement of the concentric force production (Wagle et al., 2017). Accentuated eccentric loading (AEL) is a loading scheme that has been growing in popularity over the last few years (Suchomel et al., 2019; Wagle et al., 2017). AEL takes advantage of the enhanced force production properties displayed by eccentric contractions by overloading the eccentric movement with a greater load compared to the concentric movement. Logically, this could provide a superior stimulus for force development adaptations (Wagle et al., 2017). Recently, research has resulted in methods appearing to augment force production and power output adaptation beyond traditional methods (Brandenburg & Docherty, 2002; English et al., 2014; Friedmann et al., 2004; Walker et al., 2016; Walker et al., 2020), and while the research on AEL continues to grow, there remains a paucity in the literature.

It is known that higher volumes of resistance training can augment alterations in body composition, metabolic aspects and work capacity (Stone et al., 2022). However, there has been a lack of research on the metabolic aspects of high-volume training particularly as it pertains to neuroendocrine alterations as well as use as the paring of AEL with training blocks that utilize higher volume loads.

Therefore, the purpose of this review is to examine the potential strength and endocrine benefits of combining AEL with higher volumes of training. The review summarizes: 1) Loading Considerations, 2) AEL's Acute and Chronic Impact on Strength and 3) Endocrine Alterations.

Literature Search Methods

The search was conducted in October 2023 using the following databases: Google Scholar, PubMed and EBSCOHOST. There were no limitations regarding publication date. The investigators performed the search and collection of manuscripts and papers through the terms "accentuated eccentric load", "eccentric overload", "weight releaser training", and "enhanced eccentric load". For the sake of continuity, better representation of training in athletic settings, and improving the ability to make generalizable assumptions based on a common AEL method, AEL loading methods in the review are focused on primary multi-joint exercises performed with a barbell. Flywheels, machines and single joint exercises have not been included as well as eccentric only repetition studies in order to better compare volumes and intensities between studies (Munger et al., 2022). Based on these search criteria, nineteen studies were found (acute = 14, chronic = 5). Due to the lack of research on the morphology and endocrine response to AEL with barbell movements, additional studies performed with non-barbell equipment were included to broaden the scope of endocrine response to AEL (Friedmann et al., 2004; Friedmann et al., 2010; Walker et al., 2017; Yarrow et al., 2007; Yarrow et al., 2008). The only works included in the review are peer-reviewed papers that had full access to their works available.

Loading Prescriptions

The available research on AEL loading prescriptions is mixed as studies used a variety of loading intensities and a variety of loading modes (e.g. free weights, flywheels etc.) for both the eccentric and concentric movements of exercises (Merrigan et al., 2022; Wagle et al., 2017). This has been discussed as a likely contributing factor to the mixed and inconsistent findings and requires further investigation (Ersoz et al., 2022; Suchomel et al., 2019). These methodological limitations exist for both acute and chronic studies.

The uses of supramaximal loads (greater than 1RM) are based on the notion that 1RM loads are limited by the concentric contraction and that a superior load during the eccentric portion, which can be substantially greater and is the most common form of loading prescription for AEL (Wagle et al., 2017). However, as previously stated, there are discrepancies in study conclusions which may have resulted from loading strategies as some investigators used overloads of 100-105% 1RM (Castro et al., 2020; Doan et al., 2002; Lates et al., 2022; Wagle et al., 2018; Yarrow et al., 2007; Yarrow et al., 2008), some at 110-120% (Kristiansen et al., 2022; Merrigan et al., 2020; Merrigan et al., 2021; Merrigan & Jones, 2020; Montalvo et al., 2021; Munger et al., 2017; Ojasto & Hakkinen, 2009; Taber et al., 2021; Walker et al., 2017) and some with submaximal loads (Moore et al., 2007; van den Tillaar & Kwan, 2020;). These differences, albeit minute, likely cause slightly different stimuli and thus different acute and chronic adaptations can manifest as a result (Wagle et al., 2017). This is part of the reason why non-barbell methods of applying overloads to eccentrics were left out of this review as the number of differences in loading only increase, and the methods are less likely to be observed in athletic performance environments.

The acute response to AEL is believed to be an enhanced concentric contraction via potentiation mechanisms brought on by the overloaded eccentric contraction (Suchomel et al., 2019). These mechanisms potentially include an enhanced muscular activity (Komi, 1984; Sweeney et al., 1993) and neuromuscular patterns between eccentric and concentric muscle contractions (Enoka, 1996; Kay et al., 2000; Nardone & Schieppati, 1988). There are similar theoretical concepts for the chronic use of AEL as well, with the addition of a possible greater increase in muscle cross-sectional area compared to TRAD training (CSA) (Saxton et al., 1995). However, the different loading prescriptions used in the literature make it more difficult to draw conclusions from.

As previously mentioned, the supramaximal loading prescriptions range anywhere from 105% to 125% (Wagle et al., 2017) and the results produced from using these loads are just as varying. Acute increases in 1RM following eccentric and AEL overload have been reported (Doan et al., 2002; Friedman-Bette et al., 2010). The eccentric overload can also acutely increase concentric velocities (Merrigan et al., 2020; Munger et al., 2017; Taber et al., 2021). However, this has not been a consistent finding in the literature as some investigations have found mixed results between AEL and TRAD (Lates et al., 2022; Merrigan & Jones, 2020; Merrigan et al., 2021; Ojasto & Hakkinen, 2009; Wagle et al., 2018) while others have found that TRAD produces superior acute responses (Kristensen et al., 2022). The use of supramaximal loads is considered potentially overly fatiguing and can be difficult to implement in doses that will consistently produce desirable acute responses, especially in upper body exercises (Kristiansen et al., 2022; Lates et al., 2022; Merrigan et al., 2021; Ojasto & Hakkinen, 2009; Wagle et al., 2017).

Additionally, there is evidence to suggest that as concentric loads become greater, the effectiveness of AEL begins to decrease (Merrigan et al., 2020). While it remains inconclusive as to whether supramaximal loads acutely potentiate concentric outputs, growing evidence appears to support this notion.

Submaximal loads occur when the eccentric loading is ≤ 100% of 1RM and the results appear to be more consistent than supramaximal. A greater portion of the submaximal prescriptions found similar or mixed results between AEL and TRAD (Castro et al., 2020; Moore et al., 2007; Munger et al., 2022; van den Tillaar & Kwan, 2020; Yarrow et al., 2007; Yarrow et al., 2008) compared to the literature that found enhanced responses with lighter eccentric overloads (Ersoz et al., 2022; Taber et al., 2021). While it was theorized that these lighter eccentric overloads may better stimulate power adaptations (Ojasto & Hakkinen, 2009), the amount of evidence available may suggest otherwise as a larger body of evidence suggests concentric barbell velocities can be elevated with a supramaximal loading. As previously mentioned, evidence suggests that a greater difference between the eccentric and concentric loading schemes may be more likely to potentiate concentric contractions (Merrigan et al., 2020). However, Merrigan et al., found that this was not the case with similar loading schemes (Merrigan et al., 2021). It has been hypothesized that individual differences in subjects, such as strength levels, may influence the individuals' ability to adapt to different loading prescriptions (Merrigan et al., 2021; Ojasto & Hakkinen, 2009; Wagle et al., 2017). Currently, this is an area of research that has not been thoroughly investigated. Additionally, the desired training effect should be considered when deciding between smaller or larger differences in eccentric and concentric loads. Logically, heavier combinations of loads would stimulate force production while lighter loads (potentially lighter concentric loads with heavier eccentric loads) would better stimulate power outputs (Taber et al., 2021).

To summarize, findings are mixed and inconclusive as to whether loading prescriptions should be supra or submaximal. The available evidence on AEL with compound barbell movements suggests supramaximal loading may provide a superior training stimulus when compared to submaximal loading intensities. Additionally, subjects may be able to utilize greater eccentric overloads in lower body exercises compared to upper body exercises (Lates et al., 2022). Due to the greater force production qualities of eccentric muscle contractions, these large intensities may be necessary to cause a disruption to homeostasis during the eccentric movement to stimulate desirable adaptations. However, **some** subjects using heavier loads appear to have difficulty potentiating concentric contractions compared to submaximal loads. While it remains inconclusive as to whether supramaximal loads acutely potentiate concentric outputs, growing evidence appears to support this notion. Practitioners should keep these possibilities in mind when providing load prescriptions with AEL.

Strength

Acute AEL Mechanisms

The primary objective for acute studies investigating AEL is to examine potential mechanisms involved with AEL use. Most AEL research has been focused on acute responses and mechanisms. Understanding the physiological underpinnings involved with the response to AEL is critical in understanding circumstances warranting the use of AEL in the applied setting. There are a few possible mechanisms at play for both strength and endocrine variables.

Most research performed on AEL has concerned investigations of the acute effects AEL has on force production. While current research is inconclusive, there have been several theories developed to explain potential mechanisms. Some research suggests that AEL may enhance the subsequent concentric contraction through an enhancement of the stretch-shortening cycle (SSC) and elastic energy (Doan et al., 2002; Kristiansen et al., 2022; Lates et al., 2022; Munger et al., 2017; Ojasto & Hakkinen, 2009; Wagle et al., 2021). The investigators hypothesized that the eccentric overload would potentially increase the stored elastic energy within the muscle and tendons that aid in producing force during the concentric contraction. However, if the overload is too great, volitional eccentric contractions may be reduced and limit the SSC and thus the concentric contraction (Cormie et al., 2010; Merrigan et al., 2021; Rack & Westbury, 1974).

As part of the SSC, neuromuscular activity may be stimulated by AEL as well and assist in providing a superior neural response concentrically (Doan et al., 2002; Merrigan et al., 2021). The eccentric overload may cause a stimulation of the muscle spindle, eliciting an increase motor unit excitation in the prime mover and synergists. The intrafusal fibers (muscle spindle) then stimulate their specialized γ motor neurons, which would signal the brain to activate additional motor neurons or increase the rate of firing, thus increasing the force of contraction in the extrafusal muscle fibers leading to an increased concentric force production. Essentially, the brain is prepared neurologically for a stronger (heavier) concentric contraction as a result of applying a heavier loaded eccentric contraction (Doan et al., 2002). The resulting increase in motor unit recruitment and rate coding may explain the potentiated concentric force production characteristics in the literature (Munger et al., 2017). However, while this is a possible explanation, potentiated concentric contractions are not consistent findings in the available research (Moore et al., 2007; van den Tillaar & Kwan, 2020; Wagle et al., 2018).

The training experience of the individual is also a factor to consider when evaluating the acute response to AEL. Some evidence indicates that stronger subjects responded to the acute effects of AEL to a greater degree than weaker subjects (Merrigan et al., 2021; Merrigan et al., 2022; Ojasto & Hakkinen, 2009; Wagle et al., 2017; Walker et al., 2017). Merrigan et al. (2021) theorizes that stronger individuals are able to use pacing strategies that better allow them to enhance the subsequent concentric contraction. It has been suggested that weaker individuals must slow down the eccentric phase in order to manage the overload, potentially reducing the benefit that rapid muscle lengthening has on recruitment of fast twitch muscle fibers (Duchateau and Enoka, 2011; Merrigan et al., 2022). As previously mentioned, the SSC may play a role in the acute response to AEL, and there is literature that suggests this may play a more prominent role in weaker individuals. Merrigan et al. (2022) suggests that protective properties associated with Golgi tendon organ (GTO) stimulation and reciprocal inhibition may play a role in the effects of supramaximal loads (Merrigan et al., 2022). However, research also suggests that if the training subjects are too weak, they may lack the strength required to actively lengthen muscle fibers under overloads (Merrigan et al., 2022). As a result, they move through the descent phase too quickly and avoid some of the active lengthening of the muscle, potentially reducing the quality of the training stimulus (Merrigan et al., 2022). This is an area of research that future studies would be needed to bring clarity.

While these mechanisms appear to be enhanced by AEL, there may be drawbacks associated with the loading method. Evidence exists suggesting that overloading the eccentric contraction may be too fatiguing to facilitate any superior adaptations, particularly in the bench press exercise (Kristiansen et al., 2022; Lates et al., 2022; Merrigan et al., 2021; Ojasto & Hakkinen, 2009; Wagle et al., 2018). It has also been suggested that the difference in the amount of muscle mass involved between upper and lower body exercises would provide some of the explanation for different responses to AEL (Lates et al., 2022; Munger et al., 2017; Taber et al., 2021; Wagle et al., 2018). However, this is not conclusive, as supramaximal loads of up to 125% 1RM have been found to increase the bench press 1RM (Montalvo et al., 2021). It is possible that heavier eccentric loads for upper body exercises may require too much energy to be managed by the individual, leaving the acute fatigue response to impair the performance of the subsequent concentric contractions, while lighter loads (<85% 1RM) may be more beneficial in stimulating acute responses (Kristiansen et al., 2022; Lates et al., 2022). There is evidence suggesting that supramaximal eccentric loading enhances concentric performance for the bench press, but only when the first repetition of the set has AEL applied to it, as the increase in fatigue throughout the set may be too great with multiple repetitions of eccentric overloading (Lates et al., 2022; Merrigan et al., 2022).

Considering the last point, it is worth noting that the acute mechanisms involved may last longer than the repetition that has AEL applied to it, as evidence suggests that the mechanisms stimulated by AEL (particularly those neuromuscular in nature) may linger for multiple repetitions, allowing for a more practical application of AEL in the weight room (Wagle et al., 2018). These acute mechanisms require further research to confirm their involvement with AEL, particularly with primary compound movements.

Chronic AEL Mechanisms

Possibly, due to the level of practicality of acute studies in comparison to chronic studies, the volume of chronic investigations of AEL use is far lower than that of acute studies. With what has been observed, the proposed adaptive mechanisms involved with chronic AEL use are a mixture of neural, morphological, and architectural in nature (Douglas et al., 2017).

Montalvo et al. (2021) accredited the increases in strength to neuromuscular adaptations (particularly increased rate coding activity) resulting from the use of AEL over 4 weeks with loads gradually increasing from 105-125% 1RM for the eccentric overload and 90% for the concentric load (Montalvo et al., 2021). The investigators also acknowledge that the novelty of the AEL stimulus may have been a contributing factor to strength gains as well, even for the trained subject pool. Another training study used weight releasers to provide an eccentric overload to back squats and hip thrusts (Ersoz et al., 2022). Two groups for four weeks using 3 sets of 8 repetition scheme. The cluster set group had weight releasers attached to the bar every other rep while a second group applied AEL only for the first rep. Eccentric overload was set at 80% 1RM, while the concentric was set at 50%. The cluster set group experienced greater improvements in countermovement jump heights and short (10m and 20m) sprint times, however the single AEL repetition group improved more in the back squat and hip thrust 1RM strength, however, these improvements were not statistically significant. The authors did not speculate as to the mechanisms responsible for the results found. Ersoz et al. only compared their findings to existing research at the time of publication. It is worth noting that 50% of 1RM for the concentric loading could be considered light for both groups for sets of 8 repetitions, and different results likely would occur if both the eccentric and concentric loads were greater, particularly the concentric load (Gonzalez-Badillo et al., 2006; Suchomel et al., 2021).

Additionally, AEL has been associated with producing a stronger and faster muscle (Friedmann et al., 2004; Friedmann-Bette et al., 2010). Indeed, some evidence suggest that eccentric loading and AEL can result in superior gains in muscle CSA, particularly for Type II fibers (English et al., 2014; Norrbrand et al., 2008; Walker et al., 2017). The increase in muscle CSA can be attributed to increases in mechanical tension, stretch, or metabolic activity (Schoenfeld et al., 2010). The increase in eccentric overload could provide a greater mechanical tension to the musculature than TRAD, due to the constraint of the concentric contraction limiting the eccentric loading. Additionally, as mentioned previously, the increase in loading could potentially provide a stretch to the trained muscles. Therefore, it is within reason to believe that eccentric overloads would provide a stimulus that could provide a superior muscle hypertrophy response (Douglas et al., 2017).

It is also possible that if loading is sufficient, fascicle length may increase (Walker et al., 2020). Indeed, these alterations in the muscle, along with neural adaptations, could lead to a stronger, faster muscle. Additionally, it is possible that eccentric loading, particularly supramaximal, may better target Type II muscle fibers. Indeed larger Type II fibers and a larger II:I CSA ratio should allow greater force production and a greater RFD compared to Type I fibers (Bagley et al., 2022). Freidman et al. (2010) indicate that eccentric training was accompanied by several facors that could lead to a faster stronger muscle. These alterations included, statistically significant increases in IIx fibre CSA, in the percentage of hybrid type IIa fibres expressing MHC IIx mRNA and the concentration of mRNAs preferentially expressed in type II fibers, Friedman et al. indicate that the eccentric loading apparently led to a subtly enhanced faster gene expression pattern and induced a shift towards a faster muscle phenotype plus related adaptations that could make a muscle better suited for fast, explosive movements. This would be an ideal training adaptation for strength-power athletes.

However, there is also evidence that chronic AEL use in training with primary compound movements will not lead to superior adaptations compared to TRAD (Munger et al., 2022). Munger et al. found similar strength results between AEL and TRAD after training for twice a week over 5 weeks with gradually increasing eccentric overloads from 105-125%. The sets and repetitions for the study started at 4 sets of 5 repetitions and volume decreased as the training loads increased to 3 sets of 4 and finally 3 sets of 2 (Munger et al., 2022). Even though strength results were similar between groups, countermovement jump height improved more in the AEL group; however, this was not statistically significant.

It has been speculated that the increases in volume and intensity via AEL may possibly cause a superior training stimulus and adaptation (Doan et al., 2002; Rhea et al., 2003). AEL may provide a stimulus that enhances neuromuscular activity, perhaps hypertrophy and thus provides a superior neuromuscular adaptation than TRAD (Doan et al., 2002; Merrigan et al., 2022; Wagle et al., 2017). The relatively few chronic research studies dealing with AEL use during training that exist suggests there is a benefit exposing athletes to AEL during their training. However, the volume of research is too sparse to make any strong assumptions. In summary, the available evidence suggests that the strength adaptations from AEL are comparable to those of from TRAD, albeit slightly superior for some training characteristics, yet more research is required to have a conclusive understanding.

Endocrine Response

The endocrine system's response to AEL use is worth investigating given its relationship with resistance training and adaptations (Hakkinen et al., 1988; Kraemer, 1992; Kraemer & Ratamess, 2005). Hormones respond differently to a variety of training methodologies, and very few investigations have been performed using AEL (Hakkinen et al., 1987; Kraemer, 1992). Due to the large gap in the literature concerning endocrine response to AEL use with primary movements, the endocrine data will be summarized in one section and acute and chronic studies will be addressed together. Three studies referenced in this section are exceptions to the original search criteria due to the lack of research available, particularly regarding blood and endocrine variables (Walker et al., 2017; Yarrow et al., 2007; Yarrow et al., 2008).

Currently, only a few hormones have been investigated. The catabolic hormone cortisol acts as a regulator of inflammation resulting from training and has been observed regarding its acute response to AEL exercise (Izquierdo et al., 2009; Merrigan & Jones, 2021; Walker et al., 2017). There appears to be similar cortisol response for AEL and TRAD (Merrigan & Jones, 2021). The inclusion of additional loading on the eccentric portion for the first repetition of the set may not be a disruptive enough stimulus to the endocrine system to warrant different adaptations compared to TRAD (Merrigan & Jones, 2021). However, it has been suggested that if AEL were applied to multiple repetitions throughout the sets, there may be different hormone results, particularly an increase in cortisol levels (Merrigan et al., 2022).

In addition to cortisol, anabolic hormones (i.e. human growth hormone and testosterone) have also been studied and results show similar results (Walker et al., 2017; Yarrow et al., 2007; Yarrow et al., 2008). Existing evidence indicates that human growth hormone and testosterone increase, following a similar trend as found with TRAD training sessions, and remain elevated post training for a period (Kraemer et al., 1990). Resting and post exercise testosterone and human growth hormone have been observed with AEL use (Yarrow et al., 2007; Yarrow et al., 2008). Testosterone concentrations were not elevated during exercise while growth hormone concentrations were elevated in both training methodologies in acute (Yarrow et al., 2007) and chronic (Yarrow et al., 2008) settings. The authors speculate that this was due to an increase in testosterone bound to androgen receptors, a desirable effect that would help to stimulate protein synthesis (Yarrow et al., 2007; Yarrow et al., 2008). However, there has been conflicting evidence showing that testosterone concentrations increase after training sessions, but regardless whether AEL was implemented or not (Yarrow et al., 2008).

There is evidence that contradicts this finding, as AEL has been shown to have a greater effect on testosterone with chronic training (Walker et al., 2017). While statistically insignificant, Walker et al. found that acute testosterone concentrations decreased more in the TRAD group during a 10-week training study compared to the AEL group. There may be a few explanations for this. Hormone concentrations have been found to be impacted by a number of variables (i.e. the size of muscle groups worked and overall program design such as training volume and rest times between sets) (Hakkinen et al., 1987; Kraemer, 1992). The exercise selection used in these studies were similar as most used compound movements (Merrigan & Jones, 2021; Yarrow et al., 2007; Yarrow et al., 2008), however, one study investigated single joint exercise on machines (knee-extension) (Walker et al., 2017). This difference may have impacted the findings of Walker et al. as less muscle mass would have been involved in the work and would elicit a quantitatively different endocrine response (Walker et al., 2017; Izquierdo et al., 2009). As previously mentioned, these points of research design are believed to be one of the reasons why AEL findings are not consistent. Given the impact that testosterone and human growth hormone have on muscle tissue, more research is warranted on how AEL affects anabolic hormone levels over time (Kraemer et al., 1990; Kraemer & Ratamess, 2005).

The general summation of results indicates that there are similar acute and chronic hormone responses to AEL use compared to TRAD (Merrigan & Jones, 2021; Yarrow et al., 2007; Yarrow et al., 2008). With the majority of AEL research on barbell primary movements supporting the notion of similar endocrine responses between AEL and TRAD. This leads to a rationale speculation that AEL's enhanced loading would potentially stimulate superior force production qualities and training volumes without hindering the hormone response to training. Similar post exercise endocrine responses, compared to TRAD, suggest a similar recovery response, which is supported by similar HR and VO_2 recovery patterns (Chae et al., 2023). Similar recovery patterns suggest that the subjects using enhanced loads experienced with AEL would be able to manage the loading without excessive fatigue, potentially allowing for superior adaptations. However, the recovery response (and adaptations) is likely influenced by the loading pattern. As previously mentioned, multiple AEL repetitions per set may generate too much fatigue and jeopardize recovery (Lates et al., 2022).

Conclusions and Direction of Future Research

AEL may provide a superior training stimulus that allows for enhanced physiological and performance responses over what TRAD may elicit (Wagle et al., 2017). The efficacy of AEL as a training modality must be considered within program design. During blocks of training with the primary objective of force production adaptation (Basic Strength Blocks), AEL could be applied for the lower repetition sets typically used during these blocks of training. However, it has been suggested that AEL could be a practical choice for blocks with higher volumes (Strength-Endurance Blocks) based on acute observations (Chae et al., 2023). AEL, using weight releasers, may provide athletes an equivalent, potentially superior, training stimulus but at a lower fatigue cost and training strain as a result of the use of cluster training with the weight releasers. Thus, cluster sets would enhance the feasibility of AEL application at higher volumes of training. Additionally, the neuromuscular adaptation to eccentric overloads may allow for a superior potentiation of the Basic Strength block following the Strength-Endurance block (Stone et al., 2021).

While the available body of research on AEL has grown over the last two decades, further research is required to investigate AEL's use of primary compound movements, particularly from a chronic standpoint as training studies are particularly few. As, is the case, with most training studies, it would be ideal for future research to investigate the affect AEL has on trained subjects as the literature is clear that untrained subjects will likely respond to a much greater degree, thus confounding the results (Moritani & DeVries, 1979). Additionally, an improvement in the consistency of research design choices, such as training program design and loading prescriptions, should take a priority of future AEL research to better compare findings.

While current findings are mixed, evidence appears to suggest that supramaximal eccentric overloading can provide a superior training stimulus acutely and potentially chronically (Doan et al., 2002; Ersoz et al., 2022; Lates et al., 2020; Merrigan et al., 2020; Montalvo et al., 2021; Munger et al., 2017; Walker et al., 2017). These may be a result of enhanced SSC (Doan et al., 2002; Kristiansen et al., 2022; Lates et al., 2022; Ojasto & Hakkinen, 2009; Munger et al., 2017; Wagle et al., 2021), hypertrophy and improved neuromuscular activity (Doan et al., 2002; Merrigan et al., 2021). It has been suggested that AEL be applied for the first repetition within the set or that a cluster set scheme be used to reapply AEL to the barbell multiple times should the set be (Lates et al., 2022; Merrigan et al., 2022; Wagle et al., 2017). Caution should be exercised when applying AEL to multiple repetitions per set as the fatigue incurred as a result may be too great and recovery capacities may be compromised (Ojasto & Hakkinen, 2009; Wagle et al., 2017).

Chapter 3. Study I

COMPARISON OF STRENGTH RELATED EFFECTS OF TRADITIONAL SET/REP CONFIGURATION TO AEL TRAINING OVER A FOUR WEEK BLOCK OF STRENGTH-ENDURANCE TRAINING

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Abstract

The purpose of this study was to investigate the chronic effects of accentuated eccentric loading (AEL) paired with cluster sets (CS) on dynamic and maximal strength. Seventeen recreationally active subjects (male = 11, females = 6, age = 23.05 ± 4.07, height = 172.09 ± 9.98, body mass = 81.29 ± 22.18, back squat to body mass ratio = 1.55 ± 0.33, bench press to body mass ratio = 1.06 ± 0.28) participated in one familiarization week, 2 weeks of testing, and 4 weeks of training. A strength-endurance block (4 wks) was used for training in which the target load consisted of 3 sets of 10 repetitions. The AEL group performed 3 sets of 10 repetitions for the squat and bench press using AEL every other repetition (5 AEL repetitions per set). Because of this protocol, CS were also performed as one AEL repetition plus one traditional repetition followed by 15 s rest. Weight releasers were attached during the rest between clusters. Resistance training was performed three days a week, sprint and agility work were performed two days a week. Maximum dynamic strength (1 RM squat, 1RM bench press), isometric maximum strength (Isometric midthigh pull) and rate of force development (RFD) were tested before and after. Although maximum strength increased over time (n= 17), no statistically significant differences in strength occurred between the AEL and TRAD protocols after 4 weeks of training.

Introduction

Recent evidence has emphasized the importance of strength and how it is the cornerstone for many athletic attributes such as speed, power, injury resistance etc. (Suchomel, Nimphius & Stone 2016; Wagle et al., 2017,). This highlights the importance of sound strength and conditioning practices. Resistance training is used to better prepare athletes for competition as it has routinely demonstrated the ability to improve one's physical capabilities for decades (Nuzzo 2021).

One aspect that has not been investigated thoroughly is the chronic use of AEL with primary exercises during higher volume blocks of training typically used during higher volume phases such as "accumulation" phases within a block periodization approach to training. A primary goal of the early portions of an accumulation phase is concerned with enhancing work capacity and strength-endurance development (Stone et al., 2021). Thus, AEL, which has been largely associated with strength development, has not been well studied as part of the accumulation phase. The desired adaptations between strength and improved strength-endurance and work capacity could be in conflict with each other, and both adaptations could be better suited to different programming strategies (Stone et al., 2021). While higher volumes of training, particularly with higher repetitions have been shown to enhance work capacity as measured by repetitions to failure (Stone et al., 2022), higher volumes, particularly higher repetitions, even for a few weeks, can result in stagnated maximum strength alterations and decreases in rate of force development (RFD). These negative effects appear to be especially apparent among moderately and well-trained strength power athletes (Stone et al.2019; Suarez et al., 2019).

However, the pairing of a higher volume strength-endurance concentrated load, typically occurring early in the accumulation phase, with AEL may provide stimulus that allows the development of strength- endurance and mitigate some of the negative effects on maximum strength and particularly RFD (Chae et al., 2023). Traditional resistance training (TRAD) uses the same load for both the eccentric and concentric movements of exercises and is the most common method of resistance training (McMaster, Cronin & McGuigan 2009). However, AEL is a training modality that is growing in acceptance. AEL uses a greater load during the eccentric movement and a lighter load during the concentric (Suchomel et al., 2019). Greater eccentric loads can be used because of the greater force production capabilities of eccentric muscle contractions compared to concentric (Dudley et al., 1991; Hortobagyi & Katch 1990; Prilutsky 2000). For AEL training, it has been suggested that eccentric overload intensities should range from 105% to 130% of the 1RM (Suchomel et al., 2019). However, the prescriptions used in the current literature have been inconsistent as to the implements used, the loading, and the tempo of the eccentric movements, likely providing varying stimuli as a result (Suchomel et al., 2019; Wagle 2017). Indeed, several devices have been used to overload eccentric contractions such as bands (Aboodarda et al., 2014), flywheels (Maroto-Izquierdo et al., 2021), and weight releasers (Walker et al., 2017).

While there has been an increase in the number of investigations associated with AEL training, it is still unclear whether or not AEL stimulates superior strength adaptations over time compared to TRAD (Brandenburg & Docherty 2002; Chakshuraksha & Apanukul 2021; Doan et al., 2002; Douglas et al., 2017; Douglas et al., 2018; English et al., 2014; Friedmann et al., 2004; Helland et al., 2017; Montalvo et al., 2021; Walker et al., 2016; Walker et al., 2020). While there is evidence to suggest that AEL use can lead to greater increases in strength (Brandenburg & Docherty 2002; English et al., 2014; Friedmann et al., 2004; Walker et al., 2016; Walker et al., 2020), there have also been opposing findings as well (Goddard et al., 1998; Ojasto & Hakkinen 2009; Toien et al., 2018; Yarrow et al., 2008).

Another training method which has been used with some success is cluster training (CS). CS training allows for rest periods, typically 15 – 30 s, between repetitions (Haff et al., 2008). Compared to traditional training on a repetition-by-repetition basis, CS's have been shown to acutely better maintain force, velocity and power output (Haff et al., 2008; Wetmore et al., 2019). Furthermore, as a result of the inter-repetition rest, less fatigue is experienced for the same number of repetitions (Davies et al., 2017; Tufano et al., 2017;). Review of the literature indicates CS results in equal or somewhat better results compared to traditional training, but with substantially less fatigue (Davies et al., 2021).

In typical training, particularly with athletes, AEL is typically accomplished using weight releasers. The result of replacement of the weight releasers on the bar after an AEL repetition is a CS (Chae et al., 2023; Lates et al., 2023). Thus, CS coupled with AEL may be a viable training strategy that would both mitigate the additional fatigue brought on by the enhanced eccentric overload and allow for the weight releasers to be reapplied to the bar for multiple repetitions (Chae et al., 2023; Tufano, Brown & Haff 2017; Wagle et al., 2021). This would enable a practical AEL/CS set-rep scheme for weight releasers to be used for multiple repetitions within a set.

Assuming that AEL/CS combined training can reduce or obviate the negative effects of high volume/high repetition training, this could further potentiate strength power training aspects that typically take place later in the training process. However, there is currently a paucity of research concerning the adaptation to chronic use of AEL combined with CS, particularly using strength-endurance concentrated loads (Lates et al., 2022; Wagle et al., 2017).

Thus, the purpose of this study was to investigate the maximum strength, and RFD alterations associated with traditional training compared to the combined use of AEL and CS during a high volume- high repetition 4 week block of training. The results of the current investigation aim to add to the growing body of research on training methodology and offer strength and conditioning practitioners more information to better design training programs.

Methods

Experimental Approach to the Problem

This was a between-group repeated measures design where paired subjects were randomly assigned to either the AEL or TRAD training group. The training study took place over 7 weeks. The first week was a familiarization week where subjects were exposed to the tests prior to maximal effort as well as weight releaser use. Weeks 2 and 7 were pre and post-test weeks where strength data were collected. Weeks 3 through 6 all of the subjects participated in three days of resistance training and two days of sprint and agility training. In order to make the training more typical of that of athletes, sprints and change of direction (COD) exercises were added. Each resistance training session (M, W, F) was composed (after warm-ups) of 3 sets of 10 reps for every exercise. Tuesday focused more on sprint work and mechanics while Thursday focused more on change of direction.

Subjects

Seventeen recreationally active individuals (11 males, 6 females, age = 23.05 ± 4.07, height = 172.09 ± 9.98, body mass = 81.29 ± 22.18, back squat to body mass ratio = 1.55 ± 0.33, bench press to body mass ratio = 1.06 ± 0.28) volunteered for the current investigation. Subjects qualified to participate if they had resistance training experience with the back squat and bench press exercises for at least a year.

Subjects were excluded from the investigation if they had previous experience with weight releasers in training over the last year, missed more than 10% of the training sessions, missed any testing sessions, or had any injuries that limited their performance during training or testing. Eighteen subjects were recruited, one was excluded from the study for missing the post training testing measurement sessions. Therefore, there were 17 subjects who completed the strength tests and. All subjects read and signed a written informed consent document, and the procedures of the investigation were approved by the university's Institutional Review Board (ETSU IRB ID# 0822.2f).

Procedures

Familiarization. The subjects went through a familiarization period the week before testing. A standardized warm up was used before each familiarization session and testing session (Kraska et al., 2009). Subjects were introduced to the back squat and bench press 1RM protocols used by Wetmore et al (2020). On Wednesday, subjects were exposed to back squats with weight releasers (Rogue; Columbus, OH) in order to better prepare them for the uniqueness that comes with weight releaser use. Subjects performed 3-4 sets with low repetitions (2-5) up to a weight releaser load of 50% of their 1 RM (weight releaser and the load attached to each weight releaser). A similar process with the weight releasers was used for bench press on Friday. Additionally, subjects performed isometric midthigh pulls (IMTP) on Thursday using a standard warmup (Kraska et al.2009). IMTP attempts were performed inside a custom-built rack (Sorinex Exercise Equipment; Lexington, SC, USA) with dual force plates (2cm x 91 cm x 45.5 cm) sampling at 1000 Hz (Rice Lake Weighing Systems; Rice Lake, WI, USA) used to assess IMTP force production. Isometric peak force and rate of force development (0-200 ms) were derived from the isometric force-time curve (Kraska et al., 2009, Chae et al., 2023).

Testing. Subjects underwent a testing week (Pre) after the familiarization week and after the final week of training (Post). Before any testing was performed, subjects had to be reasonably hydrated as assessed by using a refractometer (Atago CO., LTD, Tokyo, Japan) to test urinary specific gravity (Wetmore et al., 2020). Upon passing hydration, body mass (BdM) was assessed first using a SECA mBCA 514 (Seca Medical Scales, Chino, CA).

Afterwards, dynamic strength was measured via 1RM test for back squat and bench press using the protocol described by Wetmore et al., (2020). The 1RM back squat test took place on Monday while the bench press 1 RM test took place on Wednesday. IMTP testing took place on Friday. Peak force and RFD at 0- 200 ms were recorded. The ratio of absolute 1RM to BdM and allometrically scaled 1RM for back squat and bench press were also calculated for each subject. The allometric scaling was carried out by dividing absolute 1RM by BdM taken to the power of two-thirds (Stone et al., 2019, Suchomel 2018).

Training Program. The *relative strength* score (BS 1RM/BdM + BP 1RM/BdM) was used for pairing subjects. Initial strength values (total, squat or bench press) were not statistically different between groups. The pairs were then randomly assigned to groups AEL (males = 6, females = 3) and TRAD (males = 5, females = 3). The two groups participated in a four-week strength-endurance block of training. Each week, training sessions lasted for ~45-60 minutes each day. Resistance training was performed on Monday, Wednesday, and Friday. Sprint and agility training were Tuesday and Thursday respectively **(Tables 1- 3).** Sprints were included to better simulate a typical training program of strength-power athletes (Carroll et al., 2019; Wetmore et al., 2020). Additionally, training volume was not equated as previous research has shown difficulties in trying to match volume between TRAD and AEL training (Yarrow et al., 2008). Although all studies do not agree (Painter et al., 2012; Schoenfeld et al., 2019), it is possible, and commonly believed, that greater volumes of work would stimulate a larger performance adaptation (Rhea et al., 2003; Crewther et al., 2008). Additionally, training volumes were not equalized in order to better represent an ecologically valid scenario for training in an athletic environment. A duration of four weeks of training was selected as existing evidence has shown AEL can stimulate adaptations within that time frame (Doan et al., 2002; Friedman et al., 2004) and this is a common time frame for a strength-endurance concentrated load used as part of an accumulation block (Stone et al., 2021).

Prior to each training session, subjects completed a dynamic warm-up. Upon completion of the warm-up, the two groups began their training session while being supervised by a minimum of two certified strength and conditioning specialists (CSCS). Subjects performed resistance training sessions at the same times, but in separate weightrooms and performed sprint and agility sessions together. Investigators were periodically rotated to limit any coaching bias.

On days where subjects performed the back squat and bench press, specific warm-up protocols were performed before moving to working sets (Table 4). The AEL group would perform their working sets as 3 sets of 5 clusters of 2 repetitions (3x5x2 = 30 total repetitions). Weight releasers would be applied to every other rep for the back squat and bench press exercises. This was performed during a 15 second intra-repetition rest after every cluster, forming 5 CSs, each of 2 repetitions. Volume load (VLd) was calculated as total number of repetitions x load in kilograms x barbell displacement in meters for the back squat and bench press. The displacement, using a metric tape measure, was recorded during the familiarization week, (Hornsby et al., 2018). VLd for the AEL group included the enhanced eccentric loading applied via weight releasers. Relative VLd was calculated in two manners VLd/BdM and VLD/relative strength measures, to gain insight on how body size and relative strength levels impacted their total work (Table 5). Maximum strength was also allometrically scaled (Absolute kg x $Bdm^{(-0.67)}$) (Stone et al., 2019).

Table 1

Resistance Training Overview

		TRAD		AEL		
Week	**Sets x Reps**	**Day 1 & 3**	**Day 5**	**Day 1**	**Day 3**	**Day 5**
1	3 x 10	57.5%	50%	110*/57.5%	57.5%	110*/50%
2	3 x 10	62.5%	55%	110*/62.5%	62.5%	110*/55%
3	3 x 10	67.5%	57.5%	110*/65%	67.5%	110*/57.5%
4	3 x 10	52.5%	45%	110*/52.5%	52.5%	110*/45%

*Intensity is prescribed as % 1RM. AEL = Accentuated Eccentric Loading, TRAD = Traditional, Isoinertial Resistance Training. * Indicates AEL repetitions **Indicates down sets (traditional 1x5 55% of target con).*

Table 2

Resistance Training Exercise Selection

Day 1	Day 3	Day 5
BS*, BP*, DB Triceps Extension	CG MTP, CG SLDL, BB Row	BS*, BP*, DB Triceps Extension

BS = Back Squat, BP = Bench Press, CG = Clean Grip, SG = Snatch Grip, MTP = Mid-thigh Pull, SLDL = Stiff Legged Dead Lift, DB = Dumbbell
** Indicates exercise performed with AEL repetitions by the AEL group*

Table 3

Sprint and Agility Training Overview

Week	Day 2	Day 4
1	BU: 2x15m BU: 2x25m Accel: 4x4x10m Crunches: 3x25	BU 2x20m Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit 5m to decel) 1x4x5m 180* turn (exit 5m ro decel) 1x4x5m

2	BU: 2x15m BU: 2x25m Accel: 4x4x15m Crunches: 4x25	BU 2x20m Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit to 5m decel) 1x4x10m 180* turn (exit 5m to decel) 1x4x10m
3	BU: 2x15m BU: 2x25m Accel: 4x4x20m Crunches: 4x25m	BU 2x20m Linear Decel 1x4x7.5m Lateral Decel 1x4x7.5m Sidetep cut (exit to 5m decel) 1x6x10m 180* turn (exit to 5m decel) 1x6x10m
4	BU: 2x15m BU: 2x25m Crunches: 2x25	BU 2x20 Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit to 5m decel) 1x4x5m 180* turn (exit to 5m decel) 1x4x5m

BU = Build Up

Table 4

Overview of Back Squat and Bench Press Warm Up Procedures

5-Minute General Dynamic Warm Up

Back Squat Warm Up:	Bench Press Warm Up
TRAD	TRAD
1x5 at 30% 1RM	1x5 at 30% 1RM
1x5 at 50%1RM	1x5 at 50% 1RM
1x2 at 75% 1RM	1x2 at 75% 1RM
AEL	AEL
1x5 at 30% 1RM	1x5 at 30% 1RM
1x5 at 50% 1RM*	1x5 at 50% 1RM*

Table 5

Volume Loads (Back Squat + Bench Press)

Groups	VLd	VLd/Body Mass	VLd/Allometricaly Scaled	VLd/Relative Strength
AEL	30,774 ± 7712	408.54 ± 79.96	1693 ± 329	12,102 ± 3679

TRAD	30,950 ± 14,367	341.93 ± 104.18	1500 ± 513	11,572 ± 4133

VLd= Volume Load displacement (total reps x kilos x barbell displacement in meters)
VLd/Allometrically Scaled = VLd/BM $^{0.67}$
VLd/Relative Strength = VLd /(Relative Back Squat 1RM + Relative Bench Press 1RM)

Statistical Analyses

Data were analyzed via R (Version 4.3.2; R Core Team, Vienna, Austria). Descriptive statistics were calculated along with mean and standard deviation (SD) (Table 6). A 2 (groups) x 2 (time points) mixed analyses of variance (ANOVA) was performed to examine if the AEL application was likely to produce unique effects as compared to the traditional method for each dependent variable. The critical alpha level was set at 0.05. Hedges' g was used to estimate magnitudes of various effects investigation (0.0 – 0.2 (trivial); 0.2 – 0.6 (small); 0.6 – 1.2 (moderate); 1.2 – 2.0 (large); 2.0 – 4.0 (very large); 4.0 - ∞ (nearly perfect) (Hopkins et al., 2009). When the residuals were not normally distributed for a given ANOVA model, the permutation test was used to conduct the null hypothesis testing for the omnibus ANOVA, followed by the non-parametric bootstrap for the post hoc analysis depending on the outcome of the omnibus ANOVA and the calculations of Hedges'g.

Results

Descriptive statistics (pre-post) were calculated as mean and standard deviation (SD) (Table 6).

Table 6

Descriptive Statistics Using Mean ± SD (Upper and Lower Limit of CI)

Independent Variable	Pre-Test AEL	Post- Test AEL	Pre-Test TRAD	Post -Test TRAD
Body Mass	75.62 ± 17.04 (64.49-86.75)	76.24 ± 17.38 (64.89-87.59)	87.68 ± 26.55 (69.28-106.08)	88.0 ± 26.89 (69.36-106.64)
Back Squat 1RM	113.22 ± 23.11 (98.12-128.32)	119.22 ± 22.64 (104.43-134.01)	138.38 ± 55.90 (99.64-177.11)	144.13 ± 55.75 (105.50-182.75)

Bench Press 1RM	81.11 ± 21.60 (67.00-95.22)	83.22 ± 21.06 (96.46-96.98)	94.88 ± 44.13 (64.29-125.46)	96.0 ± 46.48 (63.79-128.21)
Absolute Total	194.33 ± 43.15 (167.59-221.08)	202.44 ± 41.82 (176.52-228.67)	233.25 ± 98.34 (169.00-297.50)	240.13 ± 100.43 (174.51-305.74)
Isometric Peak Force	3322 ± 413 (3053-3593)	3383 ± 432 (3101-3666)	3975 ± 1194 (3148-4803)	4118 ± 1214 (3276-4959)
Isometric RFD	4077 ± 2345 (2545-5609)	4039 ± 1550 (3027-5052)	4306 ± 3478 (1895-6716)	3420 ± 3504 (991-5848)
Relative Squat 1Rm	1.53 ± 0.32 (1.32-1.73)	1.60 ± 0.30 (1.40-1.79)	1.56 ± 0.38 (1.30-1.81)	1.61 ± 0.27 (1.43-1.80)
Relative Bench Press 1RM	1.08 ± 0.27 (0.91-1.26)	1.10 ± 0.24 (0.95-1.25)	1.04 ± 0.30 (0.83-1.25)	1.04 ± 0.30 (0.83-1.25)
Relative Total	2.61 ± 0.56 (2.24-2.98)	2.70 ± 0.49 (2.37-3.02)	2.60 ± 0.63 (2.16-3.04)	2.66 ± 0.52 (2.30-3.01)
Allometrically Scaled ISO PF	184.96 ± 12.86 (176.56-193.36)	187.65 ± 16.19 (177.08-198.22)	197.62 ± 35.68 (172.89-222.34)	204.09 ± 30.43 (183.00-225.18)
Allometrically Scaled Back Squat	6.30 ± 1.15 (5.54-7.05)	6.60 ± 1.06 (5.90-7.29)	6.78 ± 1.82 (5.52-8.05)	7.04 ± 1.52 (5.99-8.10)
Allometrically Scaled Bench Press	4.48 ± 1.07 (3.79-5.18)	4.57 ± 0.94 (3.95-5.18)	4.58 ± 1.54 (3.52-5.65)	4.60 ± 1.58 (3.50-5.70)

Body Mass, Skeletal Muscle Mass, Back Squat and Bench Press = kg
Absolute Total = back squat 1RM + bench press 1RM
Allometrically scaled data = Exercise/Body Mass ^ 0.67
Relative Exercise 1RM = Exercise 1RM/ Body Mass
ISOPF=Isometric Peak Force, measured in Newtons (N)
ISO RFD= Isometric Rate of Force Development, measured in N*s

Although the males were larger and stronger than the females, both responded similarly from pre to post testing (Male BS = 1.64 ± 0.32 kg*kg^{-1}, Female BS = 1.39 ± 0.32 kg*kg^{-1}, Male BP = 1.21 ± 0.22 kg*kg^{-1}, Female BP = 0.80 ± 0.14 kg*kg^{-1}). Therefore, the effect of sex was not considered further.

Allometrically scaled back squat, relative back squat, and absolute back squat 1RM all violated normality, according to the Shapiro-Wilks test. The permutation test was applied for the omnibus ANOVAs for allometrically scaled, relative, and absolute back squat 1RMs. ANOVA tests showed statistical significance only for the main effect of time for BS and Strength Total variables (Absolute BS $p = 0.008$, Relative BS $p = 0.02$, Allometrically Scaled BS $p = 0.02$, Absolute Total $p=0.02$, Relative Total $p = 0.04$, Allometrically Scaled Total $p = 0.02$).

No other variables showed signs of deviation from the normal distribution, nor was any statistical significance observed among the variables for any of the main or interaction effects. There was a trend of greater effect size in AEL among most variables (Table 7).

It is worth noting that one of the TRAD training subjects became ill during the functional overreach week of training. Their performance decreased from pre to post-test. However, removing them from the data set did not change any statistical significance nor the effect sizes.

Table 7

Percent Change and Hedge's g Results

Variable	AEL % change (Hedges' g)	TRAD % change (Hedges' g)
Body Mass	0.82% (0.33)	0.36% (0.16)
Back Squat 1RM	5.30% (0.58)	4.16% (0.52)
Relative Squat 1RM	4.49% (0.52)	3.76% (0.42)
Allometric Back Squat 1RM	4.72% (0.55)	3.86% (0.46)

Bench Press 1RM	2.60% (0.36)	1.19% (0.18)
Relative Bench 1RM	1.49% (0.22)	0.07% (0.01)
Allometric Bench Press 1RM	1.84% (0.28)	0.42% (0.06)
Absolute Total	4.17% (0.54)	2.95% (0.43)
Relative Total	3.24% (0.47)	2.28% (0.31)
ISOPF	1.84% (0.13)	3.58% (0.28)
Allometric ISOPF	1.45% (0.01)	3.28% (0.10)
ISO RFD (0 – 200 ms)	-0.93% (-0.01)	-20.57% (-0.33)

Discussion

The primary purpose of this study was to investigate the strength responses from implementation of AEL paired with CS during a strength-endurance block. A large volume of this research has been performed using machines, did not include CS, only used AEL on one exercise, or they lacked any sprint and agility training as is typical for strength and conditioning programs for athletic performance. To the authors' knowledge, this is the first training study that applied weight releasers with supramaximal loading to two primary compound exercises during higher training volumes (sets using 8 or more repetitions), which is not typically used for developing maximal strength. Importantly, the experimental design used a strength and conditioning program often observed with collegiate athletes.

A strength-endurance concentrated load functions to alter body composition and especially work capacity (Plisk & Stone 2003; Stone et al., 2021). Although there is some disagreement, existing evidence indicates that AEL might be able to stimulate a superior strength response (Doan et al., 2002; Friedmann et al., 2004; English et al., 2014; Ersoz et al., 2022; Hortobagyi et al., 2000). In the current study, although the statistical results do not support greater gains in maximum strength, the magnitude of gain (ES) did generally, if trivially, favor AEL (e.g. ISORFD, back squat, and bench press).

Of particular note is the AEL induced maintenance of RFD. While RFD resulted in a characteristic training volume induced decrease in the TRAD group (Stone et al., 2019; Suarez et al., 2019), no decrease was observed in the AEL group (TRAD = -20.40%, AEL = -1.08%).

Decreases in isometric RFD following a training block with higher training volumes have been consistently noted among well-trained strength power athletes (Stone et al., 2019; Suarez et al., 2019). Wagle et al., (2018), using trained subjects (Sq/BdM = 1.8), observed acute decreases in concentric RFD, peak power, and average velocity in the TRAD group compared to the AEL group during squatting. In the current study, the subjects, as a group, were considered moderately trained. A trend, based on % loss and effect size, in isometric RFD was noted with the AEL group realizing a smaller decrease. There are several factors which may explain this apparent decrease in RFD. First there can be a shift of myosin heavy chains toward a slower type with higher volume training (Andersen et al., 2005; Travis et al., 2020), and second, there may have been a fatigue difference in the groups. Perhaps chronic use of AEL may better maintain RFD characteristics compared to TRAD, which would be ideal during a high-volume block where RFD characteristics are not maintained well. This may especially be true when paired with CS, which may also help to mitigate fatigue and RFD decreases (Haff et al., 2008; Tufano, Brown, & Haff 2017). It is possible that the AEL induced a trend toward increased maximum strength and, especially, the maintenance of RFD could create more favorable potentiating characteristics for the later training blocks, emphasizing strength gains. Further research is warranted to ascertain whether or not the use of weight releasers and CS during higher volume sets of resistance training may help to attenuate decreases in RFD.

It should be noted that different exercises activating different muscle groups, different loading and repetitions schemes, and different training devices can induce different levels of fatigue, force and power output, recovery times and adaptations (Ma 2011; Nuzzo et al., 2023) making it difficult to compare results between studies. For example, the findings of this study conflict with Brandenburg & Docherty (2002) who found statistically significant increases in strength in an AEL group using sets of 10 reps. However, Brandenburg and Docherty (2002) used AEL (110-120% eccentric/75% concentric) with the single-joint preacher curl and triceps extension exercises. The differences in range of motion and the amount of muscle mass under eccentric overload between these exercises and those used in the current study may explain the conflict in the findings within the available body of research (Merrigan et al., 2022).

The lack of sprint and agility training in the available research could also help explain the lack of interaction effect observed in the current investigation. The addition of these two days of training would have required a greater energy demand from the subjects and may have interfered with recovery abilities, reducing their responses to the strength training compared to the other studies that only strength trained.

However, other investigators also reported the lack of unique responses after AEL applications (Barstow, Bishop & Kaminski 2003; Godard et al., 1998; Johnson et al., 1976; Yarrow et al., 2008; Ojasto & Hakkinnen 2009). Johnson et al., (1976) had a TRAD group use 75/75% with 2 sets of 10 and an AEL group use 120/80% for 2 sets of 6 with the arm curl, arm press, knee flexion and knee extension exercises. The investigators found no differences in strength responses. This was attributed to the difference in work done between the two groups as the TRAD group performed more work even with less eccentric loading. Likewise, Yarrow et al., (2008) had more work performed with the TRAD group and found similar strength results between the TRAD and AEL groups after training 3 sessions per week for 5 weeks. AEL intensities started at 100/40% and progressed over the 5 weeks up to 121/49% (3 sets of 6 reps) while the TRAD group started at 52.5% and finished at 75% (4 sets of 6 reps). Additionally, Godard et al., (1998) used sets of 8-12 repetitions and semi-isokinetic leg extensions and found no statistical differences between AEL and traditional training agreeing with our findings. As previously mentioned, these studies investigated AEL use with machines or single joint exercises, which make it difficult to compare results with the present study (Brandenburg and Docherty 2002, Godard et al., 1998, Johnson et al., 1976, Yarrow et al., 2008).

Unlike the previously mentioned studies, more volume was used for the AEL group compared to the TRAD in relative terms, (Table 5: Relative VLd/Relative Total Strength = 4.50%, Relative VLd/BdM = 17.75%) yet similar maximum strength responses were noted between both groups (Table 6). This again suggests that the volume of work does not necessarily affect the magnitude of strength alterations (Painter et al., 2012; Schoenfeld et al., 2019). The current evidence presented suggests that the difference in relative volumes and exercise selections observed in AEL training studies do not explain their results.

The findings of this study conflict with another chronic training study by Ersoz et al., (2022), who used AEL with a similar training program, but used much lighter loads (85% eccentric/50% concentric) for two groups. One group used CS and applied AEL to every other rep while the other group applied AEL to the first rep only. Results showed that using AEL every other rep provided superior results over the single group. While Ersoz et al., (2022) found greater maximum strength improvement with more AEL repetitions, this may be due to concentric loads being too light, and the single AEL repetition group only experienced 80% 1RM for one eccentric movement for a set of 8 reps while the rest of the set used 50%, which may be too light to result in substantial strength adaptations (Cunanan et al., 2018). While the additional 80% is still considered light by most AEL investigators (Suchomel et al., 2019; Wagle et al., 2017), it would likely provide a much greater strength stimulus compared to 50% 1RM.

Research indicates that AEL may not stimulate superior strength adaptations due to the fatigue incurred by using AEL (Ojasto & Hakkinnen 2009). It is possible that the subjects in the current study were unable to optimally recover from the AEL due to the enhanced workload performed using the weight releasers. Pair this with the addition of sprint and agility work on days between resistance training and individuals may struggle to recover enough between sessions. However, for the current study, there are several factors which may obviate this argument. First there were heavy and light days during training to better manage fatigue of the training subjects (DeWeese et al., 2015). Second, it should be noted that there was unloading during the final training week and the two days of no training before testing. These factors should have facilitated recovery, thus differences between groups in accumulated fatigue would be less likely. Indeed, in a previous acute study, Chae et al., (2023), using the same protocol as in the current study, demonstrated that the AEL protocol resulted in lower lactates during exercise and 10 min recovery, and similar HR's and VJ alterations at 5 and 10 min post exercise compared to the TRAD group.

Additionally, an optimal relative strength ratio and trained status has been speculated to exist for individuals to better respond to the training demands of AEL (Wagle et al., 2017). However, this optimal strength ratio has yet to be defined. It is also possible that the optimal load could vary between individuals (Merrigan et al., 2020; Ojasto & Hakkinnen 2009; Wagle et al., 2017; Walker et al., 2017). Therefore, a factor affecting the outcome of the current investigation was that the sample of subjects used may not have had a high enough relative strength ratio, allometrically scaled strength level, or training status to have benefitted from the AEL protocol. Future research should investigate if there is an optimal relative strength ratio required to benefit from AEL training.

To summarize, there were significant increases in back squat 1RMs, and absolute and relative strength totals for the whole subject pool. Although statistically there were no differences in maximum strength increases between groups, ES and percent gain pre-post, particularly for RFD suggest that training with AEL may produce beneficial alterations (especially RFD maintenance) which may better potentiate gains in strength and power gains during later training blocks targeting strength and power alterations. Future research should be aimed at using multiple blocks to ascertain if a potentiated training adaptation from AEL using weight releasers use would provide enhanced adaptations.

Practical Applications

While evidence exists that AEL may stimulate acute increases in 1RM (Doan et al., 2002) it remains to be seen if it would do so chronically. The findings of the current investigation suggest that the combination of CS and AEL may be, at best, marginally more effective at developing strength gains than traditional resistance training during a strength-endurance block. Of note, it appears that AEL use may obviate decreases in RFD that are commonly noted as a result form higher training volume (Stone et al., 2019).

Considering the marginally positive effects of the current AEL protocol, the practicality of AEL should be considered. From a cost benefit ratio standpoint, based on these results, the extra- cost, time, and effort necessary to load, and re-attach weight releasers, particularly in large teams setting in which the weight releaser length must also be adjusted between athletes, may not outweigh the benefits. Another potential factor that would make the use of AEL more challenging is the notion that individuals are likely to have different optimal loading prescriptions (Ojasto & Hakkinnen 2009; Wagle et al., 2017). Should this be the case, the level of attention to each individual's training prescription increases substantially compared to traditional programming methods.

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Chapter 4. Study II

THE ENDOCRINE, CREATININE AND BODY COMPOSITION RESPONSES TO THE COMBINED USE OF AEL AND CS DURING A STRENGTH ENDURANCE TRAINING BLOCK.

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Abstract

The purpose of this study was to investigate the chronic effects of accentuated eccentric loading (AEL) paired with cluster sets (CS) on the creatinine and endocrine alterations. Sixteen recreationally active subjects (male = 11, females = 5 age = 22.59 ± 3.47, height = 173.03 ± 9.49, body mass = 82.93 ± 21.83, back squat to body mass ratio = 1.57 ± 0.34, bench press to body mass ratio = 1.09 ± 0.27) participated in one familiarization week, 2 weeks of testing, and 4 weeks of training. A strength-endurance block (4 wks) was used for training in which the target load consisted of 3 sets of 10 repetitions. The AEL group performed 3 sets of 10 repetitions for the squat and bench press using AEL every other repetition (5 AEL repetitions per set). Because of this protocol, CS were also performed as one AEL repetition plus one traditional repetition followed by 15 s rest. Weight releasers were attached during the rest between clusters. Resistance training was performed three days a week, sprint and agility work were performed two days a week. Testosterone (T), Cortisol (C), and Creatinine (CREA), fat mass (FM) and fat free mass (FFM) were assessed pre and post-test. No statistically significant differences in resting blood variables or body composition occurred between the AEL and TRAD protocols after 4 weeks of training.

Introduction

The effect that hormones have on human performance has been investigated (Crewther et al., 2008; Kraemer & Ratamess 2005). The impact that resistance training can have on the endocrine system can be substantial, particularly training programs that incorporate higher training volumes, such as a strength-endurance block used within an accumulation phase of Block Periodization (Crewther et al., 2008; Smilios et al 2003; Stone et al., 2021). A training methodology that has gained interest in recent years is AEL. Theoretically, AEL takes advantage of the superior force production capabilities of eccentric muscle contractions and overloads the eccentric movement with a greater load compared to the concentric movement (Suchomel et al., 2019). CS have been suggested as a practical means to apply AEL to multiple repetitions throughout a training set (Wagle et al., 2017). While strength-power responses to AEL have been studied (Wagle et al., 2017), however there is a paucity of literature dealing with endocrine response and adaptation.

The balance of resting hormone concentrations, such as the testosterone:cortisol ratio (T:C) can serve as an estimate of "state" of recovery and as an estimate of "anabolic state" (Ahtiainen et al., 2003; Painter et al., 2018; Peeri et al., 2012, Vervoorn et al., 1991). The post resistance exercise responses of hormones such as growth hormone, T, C, and the T:C ratio may promote protein synthesis (Kraemer and Ratamess 2005). However, the response from subsequent physiological and performance adaptations appears to be relatively minor (Brunsden 2023; Fink et al., 2018; Schoenfeld et al., 2013). Chronic elevations appear to have a substantially greater effect and can be affect by alterations in training volume (Grandys et al., 2023; Painter et al., 2018).

High-volume protocols, which are typically used to achieve muscle hypertrophy and predominantly rely on the glycolytic lactate metabolic pathway, appear to stimulate greater post-exercise responses (Kramer and Ratamess 2005). However, high-volume programs can produce different effects on endocrine alterations post-training, perhaps depending upon the trained state of the athlete. For example, among previously untrained or recreationally trained males and females, short-term high-volume training has resulted in slight elevations in T and decreases C (Staron et al., 1994; Uchida et al., 2004). Among very well-trained subjects, following high volume programs, resting concentrations of T and the T:C ratio may be depressed, and C increased, sometimes after only a few weeks, and likely reflects training monotony and strain (Hakkinen et al., 1987; Painter et al., 2018).

In addition to T and C, creatinine (CREA) has been used as a biomarker to monitor physiological alterations to training. CREA is largely created from the breakdown of creatine, which is stored in relatively large amounts in skeletal muscle (Samra 2012, Wang et al., 1996). CREA is cleared through the kidneys and urinary CREA excretion strongly reflects the amount of muscle mass in the individual (Heymsfield 2014; Vinge et al., 1999; Wang 1996). A cross-sectional study of active young men and athletes indicates that larger muscle masses among this group is accompanied by greater urinary creatinine values (Sagayama et al., 2023). Resistance training has been associated with considerable hypertrophy (Schoenfeld et al., 2019), particularly programs using higher training volumes, thus, gains in urinary CREA may be expected. However, the effects of gaining muscle mass as a result of resistance training and alterations in CREA concentrations have not been well studied.

One possible aspect that may favor the use of AEL involves work accomplished. It is possible, and commonly believed, that greater volumes of work would stimulate a larger performance adaptation (Crewther et al., 2008; Rhea et al., 2003). However, other studies do not agree and indicate that how work is manipulated may be more important than total work. (Painter et al., 2012; Schoenfeld et al., 2019). As previously noted, high-volume resistance training programs are often used during the accumulation phase of block periodization (Stone et al.2021). For strength-power athletes, the first “fitness” block of the accumulation phase is typically a strength-endurance block, usually with high repetitions per set. This strength-endurance block is used with the expectation of increasing work capacity, improving recoverability and altering body composition, including FFM (Stone et al., 2021). It is known that this block can result in considerable training monotony and strain (Painter et al., 2018). The use of a training method that could accomplish the same or superior physiological alterations with reduced training strain could be advantageous. Using acute observations, recently Chae et al., (2023; 2024) have shown that the chronic use of AEL and cluster sets (weight releasers) might be used to accomplish these chronic alterations with lower training strain.

Overall, there is a paucity in the research concerning metabolic alterations and AEL use, especially chronic training and even more so with high training volumes used in training studies. Therefore, the primary purpose of the current study was to investigate the endocrine and body composition responses to AEL, using programming that may reduce training strain, compared to TRAD during a strength-endurance training block.

Methods

Experimental Approach to the Problem

This was a between-group repeated measures design where paired subjects were randomly assigned to either the AEL or TRAD training group. The training study took place over 7 weeks. The first week was a familiarization week in which subjects were exposed to the tests prior to maximal effort as well as weight releaser use. Weeks 2 and 7 were pre and post-test weeks where strength data were collected. All of the subjects participated in three days of resistance training and two days of sprint and agility training from weeks 3 through 6. Sprints and change of direction (COD) exercises were performed on Tuesday and Thursday of each training week to make the training more typical of that of athletes. Each resistance training session (M, W, F) was composed (after warm-ups) of 3 sets of 10 reps for every exercise. Each resistance training session was composed (after warm-ups) of 3 sets of 10 reps for every exercise, Tuesday focused more on sprint work and mechanics while Thursday focused more on change of direction.

Subjects

Sixteen recreationally active individuals (male = 11, females = 5, age = 22.59 ± 3.47, height = 173.03 ± 9.49, body mass = 82.93 ± 21.83, back squat to body mass ratio = 1.57 ± 0.34, bench press to body mass ratio = 1.09 ± 0.27) volunteered for the current investigation. Subjects qualified to participate if they had resistance training experience with the back squat and bench press exercises for at least a year. Subjects were excluded from the investigation if they had previous experience with weight releasers in training over the last year, missed more than 10% of the training sessions, missed any testing sessions, or had any injuries that limited their performance during training or testing. Eighteen subjects were recruited, one was excluded from the study for missing the post training testing measurement sessions, while another was unable to have blood obtained during the post testing measurement. Therefore, both were excluded from the study.

All subjects read and signed a written informed consent document, and the procedures of the investigation were approved by the university's Institutional Review Board (ETSU IRB ID# 0822.2f).

Procedures

Familiarization. The subjects went through a familiarization period the week before testing. A standardized warm up was used before each familiarization session and testing session (Kraska et al., 2009). On Wednesday, subjects were exposed to back squats with weight releasers (Rogue; Columbus, OH) in order to better prepare them for the uniqueness of using weight releasers. Subjects performed a number of sets with low repetitions (2-3) with 50% of their 1RM loaded on the weight releasers (weight releaser plus the load added to each weight releaser) that would detach upon completing the eccentric movement. A similar process with the weight releasers was used for bench press on Friday.

Testing. Subjects underwent a testing week (Pre) after the familiarization week and after the final week of training (Post). Before any testing was performed, subjects had to be reasonably hydrated (USG < 1.02) as assessed by using a refractometer (Atago CO., LTD, Tokyo, Japan) to test urinary specific gravity (Wetmore et al., 2020). After passing hydration (urine specific gravit > 1.020), blood samples were collected Monday morning between 6:00 and 8:00 am during a fasted state (≥ 8 hrs). Blood samples were obtained from the antecubital vein by a licensed phlebotomist. Samples were collected into serum separator tubes (BD Vacutainer, Becton, Dickinson and Company, Franklin Lakes, NJ) and left to clot for 20 minutes after being drawn. After clotting, blood samples were centrifuged (VanGuard V6000, SmithKline Beecham Clinical Laboratories, Montvale, NJ) and the serum was stored at –70°C (So-Low, Environmental

Equipment Co., Inc. Cincinnati, OH) until ready to be analyzed. The blood collection and preparation process was repeated post-training.

Once ready to be removed from storage, the serum samples were thawed to room temperatures and mixed to reverse any serum separation that may have occurred. Serum samples were then transported (approximately 10 min) in an ice box to a medical lab to be analyzed via Siemens Atellica IM Analyzer 1300 (Simens Healthcare Diagnostics INC, Walpole, MA). After having blood samples collected, subjects had body mass and body composition assessed via a SECA mBCA 514 (Seca Medical Scales, Chino, CA).

Dynamic strength was measured Pre post training via 1RM test for back squat and bench press using the protocol described by Wetmore et al., (2020). The 1RM back squat test took place on Monday while the bench press 1 RM test took place on Wednesday of the test weeks. Dynamic strength was measured absolutely, per kg of Bdm and Allometrically. Allometric scaling was carried out by dividing absolute 1RM by $BdM^{(0.67)}$ (Stone et al., 2019, Suchomel 2018).

Training Program. The *relative strength* score (BS 1RM/BM + BP 1RM/BM) was used for pairing subjects. The pairs were then randomly assigned to groups AEL (males = 6, females = 2) and TRAD (males = 5, females = 3). The two groups participated in a four-week strength-endurance block of training. Resistance training was performed on Monday, Wednesday, and Friday. Sprint and agility training were Tuesday and Thursday respectively. Each week, training sessions lasted for ~45-60 minutes each day. See tables 1, 2 and 3 for details regarding program overview and exercise selection. Sprint and agility sessions were included to better simulate a typical training program of strength-power athletes (Carroll et al., 2020; Wetmore et al., 2020). Additionally, training volume was not equated as previous research has shown difficulties in trying to match volume between TRAD and AEL training (Yarrow et al., 2008) and, equating workload is not ecologically viable, particularly in sport scenarios (Stone et al., 2022).

A duration of four weeks of training was selected as existing evidence has shown AEL can stimulate adaptations within that time frame (Doan et al., 2002, Friedman et al., 2004) and this is a common time frame for a strength-endurance concentrated load used as part of an accumulation block (Stone et al., 2021).

Prior to each training session, subjects completed a dynamic warm-up. Upon completion of the warm-up, the two groups began their training session while being supervised by a minimum of two certified strength and conditioning specialists (CSCS). Subjects performed resistance training sessions at the same times, but in separate weightrooms and performed sprint and agility sessions together. Investigators were periodically rotated to limit any coaching bias.

On days where subjects performed the back squat and bench press, specific warm-up protocols were performed before moving to working sets. See Table 4 for a description of back squat and bench press warm-up protocols. The AEL group would perform their working sets as 3 sets of 5 clusters of 2 repetitions (3x5x2 = 30 total repetitions). Weight releasers were applied to every other rep for the back squat and bench press exercises. This was performed during a 15 second intra-repetition rest break after every second repetition. Volume load was calculated (total reps x load in kilograms) and then multiplied by barbell displacement in meters of the back squat and bench press (VLd). Displacement was recorded during the familiarization week. VLd for the AEL group included the enhanced eccentric loading applied via weight releasers. VLd was then divided by body mass and relative strength totals to gain insight on how body size and relative strength levels impacted their total work. See Table 5 for volume load information. Allometrically scaled VLd was calculated by dividing the total volume load by body mass raised to 0.67 power. In order to better estimate training work between groups, training monotony (Mean Allometrically scaled VLd per microcycle/Standard Deviation) and strain (Training Monotony x Allometrically scaled VLd) were calculated and displayed in Table 6 (Painter et al., 2018).

Statistical Analyses

Data were analyzed via R (Version 4.3.2; R Core Team, Vienna, Austria). Descriptive statistics were calculated along with mean and standard deviation (SD). A 2 (groups) x 2 (time points) repeated-measures analyses of variance (ANOVA) was performed to determine if any statistical significance was found amongst the pre and post-test values. Statistical significance criteria were set at an α level of ≤0.05. Hedges g was used to calculate the effect size of the results of the investigation (0.0 – 0.2 (trivial); 0.2 – 0.6 (small); 0.6 – 1.2 (moderate); 1.2 – 2.0 (large); 2.0 – 4.0 (very large); 4.0 - ∞ (nearly perfect) (Hopkins et al., 2009). To account for assumption violations, data that violated data distribution assumptions were bootstrapped in R for 1000 permutations.

Pearson's r was calculated on pre and post FFM and CREA values to identify whether CREA levels can be used as biomarkers to monitor FFM changes to resistance training. Additionally, correlations were performed between pre and post FFM and strength metrics to identify the relationship of FFM and the influence it may have on maximum strength. The magnitude of r values was set as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), and extremely large (0.9+) (Hopkins et al., 2009). Correlations were calculated in Microsoft Excel (Version 2311, Microsoft, Redmond, WA).

Table 8

Resistance Training Overview

Week	Sets x Reps	TRAD		AEL		
		Day 1 & 3	Day 5	Day 1	Day 3	Day 5
1	3 x 10	57.5%	50%	110*/57.5%	57.5%	110*/50%
2	3 x 10	62.5%	55%	110*/62.5%	62.5%	110*/55%
3	3 x 10	67.5%	57.5%	110*/65%	67.5%	110*/57.5%
4	3 x 10	52.5%	45%	110*/52.5%	52.5%	110*/45%

*Intensity is prescribed as % 1RM. AEL = Accentuated Eccentric Loading, TRAD = Traditional, Isoinertial Resistance Training. * Indicates AEL repetitions **Indicates down sets (traditional 1x5 55% of target con).*

Table 9

Resistance Training Exercise Selection

Day 1	Day 3	Day 5
BS*, BP*, DB Triceps Extension	CG MTP, CG SLDL, BB Row	BS*, BP*, DB Triceps Extension

BS = Back Squat, BP = Bench Press, CG = Clean Grip, SG = Snatch Grip, MTP = Mid-thigh Pull, SLDL = Stiff Legged Dead Lift, DB = Dumbbell
** Indicates exercise performed with AEL repetitions by the AEL group*

Table 10

Sprint and Agility Training Overview

Week	Day 2	Day 4
1	BU: 2x15m BU: 2x25m Accel: 4x4x10m Crunches: 3x25	BU 2x20m Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit 5m to decel) 1x4x5m 180* turn (exit 5m ro decel) 1x4x5m
2	BU: 2x15m BU: 2x25m Accel: 4x4x15m Crunches: 4x25	BU 2x20m Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit to 5m decel) 1x4x10m

		180* turn (exit 5m to decel) 1x4x10m
3	BU: 2x15m BU: 2x25m Accel: 4x4x20m Crunches: 4x25m	BU 2x20m Linear Decel 1x4x7.5m Lateral Decel 1x4x7.5m Sidetep cut (exit to 5m decel) 1x6x10m 180* turn (exit to 5m decel) 1x6x10m
4	BU: 2x15m BU: 2x25m Crunches: 2x25	BU 2x20 Linear Decel 1x4x5m Lateral Decel 1x4x5m Sidestep cut (exit to 5m decel) 1x4x5m 180* turn (exit to 5m decel) 1x4x5m

BU = Build Up

Table 11

Overview of Back Squat and Bench Press Warm Up Procedures

5-Minute General Dynamic Warm Up

Back Squat Warm Up:	Bench Press Warm Up
TRAD	TRAD
1x5 at 30% 1RM	1x5 at 30% 1RM
1x5 at 50%1RM	1x5 at 50% 1RM
1x2 at 75% 1RM	1x2 at 75% 1RM
AEL	AEL
1x5 at 30% 1RM	1x5 at 30% 1RM
1x5 at 50% 1RM*	1x5 at 50% 1RM*

Table 12

Average Volume Loads (Back Squat + Bench Press)

Groups	VLd	VLd/Body Mass	VLd/Allometricaly Scaled	VLd/Relative Strength
AEL	30,774 ± 7712	408.54 ± 79.96	1693 ± 329	12,102 ± 3679
TRAD	30,950 ± 14,367	341.93 ± 104.18	1500 ± 513	11,572 ± 4133

VLd= Volume Load displacement (total reps x kilos x barbell displacement in meters)
VLd/Allometrically Scaled = VLd/BM $^{0.67}$
VLd/Relative Strength = VLd / Relative Back Squat 1RM + Relative Bench Press 1RM

Table 13

Training Monotony and Strain

Groups	Training Monotony	Training Strain
AEL	1.29	544.50
TRAD	0.73	274.12

Training Monotony = Mean Allometric VLd per microcycle/SD
Training Strain = Training Monotony x Mean Allometric VLd

Results

Allometrically scaled back squat, relative back squat, and absolute back squat 1RM all violated normality, according to the Shapiro-Wilks test. The permutation test was applied for the omnibus ANOVAs for allometrically scaled, relative, and absolute back squat 1RMs. ANOVA tests showed statistical significance only for the main effect of time for BS and Strength Total variables (Absolute BS $p = 0.008$, Relative BS $p = 0.02$, Allometrically Scaled BS $p = 0.02$, Absolute Total $p=0.02$, Relative Total $p = 0.04$, Allometrically Scaled Total $p = 0.02$). No other variables showed signs of deviation from the normal distribution, nor was any statistical significance observed among the variables for any of the main or interaction effects. (Effect sizes and percent alterations are noted in Table 7. There was a trend of greater effect size in AEL among most variables.

Table 14

Strength Descriptive Statistics Using Mean ± SD (Upper and Lower Limit of CI)

Independent Variable	Pre Test AEL	Post Test AEL	Pre Test TRAD	Post Test TRAD
BdM	75.62 ± 17.04 (64.49-86.75)	76.24 ± 17.38 (64.89-87.59)	87.68 ± 26.55 (69.28-106.08)	88.0 ± 26.89 (69.36-106.64)
Back Squat 1RM	113.22 ± 23.11 (98.12-128.32)	119.22 ± 22.64 (104.43-134.01)	138.38 ± 55.90 (99.64-177.11)	144.13 ± 55.75 (105.50-182.75)
Bench Press 1Rm	81.11 ± 21.60 (67.00-95.22)	83.22 ± 21.06 (96.46-96.98)	94.88 ± 44.13 (64.29-125.46)	96.0 ± 46.48 (63.79-128.21)
Isometric Peak Force	3322 ± 413.33 (3053-3593)	3383 ± 432.69 (3101-3666)	3975 ± 1194 (3148-4803)	4118 ± 1214 (3276-4959)
Isometric RFD	4077 ± 2345.35 (2545-5609)	4039 ± 1550 (3027-5052)	4306 ± 3478 (1895-6716)	3420 ± 3504 (991-5848)
Relative Squat	1.53 ± 0.32 (1.32-1.73)	1.60 ± 0.30 (1.40-1.79)	1.56 ± 0.38 (1.30-1.81)	1.61 ± 0.27 (1.43-1.80)
Relative Bench Press	1.08 ± 0.27 (0.91-1.26)	1.10 ± 0.24 (0.95-1.25)	1.04 ± 0.30 (0.83-1.25)	1.04 ± 0.30 (0.83-1.25)
Allometrically Scaled ISO PF	184.96 ± 12.86 (176.56-193.36)	187.65 ± 16.19 (177.08-198.22)	197.62 ± 35.68 (172.89-222.34)	204.09 ± 30.43 (183.00-225.18)
Allometrically Scaled Back Squat	6.30 ± 1.15 (5.54-7.05)	6.60 ± 1.06 (5.90-7.29)	6.78 ± 1.82 (5.52-8.05)	7.04 ± 1.52 (5.99-8.10)
Allometrically Scaled Bench Press	4.48 ± 1.07 (3.79-5.18)	4.57 ± 0.94 (3.95-5.18)	4.58 ± 1.54 (3.52-5.65)	4.60 ± 1.58 (3.50-5.70)

Body Mass, Skeletal Muscle Mass, Back Squat and Bench Press = kg
Absolute Total = back squat 1RM + bench press 1RM
Allometrically scaled data = (Exercise (kg))/〚Body Mass〛^0.67
Relative Exercise 1RM = 1RM/(Body Mass)
ISOPF=Isometric Peak Force, measured in Newtons (N)
ISO RFD= Isometric Rate of Force Development, measured in N·s-1

No violation of assumptions was observed among all of the variables. No additional statistically significant pre-post training main effects were found among the variables, sexes, or groups (p>0.05). See Tables 8 & 9 for a list of the means, standard deviations and confidence interval limits. However, different effect sizes were noted (Table 10).

While not statistically significant, T and C responded differently between the AEL group and TRAD groups. Based on effect size and % change, the AEL group experienced more favorable endocrine responses overall. There was a moderate effect noted in the T alteration magnitude between AEL and TRAD (AEL = 9.12%, g = 0.30; TRAD = -11.24%, g = -0.34) and similar increases in C for AEL, but with a stronger magnitude of C increase for the TRAD group (AEL = 10.14%, g = 0.18; TRAD = 12.85%, g = 0.29). However, the T:C ratio decreased in both groups similarly (AEL = -12.18%, TRAD = -11.90%) when the individual T:C ratio per subject was calculated and averaged for each group.

CREA levels decreased somewhat in both groups. For the combined groups (n = 16) a moderate correlation was found between both pre (r=0.48) and post (r=0.36) CREA and FFM values. Additionally, very large correlations were found between pre FFM and back squat (r = 0.81), bench press (r = 0.83), and ISOPF (r = 0.86) and between post FFM and back squat (r = 0.86), bench press (r = 0.87), and ISOPF (0.88).

Table 15

Endocrine Descriptive Statistics Using Mean ± SD (Upper and Lower Limit of CI)

Independent Variable	**Pre -Test AEL**	**Post-Test AEL**	**Pre-Test TRAD**	**Post-Test TRAD**
Body Mass	**75.62 ± 17.04** **(64.49-86.75)**	**76.24 ± 17.38** **(64.89-87.59)**	**87.68 ± 26.55** **(69.28-106.08)**	**88.0 ± 26.89** **(69.36-106.64)**

Fat Free Mass	**52.50 ± 11.14 (44.78-59.78)**	**52.97 ± 11.34 (45.11-60.83)**	**60.64 ± 17.47 (48.54-72.74)**	**60.95 ± 17.62 (48.73-73.16)**
Fat Mass	**23.12 ± 5.90 (19.03-27.21)**	**23.24 ± 6.08 (19.02-27.45)**	**27.04 ± 9.09 (20.74-33.34)**	**27.05 ± 9.28 (20.62-33.48)**
Testosterone	**12.32 ± 7.77 (6.93-17.70)**	**13.44 ± 9.02 (7.19-19.69)**	**11.31 ± 9.97 (4.40-18.22)**	**10.02 ± 8.46 (4.15-15.88)**
Cortisol	**438.39 ± 183.95 (310.93-565.86)**	**482.83 ± 153.29 (376.61-589.05)**	**552.97 ± 135.88 (458.81-647.13)**	**624.00 ± 277.54 (431.68-816.32)**
T:C Ratio	**3.60 ± 2.43 (2.43-5.28)**	**3.16 ± 2.19 (1.65-4.68)**	**2.60 ± 2.36 (0.62-3.89)**	**1.99 ± 1.92 (0.65-3.32)**
Creatinine	**0.97 ± 0.11 (0.90-1.05)**	**0.96 ± 0.10 (0.89-1.03)**	**1.04 ± 0.16 (0.93-1.15)**	**1.03 ± 0.16 (0.92-1.14)**

Body Mass, Fat Free Mass & Fat Mass = kg
T & C = nmol/l
T:C Ratio = Testosterone/Cortisol x 100

Table 16

Testosterone and Cortisol Results by Sex

Group and Sex	**AEL Female (n=2)**	**TRAD Female (n=3)**	**AEL Male (n=6)**	**TRAD Male (n=5)**
Pre Testosterone	**1.54**	**1.21**	**15.91**	**17.37**
Post Testosterone	**0.97**	**1.31**	**17.60**	**15.24**
%	**-37.04%**	**8.64%**	**10.61%**	**-12.28%**

Testosterone Change				
Pre Cortisol	**626.38**	**549.15**	**375.73**	**555.26**
Post Cortisol	**589.54**	**723.49**	**447.26**	**564.31**
% Cortisol Change	**-5.88%**	**31.75%**	**19.04%**	**1.63%**
Pre T:C Ratio	**0.0024**	**0.0022**	**0.047**	**0.034**
Post T:C Ratio	**0.0016**	**0.0025**	**0.042**	**0.030**
% T:C Ratio Change	**-31.12%**	**10.73%**	**-11.86%**	**-12.77%**

Testosterone & Cortisol = nmol/l

Table 17

Percent Change and Hedge's g Results

Variable	AEL % change (Effect Size)	TRAD % change (Effect Size)
Body Mass	0.82% (0.33)	0.36% (0.16)
Fat Free Mass	0.90% (0.39)	0.51% (0.23)
Fat Mass	0.49% (0.16)	0.05% (0.02)

Testosterone	9.12% (0.30)	-11.44% (-0.34)
Cortisol	10.14% (0.18)	12.85% (0.29)
Creatinine	-1.54% (-0.19)	-0.84% (-0.11)

Discussion

While the volume of research conducted on the endocrine response to AEL is limited, conflicting findings have been found. Most evidence indicates that both acute and chronic endocrine responses are similar between training methods (Merrigan & Jones 2021; Yarrow et al., 2007; Yarrow et al., 2008). However, Walker et al., (2017) indicate that the training induced typical muted hormonal (T and hGH) response to exercise is attenuated as a result of AEL training. The trends noted in the current study challenges the notion that there is a similar endocrine response between AEL and TRAD resistance training.

Even though there was no statistical significance within sexes, there were observations worth noting when sex was considered. The AEL males experienced a small increase in both T and C, while those in the TRAD males decreased in T with slight increases in C levels. However, given that the degree of change in the two hormone concentrations were not equivalent, similar T:C ratio changes were found between the two groups (AEL males = -11.86%, TRAD males = -12.77%), which were similar to group means with females included. Additionally, the T:C ratio improved in TRAD females by 10.73% while it decreased in the AEL females by -31.12%. Additionally, these results should be considered with caution given the low sample size of females within the study.

It is within reason to speculate that due to the kinetic and kinematic characteristics of the AEL group, producing a higher loading while likely reducing fatigue would stimulate an increase in endocrine activity (Chae et al., 2023. Chae et al., 2024; Kraemer & Ratamess 2005). The greater work accomplished by the AEL group and the increase in testosterone suggests that AEL & CS allows for superior workload characteristics that could lead to superior training adaptations without the endocrine system being overly taxed by the greater work (Crewther et al., 2008; Rhea et al 2003;). This observation (more work but smaller homeostatic disturbance) is consistent with the acute findings of Chae et al., (2023; 2024). While statistically insignificant, the effect sizes listed in Table 10 strengthen the idea that AEL paired with CS for higher training volumes is able to provide a superior T:C ratio response, even with a somewhat greater training strain (Table 6).

FFM alterations as calculated from BIA (Moquin et al., 2021), while small, appear to be favoring the AEL group based on ES and percent change. Moquin et al., (2021) demonstrated substantial increases in LBM and muscle hypertrophy over a similar time period with a similar TRAD training protocol and subject pool. There are several potential reasons for the difference in result. 1) It is possible that there was not enough training volume or a long enough time period to stimulate a statistically significant hypertrophy response, even with the eccentric overload for the AEL group. 2) It is also possible that the subjects did not consume enough calories and protein in their diet to facilitate adequate levels of muscle growth (Joanisse et al., 2021; Schoenfeld & Aragon 2018). 3) 3 of the subjects (2 females and 1 male) lost BdM across the 4 wks which effected the result, with those 3 removed a larger increase in FFM was noted (AEL = %1.08; TRAD = %1.20) . Although Moquin et al., (2021) did not note any substantial alterations in diet, future research should aim to track dietary intake should the investigators have the ability to do so. It should be noted that FFM (n = 17) had very large (r= 0.8-0.9) correlations with strength metrics both pre and post training. The correlations were somewhat stronger post-test compared to pretest. These results may suggest that FFM had an influence on maximum strength values and may have contributed to strength gains (Moquin et al., 2021).

It has been suggested that CREA concentrations correlate to lean mass (Baxmann et al., 2008; Chernozub et al., 2023; Malmgren & Grubb 2023, Vinge et al., 1999). While CREA concentrations decreased in both groups, these were trivial changes and moderate correlations (n = 16) between CREA and FFM changes were noted. These correlations are weaker than what has been previously reported (Baxmann et al., 2008). However, more chronic research is required to provide a conclusive narrative on the relationship between CREA and skeletal muscle.

Overall, there appeared to be somewhat favorable endocrine and FFM alterations accompanying AEL and CS use for higher volume training blocks. Future research should investigate the differing response that sexes may experience as the current investigation was unable to recruit enough females to draw any definitive conclusions.

Practical Applications

There has been scarce research conducted on the endocrine response to AEL, especially chronic adaptations. Based on percent changes and ES, the findings of the current investigation suggest that the combination of AEL and CS may stimulate similar, if not slightly superior, endocrine and body composition responses in comparison to TRAD training programs.

Considering the marginally positive effects of the current AEL protocol, the practicality of AEL should be considered. From a cost benefit ratio standpoint, based on these results, the extra- cost, time, and effort necessary to load, adjustment of weight releaser height, and re-attach weight releasers, particularly in large teams setting, may not outweigh the benefits. Another potential factor that would make the use of AEL more challenging is the notion that individuals are likely to have different optimal loading prescriptions (Ojasto & Hakkinnen 2009; Wagle et al., 2017). Should this be the case, the level of attention to each individual's training prescription increases substantially compared to traditional programming methods.

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Chapter 5. Summary and Directions of Future Research

The results of the current studies provide additional information to practitioners regarding the physiological and performance outcomes of accentuated eccentric loading (AEL) paired with cluster sets (CS) implementation during a strength-endurance (SE) training block.

As a result of short-term (4 wks) high-volume SE concentrated load (sets of 10), AEL applied to every other repetition throughout a set of 10 did not yield a superior strength response in comparison to a traditional set rep scheme. Back squat 1 rep max (1RM) values increased for both groups ($p \leq 0.05$). Bench press 1RM values increased as well for both groups but were not statistically significant. An explanation for this could be that the back squats were trained first in the training sessions and thus the subjects were less fatigued, resulting in a superior stimulus applied by the earlier exercises in the session (Simao et al., 2012; Spineti et al., 2010). Additionally, 110% 1RM may have been too great an overload for the bench press exercise as research has found that upper body muscle groups are not able to handle the same supramaximal loading that lower body muscle groups can (Lates et al., 2022). Furthermore, investigations have primarily implemented AEL for only one exercise. It may be that the first exercise with AEL is too fatiguing to allow for a second.

Rate of force development (RFD) is an important factor that is associated with both acceleration and impulse (Maffiuletti et al., 2016). RFD is also sensitive to accumulative fatigue and can show substantial decreases after fatiguing training (D'Emanuele et al., 2021; Suarez et al., 2019). Indeed, substantial decreases in RFD have been observed following SE blocks among weightlifters (Suarez et al., 2019). Superior rate of force development mitigations were found with the AEL group, suggesting less accumulative fatigue. This is likely a result of both the eccentric overload as well as the intra-set rest from the CS used to apply the eccentric overload.

Possible explanations for the superior maintenance of RFD could be conservation (or enhancement) of faster myosin heavy chains within muscle fibers that has been associated with eccentric overload (Travis et al., 2020; Wagle et al., 2017) or a better fatigue management to help mitigate RFD decreases (Tufano, Brown & Haff 2017). Regardless, this observation suggests that the combination of AEL and CS could help to reduce the commonly observed decrease in RFD that is often associated with high-volume training blocks (Stone et al., 2019; Suarez et al., 2019).

An important research concern is the diverse methodology used in AEL studies. The differences in implementation, loading prescription, program design, subject training level, etc., all make it challenging to logically infer findings from study to study (Wagle et al., 2017). One important aspect of future research, would be to narrow the eccentric loading values for different exercises. Consistent eccentric overload prescriptions among exercises would be invaluable for interpretation of future findings.

As challenging as they are to execute, additional chronic studies are needed to better identify the training adaptations that would take place with AEL use. While four weeks of training has been sufficient time for adaptations to take place (Doan et al., 2002; Friedman et al., 2004), longer durations could better detect the efficacy of AEL as a training stimulus for superior training adaptations for athletic populations.

While the endocrine and metabolic results demonstrated a marginally superior result from AEL use, compared to TRAD, the findings were relatively similar. There was an interesting finding in testosterone (T) between the two groups, however. The AEL group experienced a moderate increase in T while the TRAD group experienced a moderate decrease. However, Creatinine decreased (CREA) and Cortisol (C) increased in both groups similarly. The volume of both acute and chronic studies investigating the effects of AEL on endocrine and other metabolic factors are particularly lacking (Merrigan & Jones 2021; Yarrow et al., 2007, Yarrow et al., 2008; Walker et al., 2017,). More acute and chronic research is required to better understand the endocrine and metabolic responses to AEL use.

Body composition results were also similar between groups. Both groups experienced slight increases in body mass, fat free mass while fat mass remained relatively the same between groups. When body composition and its components are variables of interest, AEL research should aim to track caloric and macronutrient intake as closely as these variables could impact alterations fat and fat free mass (Joanisse et al., 2021, Schoenfeld & Aragon 2018). The influence that fat free mass alterations has on strength adaptations with AEL use should also be considered by future investigators.

Overall, the effects of AEL on strength, rate of force development, endocrine and metabolic factors, and body composition are marginal in comparison to TRAD. The additional effort to implement AEL in the form of weight-releasers may warrant caution when considered a training method by practitioners, at least in part due to the additional training time. Conversely, given the potential slight benefit that AEL has demonstrated on these variables within the current investigations, elite athletes may benefit from AEL use, as even the smallest improvement has been shown to be the difference in medaling and a fourth-place finish (Tønnessen et al., 2014).

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