8-2024

Soreness and Perceptual Responses from the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength-Endurance Training Block

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Recommended Citation

Lis, Ryan, "Soreness and Perceptual Responses from the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength-Endurance Training Block" (2024). *Electronic Theses and Dissertations.* Paper 4457. https://dc.etsu.edu/etd/4457

Soreness and Perceptual Responses from the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength-Endurance Training Block

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

by

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August 2024

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Keywords: back squat, bench press, tenderness, psychological fatigue, monitoring

ABSTRACT

Soreness and Perceptual Responses from the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength-Endurance Training Block

by

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The first purpose of the current study was to analyze palpation and movement soreness via the visual analog scale (PVAS and MVAS, respectively) between accentuated eccentric loading (AEL) and traditional resistance training (TRAD) during a month of strength-endurance training. This was measured at the lower body (LB: gluteus maximus and vastus lateralis) and the upper body (UB: pectoralis major, anterior deltoid, and triceps brachii) every day of training (1-20 days) immediately before warming up and after finishing the training session. The MVAS was conducted at a self-selected fast speed. The second purpose was to measure perceptual responses between AEL and TRAD training using the short recovery stress scale (SRSS). The SRSS was measured every day of training, prior to the warmup. A total of 18 recreationally active participants were recruited (Males: $n = 12$, age 22.75 ± 4 years, BW: 89.42 ± 21.09 kg, BP 1RM: 104.67 ± 23.58 kg, relative BP 1RM: 1.19 ± 0.22, BS 1RM: 140.75 ± 39.17 kg, relative BS 1RM: 1.47 ± 0.30, Females: $n = 6$, age: 23.6 ± 4.5 years, BW: 64.3 ± kg, 10.8 kgs, BP 1RM: 51.7 ± 13.4 kg, relative BP 1RM: 0.80 ± 0.13, BS 1RM: 93.7 ± 18 kg, relative BS 1RM: 1.47 ± 0.30). Findings showed statistically lower LB soreness in AEL over time via MVAS ($p < 0.05$). PVAS showed significantly lower LB scores in AEL. The study concludes less soreness for AEL, specifically within the LB when compared to TRAD. Practitioners should not be concerned about excessive soreness when completing AEL. A statistical significant interaction of group and day for muscular stress was found for the SRSS. It appears that TRAD showed a faster decrease in muscular stress compared to the AEL over time. Additionally, physical performance capability and overall recovery increasing and overall stress decreasing reached statistical significant values as the study progressed. We conclude that AEL does not create any major differences compared to TRAD when assessed via the SRSS. Practitioners can use AEL to obtain certain training qualities without the expense of greater stress and somewhat lower recovery rates compared to TRAD.

DEDICATION

I would like to dedicate this dissertation to my parents for being by my side not only for my dissertation, but for my entire life. It would’ve been impossible to get here without your support. A bridge to success cannot be built without a support system.

ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Michael Stone for being a great mentor and educator. You have shown me why ETSU is the number one sport science college in the US. You've shown me all the hard work of completing research. Throughout the years, you've indirectly shown me to never stop learning and to have a passion to learn.

I would also like to acknowledge my undergraduate mentor Dr. Jo Morrison at Longwood University. It is because of you that I am achieving a PhD, because you pushed me academically, because you created hard exams, because you had an interest in exercise physiology, and because you believed in me! Thank you for telling me to pursue a higher education.

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Chapter 1. Introduction

The training stressors that athletes or resistance trained individuals experience within the weight room are important for improving performance on the court/field or in the gym. These training stressors can be modified in numerous ways that involve reps, sets, rest durations, exercise selection, exercise order, training intensities, etc. In the weight-room, one specific training method that is relatively new, is the use of accentuated eccentric loading (AEL). The main rationale for the use AEL is due to the heavier eccentric load that is removed prior to the concentric (Crenshaw et al., 1995; Roig et al., 2009). Currently, the rationale for why AEL appears to elicit better adaptations includes acute neural potentiation that may aid in targeting larger motor units, a fiber-shift towards type IIx, and greater involvement and growth of type II fibers (Wagle et al., 2017). Typically, these are the adaptations that practitioners are striving for in the weight room with strength and power athletes.

The use of AEL has shown better improvements in multiple training adaptations and performances compared to traditional loading (TRAD). Indeed, substantial evidence exists showing support in terms of strength & power outcomes (Brandenburg & Docherty, 2002; Doan et al., 2002; Douglas et al., 2018; English et al., 2014; Friedmann-Bette et al., 2010; Friedmann et al., 2004; Lates et al., 2020; Merrigan et al., 2020; Montalvo et al., 2021; Munger et al., 2017; Walker et al., 2017). However, when comparing AEL vs TRAD, there are some studies that show no differences in terms of strength (Friedmann-Bette et al., 2010; Godard et al., 1998; Moore et al., 2007; Munger et al., 2022; Ojasto & Häkkinen, 2009a) and power (Merrigan et al., 2021; Moore et al., 2007; Munger et al., 2022; Wagle et al., 2018a; Wagle et al., 2018b). In terms of hypertrophy, a few studies have shown better outcomes (English et al., 2014; Friedmann et al., 2004; Norrbrand et al., 2008; Walker et al., 2017). On the other hand, Friedmann-Bette et al. (2010) & Godard et al. (1998) did not find any differences between AEL and TRAD for hypertrophy. The use of AEL has also shown improvement in athletic performances such as 40 m sprints (Douglas et al., 2018). Internally, a physiological adaptation, such as lactate recovery, has also been observed after AEL training (Yarrow et al., 2008). To the author's knowledge, there is only one study (Ojasto & Häkkinen, 2009a) that has shown a significant decrease in force and power with the use of AEL vs TRAD.

There are some concerns and issues that coaches and practitioners may want to avoid with the use of AEL. The first issue is exercise induced muscle damage (EIMD), which can lead to delayed onset muscle soreness (DOMS). This phenomenon has been shown to be substantially elevated 72 hours after intense eccentric exercise intervention (Eston et al., 2000; Saxton et al., 1995). Not only was there soreness but there was also a decrease in maximum strength. The subjects' maximal voluntary contraction (MVIC) remained lower compared to baseline for 5 days (Saxton et al., 1995). Aerobically, RT training methods that involve eccentrics can decrease high intensity (~90% VO2 max) running economy (Assumpção et al., 2013). This time frame may be considered too long, especially if athletes have to complete practice daily. These practice sessions may also be subpar as the athletes would be dealing with soreness, decreased strength and prolonged recovery. It has also been observed that eccentric exercise can impair motor control post exercise (Byrne et al., 2004; Saxton et al., 1995). The time frame for these impairments lasted 48-96 hours post eccentric exercise (Brockett et al., 1997; Saxton et al., 1995, respectively). Overall, the athletes that complete an AEL training session may suffer from DOMS, a decrease in maximum strength, and impaired motor control. All of these factors combined could lead to less than ideal practice sessions, longer recovery and sport coaches not being satisfied with the use of AEL.

Considering subjective evaluations of AEL compared to TRAD sessions, rating of perceived exertion (RPE) values and soreness levels have been consistently higher in AEL conditions (Crenshaw et al., 1995; Merrigan & Jones, 2021; Yarrow et al., 2008). In fact, some study protocols resulted in subjects dropping out due to excessive soreness (Friedmann et al., 2004; Walker et al., 2016). These findings are in part due to the implementation of AEL being a novel stimulus for most individuals (Byrne et al., 2004). Additionally, there is a potential for eccentric contractions to create higher peak and mean forces compared to isometric and concentric contractions could also play a role (Eston et al., 2000). Furtheremore because the tissue is being stretched under tension, there is a marked potential for the shorter fibers to sustain microtears, disrupted sarcomeres and damage to the excitation-contraction (E-C) coupling system, resultant inflammation (Hody et al., 2019; Proske & Morgan, 2001). Indeed, this cascade of events leading to muscle soreness can be of considerable concern. A systematic review by (Douglas et al., 2017a) indicated that the management of soreness is a primary concern for practitioners utilizing AEL.

In terms of psychological modifications from intense training, a review by Nässi et al. (2017) suggested that changes in psychological reactions are more sensitive than physiological markers when assessed via training load. It is also possible that motivated subjects using AEL could derive positive psychological/emotional benefits, resulting from intense exercise and training relating to the enhancement of irisin and beta-endorphin release and accumulation (Daniela et al., 2022).

As the sequelae of events following an AEL session can lead to marked soreness, decreased performance and increased recovery time, coaches should consider the possible physiological and psychological consequences that may occur (Byrne et al., 2004; Nässi et al., 2017). Importantly, to the author’s knowledge, there have been no studies assessing psychological variables with the implementation of AEL.

Furthermore, because research on AEL is in its infancy, 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 (BPR) programs. BP consists of three basic periodization blocks, Accumulation, Transmutation (transition) and Realization (M. Stone et al., 2022). 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 an integrated sprint and resistance training program mimicking a strength-power sport such as throwers would use. 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 (M. Stone et al., 2022). 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 increase 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 that 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. Additionally, 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., 2023a, 2023b). However, this aspect has not been studied. Indeed, exactly how this integration of AEL into an Accumulation phase (SE block) would effect psychological alterations or aspects of injury/soreness is unknown.

The purpose of this study was twofold: 1) compare the soreness values of the upper extremity (pectoralis major, anterior deltoid, and triceps brachii) and the lower extremity (vastus lateralis and gluteus maximus), and 2) compare the psychological recovery variables via the short recovery and stress scale (SRSS) between AEL and TRAD over the course of a 4 week SE fitness block. We hypothesize that the AEL group would have higher soreness in all of the muscles measured and under recovered psychological values compared to the TRAD group.

Chapter 2. Literature Review

Overview

Accentuated Eccentric Loading (AEL) involves completing the eccentric portion of a muscle contraction with a greater load than the subsequent concentric contraction. The use of AEL training has shown benefits across multiple training characteristics such as strength (Brandenburg & Docherty, 2002; Cook et al., 2013; Doan et al., 2002; English et al., 2014; Friedmann-Bette et al., 2010; Norrbrand et al., 2008; Walker et al., 2016, 2017), power (Cook et al., 2013; Friedmann-Bette et al., 2010; Lates et al., 2020; Merrigan et al., 2020; Munger et al., 2022; Ojasto & Häkkinen, 2009a; Taber et al., 2021), and hypertrophy (English et al., 2014; Norrbrand et al., 2008; Walker et al., 2017). All of these are attributes that practitioners strive for their athletes to develop through the course of traditional resistance training (TRAD). However, it is important to note that the previous references cited have shown that AEL has induced statistically significant, greater adaptations compared to TRAD. As McKay et al. (2022) categorized specific groups of individuals based on performance calibers, it's considered that more advanced athletes (highly trained/national level and above) have completed periodized and structured RT within 20% of maximal or close to maximal standards for their respective sport. Therefore, these well-trained individuals may require the use of a novel stimuli, such as AEL, in order to realize a non-uniform increase in performance adaptations (Pearcey et al., 2021).

Implementation of AEL has not always shown positive strength benefits, as several authors have found similar improvements compared to TRAD (Friedmann-Bette et al., 2010; Godard et al., 1998; Moore et al., 2007; Munger et al., 2022). Only one study has demonstrated an AEL induced decrease in strength performance, using the bench press and weight releasers (Ojasto & Häkkinen, 2009a). There are also a few studies that have shown no statistical differences in power improvement (Kristiansen et al., 2022; Moore et al., 2007; Munger et al., 2022; Taber et al., 2021; Wagle et al., 2018a; Wagle et al., 2018b). In terms of hypertrophy, Godard et al. (1998) found no statistically significant differences in thigh girth between AEL and TRAD. While the cited studies indicate that AEL is not guaranteed to produce positive gains compared to TRAD, the majority of the research tends to show that AEL will produce the same, or statistically superior performance adaptations compared to TRAD.

Just like any other training methodology, there are potential drawbacks that may arise from the acute use of eccentric exercise or AEL which has a large eccentric component. These include soreness (Brockett et al., 1997; Crenshaw et al., 1995; Eston et al., 2000; Friden et al., 1983; Hyldahl et al., 2014; Merrigan & Jones, 2021; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995; Yarrow et al., 2008), impaired coordination (Brockett et al., 1997; Byrne et al., 2004; Chen et al., 2023; Paschalis et al., 2008; Saxton et al., 1995), impaired joint reactions (Chen et al., 2023), impaired peak strength (Chen et al., 2023; Friden et al., 1983; Hyldahl et al., 2014; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995), impaired force modulation (Brockett et al., 1997), impaired power output (Friden et al., 1983; Peñailillo et al., 2013), and an increase in the magnitude of perceived efforts (Chae et al., 2023b; Yarrow et al., 2008). Typically, the use of AEL is performed using free weights as it’s more ecologically valid than the use of machines, particularly when working with multiple athletes in a session. However, Papadopoulos et al. (2014) suggested that high eccentric loads should be used for closed kinetic-chain movements (i.e., machines), to help reduce the load on the spine that would occur if open kinetic-chain movements (i.e. free weights) were used. In contrast, substantial evidence suggests that machine training does not always transfer to athletic movement and cognitive function as readily as with free weights (Maior et al., 2020; Prieto-

González & Sedlacek, 2021; Rossi et al., 2018; Stone et al., 2002; Wilke et al., 2020; Wirth et al., 2016). Lastly, a review by Enoka (1996) indicates that eccentrics enhance the tissue damage that is involved with resistance training, which may induce considerable muscle soreness and prolong recovery. Often practitioners attempt to obviate or reduce these conditions in order to avoid interfering with normal sport training, and prevent undue coaches' concerns. It has been suggested that individuals should have a sufficient time length to recover from eccentric based training, especially in sports that require forceful or precise movements in order for peak performance to occur (Child et al., 1998). Therefore, practitioners should consider whether the beneficial adaptations, time requirements, time before competition, and expenses for the implementation of AEL are substantially superior to standard TRAD. Monitoring soreness and psychological variables may provide insight as to whether athletes are expediently recovering from the use of AEL (Nässi et al., 2017). Understanding how AEL affects these variables will help educate practitioners on potential benefits and drawbacks. Currently, there is limited evidence in regards to monitoring soreness and psychological variables in AEL vs TRAD training.

Physiology/Mechanisms

Muscle: Fibers, Bioenergetics, MTU, Fascicle length, and Titin

Muscle fiber (myosin heavy chain, MHC) adaptation may play an important role, as fast twitch fibers have demonstrated the ability to produce 5-6x (type IIa) or 20x (type IIx) more power compared to type I fibers (Bagley et al., 2022). For strength-power athletes a training paradigm that shifts MHC toward IIx or enlarges the type II fiber content, could be of considerable advantage. Therefore, it would be important to have a training methodology focusing on this type of adaptation. However, early studies (Friedmann et al., 2004) indicated a statistically significant increased myosin heavy chain (MHC) IIa content and a marginally statistically significant (p = 0.056) increase of MHC IIx mRNA as a result of AEL training. Additional support was found via Friedmann-Bette et al. (2010), as there was a statistically significant increase in MHC IIB (MHC IIx) mRNA in the AEL group only. In terms of cross-sectional area (CSA), the AEL group had a statistically significant correlation with a change in 1 rep max (RM) and change in functional CSA for type IIx (r = 0.61, p = 0.02) and type IIa (r = 0.6, p = 0.023) (Friedmann-Bette et al., 2010). By inducing adaptations involving an increase in type IIx fibers, faster fiber shortening velocities (Schiaffino & Reggiani, 2011) and improved regulatory factors leading to faster excitation-coupling rates could occur (Ruegg, 1987). These alterations could substantially contribute to an increase in power. A major component of AEL is the eccentric overload. Indirect evidence illustrating how AEL, specifically the eccentric portion, might focus on type 2 fibers is the finding of greater type II damage after eccentric exercise (Friden et al., 1983; Proske & Morgan, 2001). Interestingly, both Friedmann-Bette et al., (2010) and Friedmann et al., (2004) concluded that AEL creates a faster and stronger muscle.

Muscle hypertrophy is stimulated through three primary mechanisms: 1) tension/stretch, 2) exercise induced metabolic alterations and possibly 3) muscle damage (Lim et al., 2022; Schoenfeld, 2010). Muscle tension/stretch is likely a primary stimulatory factor (Schiaffino et al., 2021; Wackerhage et al., 2019). One main reason why eccentric training may be the ideal contraction type for muscular hypertrophy could be due to its ability to fulfill all 3 of the primary stimulatory factors that induce hypertrophy, particularly tension/stretch (Douglas et al., 2017a; Schoenfeld, 2010). Very high mechanical tension will be created when AEL is implemented due to the maximal-supramaximal eccentric loads used (Schoenfeld, 2010). Completing the eccentric portion of an exercise also creates substantial metabolic alteration as well as a high degree of muscle damage (Hyldahl et al., 2014). While TRAD also creates all three stimulatory mechanisms, tension/stretch and muscle damage may not be as readily produced.

Eccentric training increases the signaling molecule interleukin-6 (IL-6), which is responsible for satellite cell activation (McKay et al., 2009). This can explain why there is an increase of satellite cell proliferation following eccentric training, but not as readily for concentric (Cermak et al., 2013; Hyldahl et al., 2014; Suchomel et al., 2019a; Wehrstein et al., 2022). Interestingly, this adaptation seems to only occur in type II fibers and not type I (Cermak et al., 2013; Wehrstein et al., 2022). In contrast, Hyldahl et al. (2014) did not find a fiber specific satellite cell response. One of the possible reasons as to why this primarily occurs in type 2 fibers could be due to the higher motor unit recruitment and fast twitch motor unit preferences during high force contractions (Suchomel et al., 2019a). Therefore, Douglas et al. (2017b) has suggested that maximal eccentric exercise may upregulate signaling pathways for satellite cells, specifically within type 2 fibers.

Friedmann et al. (2004) found a nearly perfect correlation between MHC IIx changes and LDH A mRNAs ($r = 0.97$, $p = 0.001$), suggesting that AEL induces adaptations within the glycolytic pathway. Additionally, Yarrow et al. (2008), found a statistically significant increased lactate clearance in AEL vs TRAD post exercise. The author’s suggested that the use of AEL may offer benefits for athletes who compete at the lactate threshold. Evidence by Peñailillo et al. (2013), in which subjects completed eccentric cycling at 60% of maximum eccentric power produced lower blood lactate levels compared to concentric cycling at the same work-rate and lower values for the second eccentric cycling bout performed 2 weeks later. The physiology behind these improvements could be due to oxygen use being 20-50% less during the eccentric work (Davies & Barnes, 1972; Dufour et al., 2004; Peñailillo et al., 2013), faster VO_2 kinetics

(Perrey et al., 2001), lower metabolism (Dufour et al., 2004; Peñailillo et al., 2013), and a lower cardiac output (Q), heart rate (HR), arteriovenous oxygen difference response (Dufour et al., 2004; Peñailillo et al., 2013). Perrey et al. (2001) did observe higher HR and RPE values compared to the same metabolic rate in the concentric condition, and proposed it was due to peripheral mechanoreceptors (group III and/or IV) and activation of the motor cortex. However, these measurements have only been observed in eccentric cycling when compared to similar workloads of concentric exercise. Using a different exercise mode, downhill walking, Davies & Barnes (1972) found a decrease in the arteriovenous oxygen difference response, which lead to an increase of cardiac output. Paradoxically, Ruegg (1987) has mentioned that fast twitch fibers utilize more ATP and have a higher cost of activation for calcium cycling compared to slow twitch fibers. It could also include the possibility of the eccentric contractions recruiting fewer motor units for the same amount of force compared to a concentric contraction, thus maintaining the same work rate and VO_2 (Perrey et al., 2001). In terms of heat stress, eccentric exercise elicits three times greater heat production (Nielsen et al., 1972), which can increase O_2 dissociation kinetics via the Bohr effect. Contrasting evidence is presented by Peñailillo et al. (2013) who found no statistically significant increase in tympanic temperature during 30 minutes of eccentric cycling, but there was an increase for the concentric cycling condition, which required a greater relative work-rate. However, when focusing on the design of the study, there are two possible confounding factors within Yarrow et al. (2008). The first involved the lower amount of volume (-15%) that AEL completed compared to TRAD (Yarrow et al., 2008). Secondly, the subjects were completely untrained. Contrasting results were noted by Ojasto & Häkkinen, (2009b) using the bench press and finding statistically significant, greater lactate values in the AEL group compared to TRAD in moderately trained individuals (1.2-1.4x BW BP). Thus, AEL may better enhance the lactate threshold (LT) compared to TRAD.

Traditional strength training can cause increased tendon stiffness, which may translate to enhanced performance during stretch shortening cycle (SSC). These adaptations could increase the storage and return of elastic strain energy which may contribute to an enhanced SSC capability. Furthermore, Aagaard (2011) suggested the SSC performance will improve when there is greater eccentric coordination as a result of strength training. For example: Cormie et al. (2010) found greater stiffness via ballistic and traditional squat training improved the capacity to transfer momentum from the eccentric phase into concentric force. The use of eccentric training also increases tendon stiffness (Malliaras et al., 2013) and tendon CSA, due to the tendon's response to high intensities (Douglas et al., 2017a; Logerstedt et al., 2022). Papadopoulos et al. (2014) found a substantially higher degree of stiffness in the ankle, knee, and hip in the drop jump after 16 sessions of eccentric training, resulting in an increase of elastic energy. This led to a statistically significant increase in drop jump height and maximum power in recreationally active individuals (Papadopoulos et al., 2014). Because of the high forces generated during the eccentric portion, it is possible that AEL training may enhance tendon achitechture/stiffness such that a SSC is enhanced beyond TRAD training adaptations. As eccentric strength training appears to enhance eccentric coordination through the nervous system in SSC dependent movements (Aagaard 2011), it is possible that AEL may enhance SSC cycle movments through both increaseing tendon stiffness and nervous system alterations.

Walker et al. (2020) assessed the muscle architecture changes dealing with fascicle length in AEL training. There was a statistically significant increase in fascicle length for AEL only in the vastus lateralis (+14%) and medialis (+19%, $p < 0.001$). For reference, the TRAD group increased fascicle length by only 1 and 5% for the vastus lateralis and medialis, respectively. These subjects (*n* = 28) are a subsample of Walker et al. (2016), which was composed of 20 well-trained men completing an incline leg press and unilateral knee extensions for 10 weeks. The remaining 8 subjects served as a control and completed their regular resistance training. The observation of an increased fascicle length in well-trained men in 20 total sessions is interesting. The only difference from the TRAD group was that AEL used a 40% additional eccentric load. This increase in fascicle length could carry over into greater velocity of movement and power output (Cormie et al., 2010; Hinks et al., 2022). The use of eccentric training can also create a shift to a stronger length-tension relationship in lengthened positions (Brughelli & Cronin, 2007). Interestingly, this shift appears to have a residual training effect which lasts around 4 weeks past the eccentric exercise condition. This increase in strength in a lengthened position may involve a higher degree of stiffness, which can translate to a greater release of elastic energy, which means a better SSC and potentially better athletic performance. It was also speculated that this shift can decrease the chance of muscle strains, which typically occur at longer muscle lengths where humans are weakest.

A review by Douglas et al. (2017b) suggests that titin is the long-sought spring in skeletal muscle, and is largely responsible for the elastic properties of the sarcomere. A hypothesis called the winding filament assesses the functional unit of a muscle fiber, the sarcomere (Nishikawa et al., 2012). It may explain why there is an increase in force in AEL training. This hypothesis involves cross-bridges acting as rotors that wind the titin filament on actin. This stores elastic potential energy in the proline-glutamate-valine-lysin (PEVK) region of titin during contractions and active stretching. This storage can then be utilized for the contraction of a muscle. Based on this hypothesis, the use of AEL may enhance the winding of titin around actin as a result of the heavier eccentric loads during active lengthening. When the release of the heavier eccentric contraction occurs (amortization), this winding may help increase the total potential energy released thus, contributing to greater concentric force or contraction velocity. (Douglas et al 2017b).

Neural Adaptations: Excitation, Neurophysiology, Electrical Stimulation, Modulators

A review by Wagle et al. (2017) suggested that AEL may be a superior form of training to increase strength and power adaptations. While reviews by Douglas et al. (2017b) & Enoka (1996) indicate that eccentric training creates a unique stimulus for the neuromuscular system that is not realized with TRAD. Higbie et al. (1996) concluded that eccentric training creates a better contraction specific stimulus for strength compared to concentric. The rationale behind why AEL is superior can include neural adaptations (Aagaard 2011; Moore et al., 2007). With only 5 weeks of training, AEL caused voluntary excitation levels to substantially increase, whereas, TRAD did not (Walker et al., 2016). A possible mechanism for improving voluntary excitation levels concerns creating a weaker modulation of inhibitory reflexes (Aagaard, 2003). In the study by Walker et al. (2016), only the AEL group realized a statistically significant increase in maximum M-wave peak to peak amplitude of the vastus lateralis ($p = 0.006$) and vastus medialis ($p = 0.038$). This indicates that AEL created better peripheral neural adaptations via propagation of action potentials, thus allowing for potentially greater force to be produced. Furthermore, training with AEL would appear to offset the decreased voluntary activation experienced among untrained subjects exposed to forceful eccentric contractions (Amiridis et al., 1996; Duchateau & Enoka 2016). Most of the literature shows that an eccentric contraction elicits an equal to or smaller electromyographic (EMG) excitation value compared to a concentric contraction (Amiridis et al., 1996; Duchateau & Baudry, 2014; Higbie et al., 1996;

Montalvo et al., 2021; Peñailillo et al., 2013; Perrey et al., 2001). It should be noted that the eccentric loads (and force) in most of these studies were likely below the relative load and force values of the concentric contractions. It should be noted that using maximum eccentric loads have resulted in equal EMG values with maximal concentric values in recreationally trained and untrained young men, respectively (Piitulainen et al., 2013; Seliger et al., 1980). A further dive into Piitulainen et al. (2013) showed that mean fiber conduction velocity was statistically significantly faster in the eccentric (4.42 m/s) contraction when compared to isometric (4.14 m/s, $p < 0.01$) and concentric (4.25 m/s, $p < 0.05$). However, for voluntary contractions, the actual EMG values may dependet al. 2009). It is important to note that most of these studies used cycling or isokinetic leg extensions, however, Berg & Tesch (1994) provided evidence that the use of a flywheel leg press elicited a nonsignificant 2% higher quadriceps EMG during the eccentric compared to the concentric in physically active men. Similarly, Norrbrand et al. (2008) found eccentric EMG in fly wheel leg extensions to be equal to or greater than the concentric portion in trained men. Interestingly, Amiridis et al. (1996) did not find a significant deficit of voluntary activation with isokinetic eccentric knee extensors across 14 velocities in international level high jumpers compared to the concentric. Based on these 2 previous studies (Berg & Tesch, 1994; Norrbrand et al., 2008), it appears that the eccentric overload induced by flywheel training induces a different neural stimulus compared to eccentric focused isokinetic or cycling training. This may be due to the eccentric loading being initially higher because of the flywheel technology. It is important to note that EMGs do not inform us as to the exact amount of force produced, rather, it indicates total amount of neural activation (muscular excitation) (Vigotsky et al., 2018, 2022). An example of this is the higher peak and mean forces, which can be observed during the eccentric contraction with typical AEL loading, although a lower activation (EMG) during the eccentric contraction can occur (Enoka, 1996). An example of higher EMG values with AEL vs TRAD in the bench press was shown by Kristiansen et al. (2022), where the higher EMG values of the pectoralis sternal and clavicular portions during the TRAD training, did not lead to better kinetic outcomes.

When a muscle is undergoing an eccentric contraction, there can be a decreased activity of the motor cortex and spinal cord, which results in a decrease of motor evoked potentials (MEP) and H-reflex responses (Abbruzzese et al., 1994; Duclay et al., 2014; Duclay & Martin, 2005; Enoka, 1996). Maximal and submaximal eccentric movements elicit almost the same relative values for the silent period (duration of time from onset of stimulus to contraction motor-evoked potentials), and the H-reflex response, all of which are substantially smaller when compared to shortening at either maximal or submaximal intensities (Duclay et al., 2014). Interestingly, there is a decrease in discharge rate for motor units during the eccentric portion of an exercise regardless of exercise mode (Duchateau & Baudry, 2014). Abbruzzese et al. (1994) noted that the size of the MEP was dependent on velocity, with a faster velocity during an eccentric eliciting a smaller MEP. Wagle et al. (2017) suggested that the higher threshold motor units being recruited in the eccentric portion would lead to higher force produced during the concentric phase. This can be a compensating mechanism as to how eccentric force is higher yet neural excitation during the eccentric contraction can be lower. Assuming that the eccentric action is performed rapidly, Nardone et al. (1989) has found a preferential velocity dependent recruitment of fast twitch motor units occurring within the plantar flexors. These fast twitch motor units were shown to be recruited right before lengthening was initiated (Nardone et al., 1989). Stretching of the series elastic component, during eccentric contractions, likely plays a role in the electromechanical delay (EMD) for creating tension (Prilutsky, 2000). Interestingly, eccentric contractions usually create the smallest EMD, which enables the creation of a faster rate of force development (RFD) (Prilutsky, 2000). Based on the findings of a smaller EMD, the muscle slack (Van Hooren & Zolotarjova, 2017) will also be reduced at a faster rate, thus allowing for initial improvements of RFD. While the single study of Nardone et al. (1989) reported a unique recruitment order for eccentric, a substantial amount of evidence indicates that recruitment order is similar between an eccentric and concentric and follows the size principle (Duchateau & Baudry 2014).

Westing et al. (1990) found superimposed and electrically evoked (electrical stimulation of a relaxed muscle) conditions had statistically significant, greater torques in 3 eccentric isokinetic knee extension velocities (180, 160, & 60° s^{-1}) in current and former athletes compared to MVC eccentric. Amiridis et al. (1996) also conducted superimposed electrical action on untrained and trained individuals and noticed a non-significant increase in peak torque for 5 eccentric isokinetic velocities compared to MVC eccentric. Both studies (Amiridis et al., 1996; Westing et al., 1990) found that the MVC concentric knee extensor velocities in both elite and trained subjects, respectively, were substantially higher than some electrically stimulated velocities. This led to the conclusion that the untrained subjects in Amiridis et al. (1996) and the trained subjects in Westing et al. (1990) cannot maximally develop eccentric tension, suggesting an inhibitory mechanism is present. In terms of eccentric endurance, Grabiner & Owings (1999) induced a fatiguing protocol (3x25 at 30° s^{-1}) for unilateral eccentric contractions and noticed a decrease in eccentric MVC of 13% after the protocol, which was statistically significant and inferior compared to the concentric condition (39%). Hyldahl et al. (2014) also noticed concentric conditions created a significant decrease in average peak torque for each set. Thus, the authors presumed that the lack of fully activating a muscle during an eccentric contraction results in differences in fatigue.

The primary factor that decreases corticospinal (i.e. motor neurons) excitability during an eccentric contraction may possibly involve inhibitory mechanisms at the spinal level (Duclay et al., 2014). Interestingly, Grabiner & Owings (1999), noted that the contralateral leg exhibited a cross over effect after a fatiguing protocol for eccentric MVC, which increased by 11% compared to baseline, while the concentric condition did not elicit any cross over effect. This led to speculation of eccentric induced spinal activity which transferred to non-active muscles. Duclay & Martin (2005) concluded that the spinal loop is modified by the supra-spinal center and possibly the neural mechanisms at the spinal level when eccentrics are completed. Contrastingly, Gruber et al. (2009) observed spinal inhibition during muscle lengthening but a possible compensation via an increase in cortical excitability. It is also important to recognize that muscle spindles (both Ia and II), golgi tendon organs, group III muscle afferents, and recurrent inhibition from Renshaw cells also regulate maximal voluntary efferent motor outputs (Aagaard, 2003). With any type of training (endurance, sprinting, RT), these modulators can demonstrate adaptive plasticity to allow greater force output (Bawa, 2002). When an eccentric is performed rapidly and forcefully, it could create higher activation of the muscle spindles (Cormie et al., 2010). This reaction should then create a concentric performance enhancement (Suchomel et al., 2019a). Training with AEL chronically could improve motor cortex activation and this effect might be responsible for the observed increase of neural drive by compensating for spinal inhibition noted within the eccentric portion of a lift (Gruber et al., 2009).

Summary Section

Understanding the possible physiological adaptations and mechanisms behind AEL may help us understand the findings of why AEL seems to rank superior to TRAD (Lates et al., 2020). A trend in the literature tends to show that AEL creates a stronger and faster muscle. Additionally, AEL may create metabolic adaptations resulting in lactate threshold alterations based on Friedmann et al. (2004) & Yarrow et al. (2008). Lastly, AEL creates unique adaptations within the neuromuscular system that TRAD cannot replicate, thus possibly giving AEL an edge in enhancing strength and power measures.

Strength

While AEL is a recently researched training method, Stone & O'Bryant (1987) reference its use as a training method in 1987. As it is relatively new in the literature, there has not been sufficient data to answer precisely how well it can increase strength in the typical compound lifts (bench press (BP) and back squat (BS)). There has also been some literature that has assessed the use of AEL in single joint movements of the knee, elbow, and ankle. Thus, only a handful of studies have been examinations of the chronic training AEL adaptations (> 4 weeks) or acutely (< 4 weeks). In each subsection, a thorough discussion of all studies (acute and chronic) will be analyzed as to how AEL or heavy eccentrics performed compared to TRAD.

Bench Press

Chronic AEL

Chronic implementation of AEL training via BP has shown statistically significant improvements compared to TRAD (Montalvo et al., 2021). Montalvo et al. (2021) assessed 5 different AEL loads (105-125% with 5% increments) within 8 competitive male (1.63x avg BW BP) and female (1.17x avg BW BP) powerlifters completing the concentric at 90%. Over 4 weeks of different AEL intensities, their BP increased ($p < 0.001$) by 6.5%. However, in a similar study design, Ojasto & Häkkinen (2009a) found AEL BP performance (105, 110, and 120% eccentric with 100% concentric) produced inferior results compared to TRAD (100% eccentric and concentric) in trained men (BP 1.2-1.4x BW) over the course of 4 weeks. The only difference that might lead to these different findings is that the Montalvo et al. (2021) subjects were slightly stronger, as the men were required to BP 1.5x BW and the women 1x BW. Additionally, the concentric intensity used with AEL was lighter (-10%) in Montalvo et al. (2021) than the 100% concentric intensity used by Ojasto & Häkkinen (2009a). Another chronic training study by Yarrow et al. (2008) revealed no significant differences in BP performance after lifting for 15 total sessions over 5 weeks between AEL or TRAD conditions. The methodology by Yarrow et al. (2008) involved 22 previously untrained men that completed 100-121% eccentric with a 40-49% concentric on a motor driven eccentric device (MaxOut) at a 6 second cadence for 3x6 (sets x reps). They did not mention the specific cadence for the eccentric and concentric portions. The TRAD group completed 4x6 with intensities ranging from 52.5-75% 1RM. Quantitatively, the TRAD realized an average increase of 10.1%, while the AEL increased 9% in 1RM BP performance. One possible confounding variable was TRAD completed substantially more volume (+15%) than the AEL group. Based on the three studies (Montalvo et al., 2021; Ojasto & Häkkinen, 2009a; Yarrow et al., 2008) assessing AEL on BP performance, it seems that individuals must be substantially stronger than average in the BP to realize a significant increase in 1RM compared to TRAD training. It is important to note that the concentric intensity may play a role when utilizing AEL. As some studies did not mention relative BP strength (Yarrow et al., 2008), it can be speculated that individuals who can BP 1.5x BW can derive benefit from the use of 105-125% AEL intensities with a 90% concentric.

Acute AEL

Support for increasing BP strength via AEL was shown by Doan et al. (2002). In this study, 8 moderately trained men performed a 105% eccentric with a 100% concentric or a TRAD 1RM randomly with 5 days of rest in between. The AEL group ($p < 0.001$) increased their 1RM by 2.2-6.8 kg more than using a TRAD approach. Indeed, these results indicate that the concentric portion of the BP can be augmented. This augmentation could translate into superior training adaptations. The study by Doan et al. (2002) did not report relative BP strength levels for their subject pool. Thus, a minimum strength level required for augmentation cannot be specified.

Eccentric Loading

There are four basic mechanisms that could potentially create superior adaptations through eccentric loading; increases in neural stimulation, recovery of stored elastic energy, contractile machinery alterations, and increased preload (Walshe et al., 1998). For example: implementing heavy eccentrics (120%) over the course of 12 weeks in a counterbalanced cross-over condition, 20 semiprofessional men rugby union players had an average increase of 4.85 kg in their BP 1 RM using webplot digitizer (https://automeris.io/WebPlotDigitizer/index.html) after eccentric training (Cook et al., 2013). The author's stated that the eccentric conditions 'substantially enhanced' the 1RM BP compared to TRAD, which only had an average increase of 2.63 kg. Considering the results of Cook et al. (2013)**,** the addition of a heavy eccentric loading phase during a BP could translate to increase training adaptations. While this was not a true AEL study, it may shed light on the mechanisms through which AEL training enhances strength. However, the authors (Cook et al., 2013) did not mention the relative BP strength for the rugby players, thus creating limited data towards strength requirements for the BP.

Back Squat (BS)

Chronic AEL

Only two studies have assessed 1RM BS performance chronically (Munger et al., 2022; Yarrow et al., 2008). Munger et al. (2022) had 33 trained men (BS 1x BW) complete AEL BS at a 3 s eccentric cadence with 105-115% eccentric and a 55-65% concentric twice weekly for 5 weeks. While the TRAD group followed the same conditions, they completed the BS at 80-90% intensity. There were no statistically significant differences in concentric 1RM after 5 weeks. The Authors did not report quantitative changes in concentric 1RM performance. However, they also measured BS eccentric 1RM via 3 s eccentric cadence. Both groups realized a statistically significant increase, but no statistical difference between conditions. The AEL group increased their average eccentric 1RM by 16.9 kg, while TRAD increased by 12.7 kg. Although statistically non-significant, the authors stated that the better performance in the eccentric 1RM by the AEL group was most likely due to specificity. Yarrow et al. (2008) also measured changes in BS after 5 weeks of training in untrained men. The methodology was previously discussed in section 2.3.1.1. There was no significant difference between AEL and TRAD for BS, but the TRAD did have a higher percent change (25.4% vs 18.6%). It is important to note that the AEL completed 15% less volume than the TRAD and completed an unspecified 6 second cadence for the BS throughout the duration of the study. Therefore, the cadence used by Munger et al. (2022) & Yarrow et al. (2008) might have played a role in the ability to utilize the SSC, as faster eccentrics appear to have greater carry over to concentric performance (Cormie et al., 2010). Based on the results of these 2 studies, it appears that AEL squats do not require a certain strength threshold to display similar improvements in concentric BS 1RM. One very important variable that was discussed was the use of a slow cadence in the AEL group specifically. This might have inhibited the ability to produce force in the subsequent concentric contraction. Thus, the literature has not adequately addressed better methodologies for the implementation of AEL, and more investigation is required comparing AEL with and without a slow cadence. A very recent narrative review by Handford et al. (2022) assessed eccentric speed and performance enhancement. This review showed that acute performances of eccentric tempos that lasted < 2 s improved strength, velocity, and power for the following concentric repetitions compared to > 4 s. Interestingly, the results of faster tempos are not replicated in chronic studies.

AEL Leg Press

A compound movement that is somewhat similar to the BS is the leg press, however, a leg press typically requires a machine and is a guided effort. Thus, the leg press is deficient in the stability requirements necessary using the free weight barbell BS. English et al., (2014) used 40 untrained men, who trained using a motorized eccentric leg press (Agaton Fitness System) over the course of 8 weeks. Subjects were divided into 5 different intensity groups (concentric only, eccentric underload at 33 & 66% concentric, 100% (TRAD), or 138% (AEL) of concentric). All groups completed 2-5 sets with 2-8 reps 3 days a week but used different eccentric intensities. All 5 groups showed a statistically significant increase in their 1RM leg press. However, the 138% AEL group displayed the greatest mean increase (+20.1%) compared to concentric only (+7.9%), 33% (+7.7%), and 66% eccentric underload (+7.5%) groups. The 100% TRAD group was the only group that was not different ($p = 0.15$) from the 138% AEL condition and had a mean increase of 12.8%. Based on these results, the authors concluded that eccentric underload would elicit the same response as concentric only training. Eccentric overload was superior compared to the other loading strategies. While it is difficult to directly compare this study of a leg press to AEL BS studies, it appears that untrained individuals do not need a minimum level of lower body strength to realize performance enhancements from AEL training. This might be due to little or no stabilization requirements when using a machine compared to free weights. Similarly, Papadopoulos et al. (2014) used an isokinetic leg press for a total of 16 sessions over 8 weeks in 18 recreationally trained men. The AEL group completed 3-6 sets for 5-10 reps with 70-90% of max eccentric force. At the end of the 8 weeks, the AEL group ($p < 0.001$) increased both concentric and eccentric maximum force. The control group did not complete any supervised training and was asked to refrain from RT, thus failed to increase maximum strength. An important note made by the authors was that each session consisted of exercising the musculature for only a total of 20-30 s, whereas a TRAD group (not used in this study) may require more sets or reps to see the adaptations elicited via AEL training.

Eccentric Loading

The methodology and subjects by Cook et al. (2013) was discussed in the previous section (see 2.3.1.3 Eccentric Loading). Using the same webplot digitizer that was mentioned earlier (https://automeris.io/WebPlotDigitizer/index.html), the 120% eccentric conditions resulted in an average BS increase of 5.72 kg compared to 3.94 kg in the TRAD group for the 1RM BS.

Single Joint

Walker et al. (2017) conducted 20 total RT sessions over the course of 10 weeks for either TRAD or AEL conditions. A total of 18 trained men with a training age of 2.7 years were used. Subjects completed 3x10 and 3x6 on different training days for the leg press, unilateral knee extension, and bilateral knee flexion for both groups. All exercises were completed with a 2 second tempo during the eccentric and concentric (cadence = 4 seconds total per rep). The AEL condition used 40% greater loads during the eccentric via weight releasers for the leg press and manually added or removed plates for the leg extension. The results showed that only AEL ($p <$

0.01) increased peak unilateral eccentric torque (+10%). The greatest changes in peak unilateral concentric torque occurred for AEL (0.4-18.3%) compared to TRAD (-0.8-16.7%). Additionally, AEL realized statistically significant differences in rate of adaptation from weeks 5 to 10 in maximum unilateral isometric knee extension torque (+18 Nm), while TRAD had a slight drop off (-3 Nm). Relative improvements were statistically significant ($p < .001$) only for AEL over the course of 10 weeks for maximum unilateral isometric torque (5.2-27.8%). These results lead to the conclusion that AEL created a better stimulus for isokinetic and isometric strength in the second mesocycle, while TRAD had similar results from the first and second mesocycle. An important note by the authors indicated that trained individuals may need several AEL sessions and time to realize performance boosts. Friedmann et al. (2004) also carried out a chronic study. A total of 16 untrained individuals completed 6x25 (30% 1RM) unilateral knee extensions within 45 s per set, three times per week for four weeks. The TRAD group used a ubiquitous leg extension, while AEL used a computer driven device (Motronic) that provided 30% concentric 1RM resistance for the concentric phase and 70% concentric 1RM resistance for the eccentric phase A statistically significant increase in maximum isokinetic concentric strength ($60° \cdot s^{-1}$) was only observed for the AEL group, with an average increase of 5%. Contrasting evidence has been provided by Godard et al. (1998). This 10-week study, in which 28 physically active men and women completed a single set of unilateral knee extensions on a dynamometer for 8-12 reps with a 6 s total cadence (3 second eccentric and concentric) two times per week. The TRAD group performed 80% 1RM, while AEL performed a 120% eccentric contraction with an 80% concentric contraction. Both groups showed statistically significant increased concentric knee extensor torque (AEL: +82.4 N·m; TRAD: +81.6 N·m). However, concentric knee torque was not statistically significant between conditions. It is important to note that the percent increase in strength was greater in AEL (106% vs 101% TRAD). However, the authors concluded that AEL did not offer any additional benefits over TRAD among untrained subjects. Based on these three studies, AEL knee extension seems to create slightly better strength adaptations compared to TRAD in chronic studies, regardless of training status. Interestingly, the cadence used does not seem to induce the same effect noted in free weight compound exercise AEL studies.

Only a single study by Brandenburg & Docherty (2002) reported the effects of AEL vs TRAD on elbow flexion and extension. In this study, 18 trained men (BP 1x BW) trained 2-3x per week for 9 total weeks. The exercises used were a preacher curl and a supine elbow extension with a 2 s eccentric and concentric phase for both groups (4 second cadence). To equalize volume, TRAD completed 4x10 with 75% 1RM while the AEL completed 3x10 with 110-120% eccentric load and 75% concentric load. Statistically significant improvements in elbow flexion 1RM occurred in both groups (AEL: 9%; TRAD: 11%). However, effects were non-significantly different between groups. In terms of 1RM elbow extension, AEL (+24%) showed a statistically significant increase compared to TRAD (+15%). The authors noted that the differences in strength gains between muscle groups could be due to differing muscular architecture, with the extensors being pennate and the flexors parallel in nature. A unique study by Norrbrand et al. (2008) compared flywheel leg extensions to traditional (a weight stack machine) leg extension over the course of 5 weeks, training 2-3 times per week. Both groups completed 4x7 maximal unilateral coupled eccentric and concentric reps. The only difference was the flywheel completed a cadence of 1.5 s for the eccentric and 1.5 s for the concentric, while the traditional leg extension was performed at a 1 s concentric and a 2 s eccentric. The flywheel group had a statistically significant increase in MVC at 90° (+62 N), while the TRAD leg extension did not (-20 N). This may be an erratum for this paper as the non-trained leg got +1

N stronger while the trained leg got weaker (-20 N) for MVC at 90°. However, assessing the MVC at 120° revealed an increase for the trained leg (+36 N), while the non-trained leg decreased (-15 N). These results led the authors to state that the brief overload of eccentric force in the flywheel created a greater increase in MVC.

The last AEL single joint movement discussed in this section involves plantar flexors (English et al. 2014). The 40 untrained men were separated into 5 different intensity groups (concentric only, eccentric underload at 33 & 66% concentric, 100% (TRAD), or 138% (AEL) of concentric). All groups completed calf raises for 2-5 sets with 2-8 reps 3 days a week with the only difference being eccentric intensities. Using the motorized leg press for calf raises over the course of 8 weeks resulted in statistically significant improvements for 1RM calf press for every condition except the concentric only (0%: +4.9%, 33%: +7.5%, 66%: +6.6%, 100%: +12%, 138%: + 11%). However, there were no statistically significant differences between groups. This led the authors to state that eccentric overload does not appear to be beneficial for plantar flexor strength. It should be noted that the eccentric underload conditions were almost half the level of percent gain of the TRAD and AEL intensities.

Section Summary

When completing AEL BP, it appears that individuals should have a minimum level of relative strength (~1.5x BW) in order to realize a benefit, while AEL BS does not appear to require a specific relatively strength level requirement. A review by Merrigan et al. (2022) noted that the adaptations between AEL BS and BP may be due to smaller ROM and not sufficient time for AEL to induce adaptation. Interestingly, Suchomel et al. (2019b) suggests, for the back squat, that advanced athletes might acquire a benefit from maximal-supramaximal AEL when they reach a strength threshold of 2x body mass. Intermediate athletes (1.5x BW) should use submaximal AEL, and untrained (<1x BW) focus on submaximal eccentric tempo training (Suchomel et al. 2019b). However, Handford et al. 2022 noted that a slow tempo (> 2 s) used during eccentrics seems to reduce the positive strength of the training methodology but noted no differences in strength when eccentric durations lasted between 2-6 s. In terms of machine-based training, AEL in the leg press, knee extension, and elbow extension were superior than TRAD for strength in untrained and trained individuals. This may suggest that AEL can be used in any individual for single joint movements due to a naturally greater degree of stability via machines. Lastly, acute studies using trained individuals may result in no differences compared to TRAD. Furthermore, to truly realize the benefits, trained individuals may require longer training (Walker et al., 2017). As noted by Walker et al. (2017), AEL creates a unique performance boost in the second mesocycle.

Power, Rate of Force Development

Power, along with impulse, is arguably one of the most important aspects to develop for most sports (Barker et al., 1993; Mizuguchi et al., 2015; Sole et al., 2018; Turner et al., 2021). Rate of force development (RFD) is a measure of explosive strength, or simply how fast an athlete can develop force and is calculated as the change in force per change in time ($\Delta F / \Delta T$) (Maffiuletti et al., 2016). RFD is a primary mechanism leading to a large impulse and greater power outputs (Maffiuletti et al., 2016; Stone et al., 2019). Indeed, RFD can be considered more important than peak force in terms of many types of sports' performance (Stone et al., 2019; Suarez et al., 2019; Turner et al., 2021). Having a higher RFD is especially important as the critical time period for performance often lasts ≤ 0.3 s (Turner et al. 2021). However, most compound movements will not be completed in 0.3 s or less, linear position transducers and force plates allow practitioners to analyze specific time points and kinetic and kinematic variables during these movements. Thus, the following section is dedicated to analyzing the literature concerning the impact AEL has on kinetic variables in the compound lifts (BS and BP) and jumps.

Back Squat Kinetics

Acute AEL

Eleven trained men (average BS: 1.8x BW) completed a cross-over of 4 BS conditions (TRAD, TRADC: 30 s of rest between reps, AEL1: only the first rep used weight releasers, and AELC: 30 s of rest between reps and reattaching the weight releasers for each rep) over a month (Wagle et al., 2018a). Subjects completed 3x5 at 80% concentric and a 105% eccentric during AEL conditions. The variables analyzed were peak power (PP), eccentric and concentric work (ECW & CCW, respectively), eccentric and concentric RFD (250 ms) (ERFD & CRFD, respectively), and concentric average velocity (CAV). There was a role of specificity, with AEL1 having statistically greater ECW compared to TRAD, while AELC also showed greater ECW and ERFD compared to TRADC. However, TRADC had greater CRFD and CAV compared to both AEL conditions. One major finding was that AELC was statistically greater than TRAD for ECW, CCW, ERFD, CRFD, and CAV. Another key finding occurred between the AEL conditions, in which AELC had substantially greater ECW, ERFD, CRFD, and CAV than AEL1. Surprisingly, there were no statistically significant differences in PP amongst all the conditions. Based on these findings, it was suggested that AELC produced superior barbell kinetics compared to AEL1. However, Wagle et al. (2018a) stated that AEL only demonstrated efficacy for ECW and ERFD but did not potentiate concentric kinetics compared to TRAD. Wagle et al. (2018b) used a subsample from Wagle et al. (2018a) and assessed kinetic differences within the set. In the straight set conditions (TRAD & AEL1), PP, CRFD, mean velocity (MV) all decreased, while the clustered conditions (TRADC & AELC) created a moderate decrease in MV. Reps 3 and 5 in the AELC had the greatest ERFD compared to all the other groups, while TRADC had the greatest CRFD and MV. In terms of PP and MV differences, TRADC was only trivially different from AELC. Wagle et al. (2018b) concluded that both AEL conditions do not potentiate higher concentric outputs, but they may create higher ERFD compared to both TRAD conditions. However, both studies (Wagle et al., 2018a & 2018b) suggest that AELC is superior to AEL1 for barbell kinetic variables.

Merrigan et al. (2020) studied AEL BS at 120% eccentric with a 3 s lowering on the first rep with a 65% (AEL65) or 80% (AEL80) concentric using weight releasers. They used 21 trained men (average 1RM BS: 169.8 kg) who also completed TRAD training at 65% and 80%. Subjects randomly completed each condition with two days of rest in between. For the 80% concentric condition subjects used 3x3, while the 65% condition used 3x5. Comparing AEL65 to TRAD at 65% revealed statistically significant differences in mean concentric velocity at the 3rd and 4th repetition. AEL65 only had a lower mean concentric velocity on the first rep but was statistically non-significantly faster for the remainder of the set compared to TRAD 65%. Peak velocity showed no significant differences, but AEL65 was quantitatively greater than TRAD 65% for every rep. In terms of eccentric peak and mean eccentric velocity, AEL65 was statistically significantly slower for both variables (eccentric peak and mean eccentric velocity) compared to TRAD 65% on the first rep. This is most likely due to the 3 s eccentric cadence on the first rep of AEL. However, there were statistically significant faster eccentric peak and mean eccentric velocities for reps 3-5 and 2-5, respectively. Both 65% conditions showed no statistically significant differences in peak concentric power, but the AEL group was higher for reps 1 and 3-5. Mean concentric power showed the AEL65 was statistically higher for reps 3 & 4.

Additionally, the AEL65 condition elicited statistically greater eccentric mean (reps 1-4) and peak power (reps 1-5) compared to TRAD 65%. Surprisingly, AEL80 did not differ from TRAD 80% for concentric mean or peak velocity, in fact TRAD 80% had a significantly higher concentric mean velocity on the first rep compared to AEL80. As previously mentioned, this may be due to the 3 s eccentric descent on the first rep of AEL. This tempo is greater than the duration (< 2 s) found to elicit strength and power improvements with eccentric training (Handford et al., 2022). The 80% conditions revealed statistically significant differences with AEL80 eliciting faster peak (reps 2-3) and mean (reps 2-3) eccentric velocities. In terms of mean and peak concentric velocity, there were no statistically significant differences between either of the 80% conditions. However, the eccentric peak (reps 1-3) and mean (reps 2-3) power was higher for AEL80. The major finding showed that AEL65 statistically increased concentric velocity after the 1st rep, while AEL80 did not. Merrigan et al. (2020) concluded that having a bigger difference between the eccentric and concentric intensity may be required to elicit a substantial performance boost. A unique study by Chae et al. (2023a), using 12 trained men (1.9x BW BS), examined the impact of AEL use throughout a set of ten repetitions in the squat. AEL was used a total of five times throughout the set (AEL5) in one group and only twice for reps 1 and 6 (AEL2 in a second group). Both AEL conditions for sets of 10 were clustered, as reattaching the weight releasers allowed the lifter to rest approximately 15 s before initiating the next repetition. Participants completed both AEL conditions with a 110% eccentric and a 60% concentric. The AEL5 condition had statistically significant higher concentric peak velocity and peak power when compared to AEL2 and TRAD. Further analysis across the set of ten repetitions showed AEL5 was still statistically significant for peak velocity and peak power at the end of the set, compared to TRAD. Lastly, concentric mean force for AEL5 elicited the highest values, with AEL2 and TRAD being 9 and 21 newtons (N) behind, respectively. These results led Chae et al. (2023a) to conclude that AEL5 can increase peak velocity and power.

The front squat (FS) was assessed in a study by Munger et al. (2017) who used 20 trained men (average FS 1RM: 131.0 kg). A total of 3 conditions were examined with 105, 110, and 120% AEL via weight releasers while using a 90% concentric for only one set of two reps with a 3 second eccentric phase. Concentric peak power and velocity were statistically greater for the 120% condition compared to 105%. The 110% condition was only 20 watts less and 0.02 $m \cdot s^{-1}$ slower than the 120% group. Concentric RFD revealed no statistically significant differences between groups; however, a gradual decrease in concentric RFD was observed from the lightest to heaviest AEL conditions. These results led Munger et al. (2017) to conclude that AEL could improve concentric power, velocity, and RFD.

Isokinetic Leg Press

Using a isokinetic leg press and 18 recreationally active men, Papadopoulos et al. (2014) demonstrated ($p < 0.001$) increased concentric and eccentric force (300 ms) over the course of 8 weeks. However, the other condition was a non-training control group, so there was no comparison of a TRAD group. Interestingly, the eccentric phase was only performed at 70-90% of max eccentric force.

Bench Press Kinetics

Acute AEL

Using 8 competitive powerlifters, Montalvo et al. (2021) found a statistically significant increase in just 5 sessions of AEL training at different intensities (105-125%) via weight releasers for 1RM BP kinetics. Peak power statistically increased by 36.67% compared to baseline. Additional statistical significance was found for a faster concentric duration for the post

1RM compared to pre. No statistically significant differences were found between concentric peak velocity, acceleration, or eccentric duration. Submaximal use of BP AEL significantly increased mean ($p < 0.05$) and peak power ($p < 0.001$) within 11 trained men (1.2-1.4x BW BP) (Ojasto & Häkkinen, 2009a). This statistical significance was only found in the AEL condition that utilized a 77.3% eccentric with a 50% concentric. The other AEL conditions (60, 70, and 90% eccentric with a 50% concentric) did not differ in any variables compared to TRAD (50% concentric and eccentric). Although non-statistically significant, the 70% AEL condition did elicit the highest peak power amongst all conditions.

Contrasting evidence is presented by Kristiansen et al. (2022). A total of 10 trained men used weight releasers at 110% eccentric with 85% concentric or TRAD at 85% for both contraction modes for a single set of two reps. The TRAD had a significantly faster concentric condition compared to the AEL. However, a possible confounding methodology within this study was that subjects were not allowed to bounce the bar during the BP. Therefore, a pause is assumed to have occurred once the weight releasers were released. Additional confounding issues in the study showed that maximal eccentric velocity was non-significantly faster in the TRAD than the AEL condition. It was not discussed in the methods section that participants tried to control the eccentric or were told to lower the BP at a specified cadence. The authors noted another limitation involving only one familiarization session for the AEL condition and agreed that this was insufficient time to learn AEL. Overall, the authors concluded that AEL with a 110% eccentric does not potentiate the concentric phase of 85%. In fact, they suggested that AEL could be beneficial for power output when the concentric is lighter than 85%. This was based on research they observed (Munger et al., 2017) and cited (Ojasto & Häkkinen, 2009a). Additional evidence that is contrary to the possibility of the possible potentiating benefits of

AEL was observed by Merrigan et al. (2021). This study involved 120% eccentric with a 50 and 65% concentric in 8 trained men and 2 women (M: 1.5x BW BP, W: 1x BW BP) with the TRAD group being 50 and 65% for both contraction modes. The 120% eccentric was performed via weight releasers and was used for the first repetition. Neither AEL conditions statistically improved concentric velocity at 50 or 65%. Both TRAD conditions had a faster concentric velocity compared to both AEL conditions. Interestingly, AEL with 50% concentric had a slower mean eccentric velocity than TRAD at 50%, which may have been due to trying to control the eccentric descent during AEL. The method section did not mention anything related to a controlled tempo for the eccentric phase in any condition. Therefore, it is hard to reconcile that a 120% AEL load moved at the same eccentric velocity as 50% TRAD. In terms of sex differences, apparently, there were no apparent influences on the results. A very important finding that the authors noted, involved relative strength. Subjects having a higher bench press relative strength (~1.5x BW) could elicit higher mean and peak concentric velocity in both AEL conditions compared to TRAD. Taber et al. (2021) also noticed a relative strength level requirement (1.5x BW) for improvements in concentric mean velocity in the BP with a heavier AEL condition (110%). Merrigan et al. (2021) concluded that AEL may not be ideal for relatively weaker subjects (<~1.4x BW) as there was no concentric potentiation in these subjects. Mixed evidence presented by Taber et al. (2021) showed a threshold of AEL potentiation in 10 trained men using the BP (1.25 x BW). Subjects completed 6 different concentric velocities (30-80%, 10% increments) in a TRAD, or AEL 100 & 110% condition. The AEL 100% condition had faster concentric velocities compared to TRAD, but only reached statistical significance at 30% and 80% concentric intensities. For the 110% AEL condition, there were no statistically significant differences in concentric velocity at any intensity compared to TRAD. However, 110% AEL showed a pattern of non-significantly greater concentric velocities at lighter loads (30%) than heavier ones (80%) compared to the other two conditions. These results led Taber et al. (2021) to state that positive effects from AEL may depend on the eccentric to concentric ratio. Additional results showed that greater displacement via AEL had an impact on concentric velocities.

Lates et al. (2020) had 13 trained men (average 1RM BP: 125 kg) complete a 105% eccentric on the first rep (AEL1) or between reps for 5 cluster reps (AELC) with an 80% concentric. They also completed TRAD with 80% and clustered with 30 s of rest (TRADC) for 80%. AEL1 created the greatest eccentric peak force and peak power when compared to the 3 other conditions and the cluster conditions, respectively. Lates et al. (2021) speculated that the use of AEL on every rep may induce too much fatigue and impact performance. The TRAD group statistically outperformed both cluster conditions for eccentric peak power, while AELC also showed greater effects compared to TRADC for the same variable. In terms of RFD, both cluster conditions performed statistically better than AEL1. Concentric mean power and velocity showed TRADC being statistically significantly higher than the other 3 conditions, while AELC only performed better for concentric mean velocity compared to AEL1. Interestingly, TRAD had statistically higher concentric mean force than both cluster conditions, however, AEL1 was statistically greater than all of the conditions. Based on these results, Lates et al. (2020) concluded that AEL1 may provide acute benefits within a set of 5.

Jumps

Acute AEL

Moore et al. (2007) assessed barbell jump squats (JS) in 13 trained men (BS: 1.5x BW) in a crossover study of 4 conditions. One condition was a control (CON) in which maximum effort counter movement jumps at 30% 1RM were completed. The remaining 3 conditions involved the use of AEL via weight releasers at 20, 50, and 80% of 1RM BS, but still completed the concentric phase at 30%. All conditions completed 2x1 of barbell jumps within a session and then repeated the exact same session order two days later. No statistically significant differences were observed for peak velocity, force, and power for any condition. Moore et al. (2007) stated that one study limitation involved the subjects being unfamiliar with the barbell jumps. It was concluded that AEL does not result in potentiation effects (Moore et al., 2007). Another study used 30 explosive strength trained male subjects (Friedmann-Bette et al., 2010). The AEL group used a computer device and completed 5x8 with an eccentric phase of 190% concentric load, while the TRAD completed 6x8 with an 8 RM. The duration of the study was 6 weeks long with sessions occurring three times per week. Both groups completed a unilateral knee extension. At the end of the study, AEL was the only group that realized a statistically significant increase in the squat jump (SJ) (+2-3 cm). This result led to the conclusion that AEL creates a better adaptation for explosive strength than TRAD (Friedmann-Bette et al., 2010). Mixed findings were presented by Munger et al. (2022) for the CMJ amongst 33 trained men (1x BW BS). The TRAD and AEL conditions both statistically increased their CMJ height after 5 weeks of training for a total of 10 training sessions. However, there was no statistically significant difference between groups. Quantitatively, AEL outperformed TRAD by jumping an additional +3.8 cm at the end of 5 weeks, while TRAD only achieved an increase of +2.9 cm (Munger et al., 2022).

Eccentric Loading

After 12 weeks of RT, semiprofessional rugby players in a heavy eccentric training and overspeed training group elicited the highest power output for a countermovement jump (CMJ) (Cook et al., 2013). The other overspeed training group that used TRAD had the second highest while the heavy eccentric only group had the third highest. Both heavy eccentric groups and TRAD training with overspeed substantially enhanced CMJ peak power when compared to the TRAD only group. Additionally, only the heavy eccentric with overspeed training group performed substantially better than the heavy eccentric only group. It is important to note that these improvements were observed in only 12 weeks in previously well-trained strength-power athletes (Cook et al., 2013).

Section Summary

The use of AEL during BS shows some conflicting results in terms of kinetics. As the main focus would be concentric peak power and RFD, there appears to be limited studies indicating AEL worsens these variables. However, Wagle et al. (2018a & 2018b) showed that AEL performed via clusters induces better outputs compared to performing a single AEL on the first rep for a set of 5. Superior concentric variables may be noted when completing AEL with a 30 or 55% greater eccentric than concentric on the first repetition. However, a lighter AEL completed with a 15% greater eccentric load induced higher concentric RFD. The use of maximal AEL loads during the BP seems to require a BP of 1.5x BW to produce higher mean velocity and power outputs. However, individuals with longer arm displacements may not realize these benefits. For BP, it is suggested to only perform AEL on the first rep and not in a clustered format as it might be too fatiguing. This finding is different from that of the BS, and it may be due to less muscle mass being used in the BP, resulting in different acute fatigue and performance via AEL (Kristiansen et al., 2022; Lates et al., 2020). It can be speculated that the mechanics of the BP may play a role in the differences as it may stress the musculature different compared to the stress encountered in the BS during AEL implementation. Submaximal AEL intensities showed significantly better mean and peak power outputs compared to TRAD. There appears to be no sex differences with the use of AEL BP. The optimum intensity used during the eccentric for BP benefits appears to be 25-30% higher than the concentric. One author has suggested that AEL will induce better outputs when the concentric is completed with <85%, however, as previously noted there were several methodological limitations in this study (Kristiansen et al., 2022). In terms of jumping kinetics, the research is limited and the methodology is quite inconsistent. However, of the four studies discussed**,** three of them indicated that AEL produced superior adaptations in concentric power outputs. Furthermore, the current state of the literature indicates that AEL's effects on jumping are more efficacious in previously trained athletes. It's important to note that almost all of the studies previously discussed in each subsection involved previously strength trained subjects. However, obviously more studies are required.

Hypertrophy

The ability to increase muscle cross sectional area (CSA) may help athletes produce more force (Duchateau et al., 2021) and power (Cormie et al., 2011). This section will not address muscle fiber characteristics as it was previously mentioned in the physiology section (2.2.1). This section will instead focus on the addition of muscle mass via AEL. A total of 6 studies have measured hypertrophy via AEL, and surprisingly all of them have only assessed lower body musculature.

Lower Body

Completing unilateral knee extensions with the addition of an incline AEL leg press showed a significant increase in quadriceps muscle mass from baseline to mid (5 weeks) in both TRAD (+2.6%) and AEL (+2.7%) conditions within well-trained subjects (*n* = 17) (Walker et al., 2017). By DEXA, there was a statistically significant difference between groups from mid to post (10 weeks) with the AEL (+1.58%) group adding more muscle mass than TRAD (-0.17%) using a webplot digitizer (https://automeris.io/WebPlotDigitizer/index.html). The TRAD actually showed a slight decrease in muscle mass in the second half of the study. Walker et al. (2017) believed that the acute anabolic hormonal responses may be linked to the increase in hypertrophy for the AEL group in the second half of the study. A unique study by Norrbrand et al. (2008) used a flywheel leg extension as the AEL group and compared it to TRAD knee extensions. Trained men (*n* = 15) completed 2-3 sessions a week for 5 weeks. For each condition, subjects completed 4x7 reps with a 1.5 s eccentric and concentric (3 s total cadence) for the AEL and a 2 s eccentric and 1 s concentric for the TRAD. Hypertrophy results of the quadriceps showed statistically significant increases via MRI for 3 heads of specific quadriceps muscles, for the AEL group only (VL: +5.8%, VI: +4%, VM: +8%). The same 3 heads resulted in non-significant increases for the TRAD group (VL: +1.8%, VI: +2.4%, VM: +3.8%). Both groups realized statistically significant increases in the rectus femoris (AEL: +9.9%; TRAD +6.7%) and total quadriceps (sum of all 4 heads) volume (AEL: +6.2%; TRAD +3%) at the end of the study. A statement made by Norrbrand et al. (2008) was that flywheel training supported a more consistent degree of hypertrophy. Therefore, Norrbrand et al. (2008) concluded that flywheel technology created similar or more muscular adaptations compared to standard leg extensions and is due to the brief eccentric overload. They continued to state that the eccentric action is not ideal unless an eccentric overload is applied during joined concentric action.

A DXA scan was used to measure quadriceps hypertrophy in untrained men (*n* = 40) completing the leg press (English et al., 2014). Results revealed a similar non-statistically significant increase in leg hypertrophy when completing a 33% eccentric underload of the concentric and 100% TRAD (+1.5%). The concentric only group had a non-significant decrease after 8 weeks of

RT (-1.5%). The 66% eccentric underload of concentric elicited the second-best increase in leg lean mass with a non-statistically significant average increase of 2.2%. The only group that realized statistical significance was the AEL group that completed a 138% eccentric of concentric load with an average increase of 2.4%. An important note is that the subjects also completed calf raises in the same study (English et al., 2014). The authors did not state if they separated the two muscles during DXA scans, therefore, an increase of calf musculature could contribute to a greater increase of lower limb lean mass. While the authors did not specify exactly where the increases of lean mass occurred, the authors did not mention improvements in hypertrophy of the calves. However, they noted the limitations of observing an increase in calf hypertrophy within 8 weeks. This is true as calf musculature, specifically the soleus, appears to be resistant to muscle protein synthesis due to training (Trappe et al., 2004). Contrasting evidence was shown by Godard et al. (1998) who used 28 recreationally active men and women (*n* = 12). These subjects completed 20 sessions over the course of 10 weeks doing unilateral isokinetic knee extensions. The TRAD completed 80% 1RM, while AEL did a 120% eccentric and 80% concentric. Both groups completed a single set for 8-12 reps with a 3 s eccentric and a 3 s concentric phase (6 s cadence). Results showed statistically significant increases in both groups for average thigh girth, but no difference between groups. Quantitative values indicate that TRAD had a 5% increase while AEL had a 6% increase. Concluding remarks by Godard et al. (1998) stated that AEL offers no significant benefits compared to TRAD in untrained subjects. Examining hypertrophy in strength power athletes (*n* = 25), Friedmann-Bette et al., (2010) showed a statistically significant increase in quadriceps CSA via MRI in both TRAD and AEL. However, no statistically significant differences were present between groups. Interestingly, quantitative values showed that the TRAD group had a greater increase of CSA (+8 cm^2)

compared to the AEL group (+5.8 cm^2). While the TRAD completed an additional set (6x8 8 RM) compared to AEL (5x8 190% eccentric), volume was equal between groups. While the training seems rather irrational, the subjects were given 4 minutes of rest in between sets, thus possibly allowing them to complete the training protocol. A second study conducted by Friedmann et al. (2004) showed no statistically significant differences in untrained subjects (n = 16) after 12 sessions of either AEL (40% greater eccentric) or TRAD after completing 6x25 at 30% 1RM in unilateral knee extensions. There may have been a trend (p = 0.092) for the AEL group to increase CSA at the end of 4 weeks, while TRAD statistical analysis did not. Analysis of the quantitative values showed AEL (+2.5 cm^2) increased quadriceps CSA non-significantly more than TRAD (+1.7 cm^2). Both articles (Friedmann-Bette et al., 2010; Friedmann et al., 2004) concluded that AEL creates a faster and stronger muscle but did not state it creates a bigger muscle.

Section Summary

The previous section illustrates that AEL may induce a higher degree of hypertrophy within the quadriceps. Only three studies have shown that the degree of hypertrophy was not statistically greater than TRAD. A closer look at the quantitative values indicates superior results via AEL in two studies, while the other study showed the opposite with TRAD creating more hypertrophy. Based on the literature, the AEL intensity necessary to enhance hypertrophy appears to be 38-40% greater eccentric values. It is important to note that three out of the six studies used trained individuals, and two of them resulted in AEL being superior compared to TRAD over the course of about 7 weeks. This may be indicative of AEL being a novel stimulus for hypertrophy to occur in trained individuals. In terms of time under tension, a narrative review by Handford et al. (2022) stated that a 2-6 s eccentric duration does not illustrate any real differences for hypertrophy.

Biomarkers

Biomarkers can be valuable for assessing both program efficacy and fatigue management (Stone et al. 2022). The literature on biomarker responses via AEL has been very limited. Only a total of 10 AEL studies have assessed hormones, specifically testosterone, (human) growth hormone, and cortisol. Other studies have assessed additional biomarkers such as lactate and creatine kinase. Walker et al. (2017) suggested that measuring hormonal responses to a training session can lead to insights concerning stimulus effectiveness for a specific outcome of training. A blunted hormonal or exaggerated exercise response or adaptation may indicate that the training methodology is no longer producing a performance enhancing stimulus, or the athlete is experiencing non-functional overreaching or overtraining, thus requiring a training modification (Stone et al., 2022; Walker et al., 2017). While the previous statements were made about hormonal responses, the same could be said for additional biomarkers that assess metabolic demands (lactate) and muscle damage (creatine kinase). Most AEL studies have been acute (exercise response) in nature. Concerning acute response of hormones, while it is commonly believed that responses have a major impact on physiological and performance adaptation, the effect is likely minor (Fink et al., 2018; Schoenfeld, 2013; Stone et al., 2022). Although the effects are likely minor, they should not be dismissed (Stone et al., 2022).

Testosterone

The protocol for measuring testosterone by Walker et al. (2017) involved 17 trained men (mean training age: 2.7 years) at the 2nd and 9th week of the 10 weeklong study. Blood samples were collected pre, 2 minutes after 3x10 RM leg press (mid-loading), and 5 minutes (5-post) and

15 minutes (15-post) after 3x10 RM unilateral knee extensions. Total testosterone was substantially elevated in the AEL group compared to TRAD at the 5 -post mark during the week 9 collection. Total testosterone in weeks 2 & 9 for the AEL group was statistically elevated at mid-loading compared to pre values, while TRAD did not have any statistical significant differences in either data collection. Walker et al. (2017) stated that this acute hormonal response falls in line with AEL creating greater increases in strength and muscle mass compared to TRAD in the second half of the 10 weeklong study. In terms of total and bioavailable (free) testosterone, only AEL statistically increased the 1-minute post values, while TRAD failed to reach significance (Yarrow et al., 2008). Additionally, AEL also reached statistical significance for the 15-minutes post when compared to pre values in bioavailable testosterone only. Interestingly, AEL total testosterone substantially decreased in the 30- and 45-minuntes post values when compared to pre, 1 minute post, and 15-minuntes post, while the 60-minuntes time point was statistically lower only when compared to pre and 1-minunte post. A similar finding was observed for AEL bioavailable testosterone, with the 30-, 45-, and 60-minuntes time points being statistically less than the 1-minute post value. There was also a statistically significant decrease for the same AEL bioavailable testosterone at the 45- and 60-minutes post values when compared to the 15-minutes post time point. In both testosterone variables, AEL was statistically non-significantly higher than TRAD at all time points. An important methodological limitation involves the use of TRAD completing 15% more volume compared to AEL. Based on the higher workload, the TRAD group might have been expected to produce higher testosterone concentrations. An additional limitation was the use of untrained subjects in the Yarrow et al. (2008) study.

Cortisol

Twenty-one trained men (BS 1.5x BW) were used as subjects. Cortisol (represents free cortisol) was assessed via saliva after a set of 120% AEL pre, immediately post, 15-, 30-, and 60-minutes post exercise (Merrigan & Jones, 2021). No statistically significant differences were observed between TRAD and AEL in both 65 and 80% concentric intensities. However, the 60-minute post time point revealed a statistically significant decrease only for the AEL 80% condition when compared to baseline. Quantitatively, both AEL conditions were statistically non-significantly higher than TRAD at all time points. However, Merrigan & Jones (2021) concluded that completing AEL at 120% eccentric on the first rep with a 65 or 80% concentric did not create higher cortisol responses compared to TRAD. The authors did note that the subjects were well trained, and this might have decreased the responses observed. Walker et al. (2017) measured cortisol via blood samples**.** The week 9 collection showed AEL statistically increased cortisol concentrations at all time points (mid-loading, 5- & 15-post) compared to pre values, while TRAD did not show statistical significance. No statistically significant differences were observed between groups at any time point.

Growth Hormone (hGH)

Twenty-two untrained men had blood samples collected at 1-, 15-, 30-, 45-, and 60-minutes post exercise after the final exercise bout in a 5 week study assessing AEL BP and BS (Yarrow et al., 2008). Growth hormone showed no statistically significant differences between TRAD and AEL, but the time points of 15-, 30-, and 45-minutes post showed a statistically significant elevation compared to pre values for both conditions. The elevated hGH levels return to baseline levels at the 60-minute post time point. Quantitatively, both groups produced similar results. An important note involves methodological limitations of more volume being completed in the TRAD and the addition of untrained men. However, evidence presented by Walker et al. (2017) revealed TRAD had statistically lower hGH responses at the mid-loading time point in the week 9 sample collection compared to AEL. Both training groups realized statistically significantly elevated hGH at the remaining time points for both data collections. However, the TRAD group showed statistically non-significant lower values in week 9 collection compared to week 2, while AEL was somewhat similar in both week 2 and 9 collections. As with the findings with testosterone in Walker et al. (2017), they believed this acute hormonal response created better neural and hypertrophy adaptations in AEL in the second half of the 10 week long study, while TRAD remained similar. Ojasto & Häkkinen (2009b) measured hGH in 11 trained men (1.2-1.4x BW BP) pre and post in a 4 conditions (TRAD, AEL at 80, 90, and 100%) crossover study with a 70% concentric performing as many reps as possible at each condition, with a cutoff of 10 reps for 4 sets total. Weight releasers were used for every AEL rep. Participants in the Ojasto & Häkkinen (2009b) study had 6 weeks of familiarization (2 weeks (5 total sessions) of unsupervised "intensive hypertrophic sessions" and then 4 weeks (5 total sessions) of using AEL). In terms of hGH, there were no pre-post statistically significant changes in any condition. However, the authors' indicated that the 90 and 100% AEL conditions showed a trend for post hGH values and change in hGH per repetition. Interestingly, the change of hGH revealed a statistically non-significant increase for the 90% AEL condition compared to the control condition (70% eccentric and concentric).

Lactate

Lactate was measured after 4 sets of 3 different AEL conditions and a control condition in 11 trained men (Ojasto & Häkkinen, 2009b). Every condition ($p < 0.001$) increased lactate levels, but the 90% AEL condition had the highest concentration of lactate. Further analysis revealed a statistically significant correlation ($r = 0.85$) for relative BP strength and the AEL conditions with the largest change in lactate. Ojasto & Häkkinen (2009b) stated that the strongest subjects did not produce high amounts of lactate at moderate AEL loads and suggested that the elastic components of muscles are storing and releasing forces during the concentric with the lower AEL intensities, thus glycolysis would be less activated. Under heavier AEL intensities, the elasticity benefits decrease. Friedmann et al. (2004) used untrained men ($n = 16$) for 4 weeks of RT and monitored lactate dehydrogenase (LDH) A (skeletal muscle) & B (heart and brain) and phosphofructokinase (PFK) pre and post. The isokinetic AEL knee extension group realized an ($p < 0.01$) increase in LDH A compared to baseline (+70%) and the TRAD group. The TRAD group did not elicit a statistically significant increase compared to baseline. Interestingly, all of the AEL subjects increased LDH A mRNA (+20-122%), while TRAD had a half and half increase (+6-58%) or decrease (-17-66%). Additionally, a nearly perfect ($r = 0.971$, $p < 0.001$) correlation existed for LDH A mRNA compared to MHC IIx-mRNA for the AEL group. The TRAD group had a statistically nonsignificant correlation ($r = -0.405$, $p = 0.426$). No statistically significant differences were noted for LDH B in any group. Another finding revealed no statistically significant changes in PFK for both groups. The key findings by Friedmann et al. (2004) led to the statement that AEL creates a unique adaptation in the glycolytic pathway. It is important to note that this study was carried out using untrained subjects who also received 3 weeks of familiarization prior to the start of the study. Yarrow et al. (2008) found supporting evidence that lactate was elevated in the TRAD group compared to AEL at the 30- ($p < 0.05$), 45- and 60-minute post exercise time points ($p < 0.01$). Yarrow et al. (2008) used a MaxOut device, a pully system by which weight is reduced during the concentric phase and added during the eccentric. Therefore, Yarrow et al. (2008) stated that AEL speeds up lactate removal post exercise, leading to better recovery from metabolic fatigue from RT. This led to the practical application of AEL being beneficial for athletes who compete at lactate threshold. One major concern for these findings was the higher volume (+15%) completed in the TRAD group. A total of 25 strength power athletes completed a maximal test of training-induced capillary blood lactate during the second and penultimate sessions of a 6 weeklong study (Friedmann-Bette et al., 2010). This blood was drawn at the earlobe at 1-, 3-, 5-, 10-, and 15-minutes after the last set of 8 reps for the unilateral knee extension. The AEL computer driven knee extension group (false detection rate = 0.0) increased mRNAs of both LDH isoforms (A & B), and the lactate transporter monocarboxylic acid (MCT4). This supports the results of AEL increasing the training-induced elevation of capillary lactate compared to baseline. This led Friedmann-Bette et al. (2010) to speculate that AEL creates more lactate and shuttles it out of the working muscle. TRAD did not realize any significant differences in capillary lactate elevation. The TRAD group only realized a statistically significant upregulation of mRNA LDH B. Lastly, Walker et al. (2017) showed no statistically significant differences in blood lactate (week 2 or week 9) between AEL or TRAD. However, TRAD had statistically non-significant lower week 9 values compared to week 2 for all time points (mid-loading, 5 post, and 15 post). AEL had slightly lower mid-loading, but the lactate levels were about the same at both week 2 and 9 for the 5 and 15 post time points. A more detailed examination of AEL: Chae et al. (2023b) noted sets of tens with AEL resulted in unique lactate responses based on total volume completed. AEL was completed with the weight releasers being reattached five times during a set (AEL5) or on the first and sixth rep only (AEL2). The weight releasers created an eccentric intensity of 110%, while the concentric was 60%. Subjects (1.9x BW BS, *n* = 12) were allotted 15 seconds of rest during reattachment of the weight releasers. The lactate responses revealed lower values for

AEL5 compared to AEL2 and TRAD at 5-, 15-, and 25- minutes post exercise. This is a very unique finding as AEL5 completed the most volume (6,630 kgs.) of all the conditions (AEL2: 5,944 kgs., TRAD: 5,487 kgs.).

Creatine Kinase (CK)

Eccentric Loading

Paschalis et al. (2008) had 14 untrained females complete 2 sessions of 75 total isokinetic maximum eccentric knee flexions separated by 24-30 days. Blood samples were collected pre, immediately after, and 1-, 2-, 3-, 4-, and 7-days after exercise in both bouts. The first bout only showed a statistically significant increase in CK values for 1-day post when compared to baseline values. Both bouts showed significantly elevated CK values at days 3 and 4 when compared to baseline values. A repeated bout effect was observed with significantly lower CK values in the second exercise bout when comparing days 3 and 4 to the first exercise bout. Both bouts of exercise returned to baseline 7-days post exercise. Additional evidence is presented by Saxton et al. (1995) with CK assessed pre, 72-, and 120- hours post exercise in 12 absolute untrained men and women. The exercise used was unilateral forearm flexion for 2x25 with a 3 s maximum eccentric phase. Only at 120 hours post exercise was CK statistically significantly elevated when compared to pre-values. Interestingly, the 72-hour post time point (average: 1363 IU/L) showed statistically non-significantly higher CK values compared to pre (average: 68 IU/L). Chen et al. (2023) had 52 sedentary men complete maximal isokinetic eccentric contractions for the elbow flexors (5x6) and knee flexors (10x6) for 2 bouts separated by 2 weeks. Resting blood samples for CK analysis were collected pre, and 1, 2-, 3-, 4-, and 5-days post exercise for both bouts in both the elbow and knee flexor groups. A repeated bout effect was shown for both flexor muscles, as there was a smaller, statistically significant, CK concentration in the second exercise bout compared to the first. Interestingly, 1-day post exercise seemed to elicit similar CK values compared to baseline, indicating a delay from the initiation of damage, due to the exercise bout. Elbow flexor CK values peaked 5 days post- exercise, while the knee flexors peaked on day 4. Another additional result not mentioned by the authors is that the elbow flexors average peak CK values was ~6000 IU/L, while knee flexors average peak CK values were ~4000 IU/L. This is interesting considering the knee flexors completed double the number of sets and are a bigger muscle group than the elbow flexors. Lastly, Eston et al. (2000) used 18 active men and women, who completed a 12% grade downhill running (7 mph) task for a total of 40 minutes. A total of 2 running sessions were completed with a washout period of 5 weeks between sessions. Creatine kinase (CK) was measured pre, 24-, 72-, and 120-hours post exercise for both workouts. In the first workout, CK was statistically significant, showing elevated CK concentrations 24-hours post compared to pre-exercise. At 72 hours post there was a statistically significant decrease compared to 24-hours post. The second workout resulted in lower CK values at each timepoint compared to the first workout, indicating a repeated bout effect that lasts for at least 5 weeks. Eston et al. (2000) noted no significant differences in CK levels between sexes or stride length (over-stride, under-stride, or normal stride). The fact that over stride did not elicit statistically significant higher CK values is interesting as it is suspected a lengthened muscle elicits greater muscle damage, as Child et al. (1998) found statistically significant higher soreness (days 1-3 and 5-6) in lengthened eccentric contractions compared to shorter muscle lengths in 7 active men and women. However, it is important to point out that the under-stride condition was statistically non-significantly lower (natural logarithm CK 1 day post: 5.32, 2 days post: 5, 3 days post: 4.88) than the other two conditions in both workouts (overstride: 5.75, 5.13, 5.33, respectively. normal stride: 5.82, 5.29, 5.48, respectively) using a webplot digitizer (https://automeris.io/WebPlotDigitizer/index.html). This finding may carry over into muscle damage observed during AEL BS compared to BP. With the BS inducing a greater range of motion under heavy eccentric load for the quadriceps. It can also be assumed that the lower body musculature has different muscular architecture and different fiber type composition, thus resulting in overall differences of CK values observed post exercise compared to the upper body.

Section Summary

While it is important to consider that increases in strength or hypertrophy are less likely to be influenced by acute hormonal responses, Walker et al. (2017) was the only study presenting interesting data illustrating that elevated anabolic hormones boosted performance in the second half of their study. Thus, AEL might induce a unique repetitive hormonal response for testosterone. For hGH, it appears that AEL induces a higher response compared to TRAD with 2 out of the 3 studies supporting this finding. The contrasting study had some methodological limitations. The suggested intensity to induce desirable hormonal responses during AEL appears to be a 20-40% greater eccentric load. The stress response of AEL seems to be mixed based on the limited literature ($k = 2$). However, quantitatively, AEL creates a statistically non-significant higher response of cortisol when compared to TRAD. For lactate, AEL creates a unique bioenergetic adaptation dealing with the glycolytic system, as this involves greater enzymes, transporters, and higher capillary lactate tolerance (increased muscular lactate generation and diffusion). Caution must be exercised for the capillary lactate tolerance as it was measured at the earlobe, which does not elicit the same values when taken from the finger. Additionally, it has been suggested that athletes who compete at lactate threshold may benefit from AEL. Lastly, Chae et al. (2023b) demonstrated lower lactate responses in AEL programming that completed more volume. Results showed that stronger individuals who engage in AEL will have higher lactate responses. The muscle damage marker, CK, showed a repeated bout effect does occur in eccentric loading, and this protection has a residual training effect of around a month. For individuals that continue to train consistently will notice a gradual decrease of CK values as they train. Interestingly, there appears to be a difference in CK values peaking between upper and lower body musculature. The knee flexors elicited peak CK values around the 3rd or 4th day post exercise, while the elbow and wrist flexors were 5 days post exercise. An important note is the eccentric duration, as a recent review by Handford et al. (2022) stated that eccentric durations of > 4 s creates higher values of blood lactate, hGH, and testosterone with equalized volumes when compared to faster eccentrics.

Potential Performance Decrements with AEL

There are some potential drawbacks with the use of AEL that practitioners may need to be aware of. When implementing AEL, individuals may experience high degrees of acute soreness and perceptual efforts, impaired coordination, joint reactions, max force, force modulation, and power. After the first few weeks of AEL training, practitioners (and subjects) will most likely not be concerned about AEL inducing elevated soreness as the repeated bout effect has a long protecting duration. Therefore, if practitioners want to avoid these possible decrements, it may be wise to introduce AEL in the off-season.

Soreness & Perceptual Efforts

AEL

Examination of studies using AEL was performed by Merrigan & Jones (2021). Using the squat, well-trained men (BS 1.5x BW, $n = 21$) completed a cross-over study with AEL or TRAD at 65 or 80% concentric intensities, with the AEL completing a 120% eccentric on the first repetition only. Perceived soreness elevated ($p < 0.01$) compared to baseline 24 hours post exercise for the AEL80 group. The authors stated that this did not exceed mild levels of soreness on average, but it is important to consider the subject population. A limitation involving the soreness values deals with the protocol order, as each condition was performed with 48 hours between measurements. The well-trained subjects completing low volume (9-15 reps) in the Merrigan & Jones (2021) study might have played a role in the data collected. While not statistically significant, Yarrow et al. (2008) noticed that more than half of the untrained subjects in their study were experiencing delayed onset muscle soreness (DOMS) in the AEL group (*n* = 10), while no issues were observed in TRAD. Interestingly, this study also had TRAD completing 15% more volume than AEL. While Friedmann et al. (2004) did not measure soreness, they reported that 2 subjects dropped out due to soreness or injury. Similar reports were made by an AEL study done by Walker et al. (2016), stating that two subjects dropped because of soreness. This is a concern as the subjects recruited by Walker et al. (2016) were well-trained, while the subject pool for Friedmann et al. (2004) were untrained. This may be of concern for practitioners prescribing AEL to athletes who are very prone to DOMS.

While not related to soreness, the perceptual efforts involved with AEL are an important factor to consider when training athletes. The best example of this is a study by Yarrow et al. (2008) who had 22 untrained men complete AEL (100-121% eccentric) for the BP and BS for 5 weeks. Using Borg’s RPE scale, the AEL group reported statistically significant, higher RPE values compared to TRAD only in the first four training sessions out of 15 total. At the same exact time, the authors noted that DOMS was occurring in more than half of the AEL subjects. Chae et al. (2023b) measured RPE via Borg Category Ratio 10 scale in 2 AEL programming conditions after each set in 12 trained men (1.9x BW BS). AEL was completed with weight releasers eliciting a 110% eccentric with a 60% concentric for sets of 10. The programming aspect involved the weight releasers being reattached either after every 2 reps (AEL5) or every 5 reps (AEL2). The reloading of the weight releasers created 15 s of rest before resuming the rest of the set. The findings by Chae et al. (2023b) revealed statistically significant greater RPE values in AEL5 after the second and third set when compared to AEL2 and TRAD. A contrasting study using the Borg RPE scale and concentric cycling produced statistically significant and higher values than two bouts of eccentric cycling in untrained men (Peñailillo et al., 2013). While there has been very limited research using RPE values during AEL, observation by the authors suggests that the initial sessions can be perceived as harder workouts compared to TRAD. It is possible that the observations made among initially untrained influenced RPE values.

Eccentric Loading

Two bouts of downhill running (7 mph, 12% grade, 5x8 minutes) resulted in significantly ($p < 0.001$) greater muscle tenderness in 18 active individuals who completed understride, overstride, and normal stride conditions (Eston et al., 2000). Tenderness peaked on the first day after exercise in the first bout, while it peaked on the third day for the second bout. Surprisingly, the overstride group was statistically non-significantly less than the preferred and under stride groups in both bouts of running. The repeated bout effect was observed in the second running bout eliciting significantly lower muscle tenderness after a 5-week intermission between runs. Investigating the knee extensors, Crenshaw et al. (1995) found eccentric contractions had a profoundly higher soreness based on a visual analog scale (VAS) when compared to concentric contractions in moderately active men ($n = 8$) 48 hours after exercise. The authors did not report a statistical value for the soreness. A closer examination of VAS scores of the lower body using eccentric only leg extensions (110% eccentric) in recreationally active men ($n = 25$) showed ($p <$

0.001) elevated values immediately, 24-, and 48-hours post exercise (Neltner et al., 2023). The authors only measured 48-hours post exercise, with immediately post-exercise peaking and soreness scores were statistically non-significant, decreasing at each time point after. Additional evidence via unilateral maximal leg extensions in untrained men (*n* = 14) showed statistically significant, higher VAS movement scores in the eccentric condition only at 1-3 days post exercise (Hyldahl et al. 2014). Movement VAS values peaked 2 days post exercise for the eccentric condition and was statistically significant and higher compared to the concentric for days 2 and 3 post exercise. Eccentric cycling for 30 minutes elicited severe soreness in the quadriceps 18-72 hours post exercise in 12 male physical education students (Friden et al., 1983). Peñailillo et al., (2013) measured VAS soreness from two bouts of eccentric cycling and one bout of concentric cycling in 10 untrained men. The first bout of eccentric cycling had statistically significant higher soreness scores 1-2 days post exercise compared to concentric cycling, and 1-4 days post-exercise compared to the second bout of eccentric cycling. Both eccentric bouts showed peak VAS values 2 days post exercise. The second bout of eccentric cycling was not statistically significant from the concentric condition. On the opposite side of the leg, Chen et al. (2023) measured VAS scores in 26 untrained men after completing two workouts of eccentric hamstring curls. Statistically significant soreness scores peaked 48-hours after exercise in the first exercise bout. A gradual decrease of VAS scores was noted for the remaining time points (5 days post exercise). The second bout VAS scores were statistically significant and lower compared to the first, showing a repeated bout effect for the hamstring musculature. A study assessing 14 untrained females noted a statistically significant elevated VAS palpation and movement values 4 days post-exercise in knee flexors (Paschalis et al., 2008). Approximately one month later, the same subjects completed a second bout of maximum eccentric knee flexion and noted VAS palpation and movement values were statistically significant and lower compared to the first bout at only 2- and 3-days post exercise. The second bout still elicited statistically significant higher soreness values 1-3 days post exercise. The only difference between palpation and movement VAS scores was movement VAS being statistically significant and higher in both RT bouts immediately after exercise. Brockett et al. (1997) presented data that showed muscle tenderness was significantly elevated in eccentrically trained biceps in 13 untrained (females = 7) adults. Tenderness values did not return to baseline till 4 days after exercise. Concentric only VAS was always less than eccentric. Completing two sessions of isokinetic bicep curls in untrained men (*n* = 26) elicited statistically significant peak VAS values 48-hours post exercise (Chen et al., 2023). The remaining time points (3-5 days after exercise) gradually decreased for both exercise bouts. The second exercise bout elicited significantly lower VAS scores compared to the first session, demonstrating a repeated bout effect. Another muscle assessed by the VAS for soreness via palpation and movement was the forearm flexors in 12 total men and women (Saxton et al., 1995). Both palpation and movement VAS scores were statistically significant and elevated 5 days after eccentric exercise. However, the Saxton et al. (1995) study only had an eccentric group.

Impaired Coordination

Eccentric Loading

Brockett et al. (1997) showed positional sense for the elbow flexors was statistically significant and impaired over 3 days and only returned to baseline by the 4th day. The eccentric trained arm (unilateral training) always achieved a more extended position. Using eccentric exercise for the forearm flexors in untrained adults (*n* = 12), Saxton et al. (1995) found statistically significant impaired joint angle proprioception compared to the control arm 24-, 96-, and 120-hours post exercise. Measuring positional sense in elbow and knee flexors in two RT sessions showed eccentric exercise created significant changes in 52 untrained men (Chen et al., 2023). The elbow flexors impairment peaked 1 day post exercise (-8°) and was still worse 5 days post exercise (-4°). A similar trend was noted with the knee flexors impairment peaking 1 day post exercise (-6°) and below baseline 5 days after exercise (-2°). Interestingly, the second bout of exercise resulted in statistically significant better positional sense compared to the first bout. Both bouts of eccentric exercise had the subjects be in a more extended position. Chen et al. (2023) also measured a fascinating variable known as joint reaction angles. This variable involves the tested limb to be passively moved to the tested angle slowly and held there till the participant relaxes. Without the participant knowing, the investigator would release the lever arm without warning, requiring the participant to stop it as fast as possible. The joint reaction angle is the difference between the specified angle and stopping angle. The elbow and knee flexors were both statistically significant and worse compared to baseline 24 hours post-exercise (-11° & -8°, respectively) and still lower 5 days post exercise (-7° & -4°, respectively). There was a repeated bout effect for joint reaction angles, with the second exercise bout showing a similar trend to the first bout but performed with a substantially smaller degree of impairment. Chen et al. (2023) noted statistically significant decreases in ROM of the elbow and knee flexors over the course of 5 days post exercise. Values peaked for both groups immediately post- exercise (elbow: -12%, knee: -10%) and were still lower compared to baseline 5 days later (elbow: -9%, knee: -5%). Again, a statistically significant difference was observed with the second exercise bout showing better ROM compared to the first bout with a similar trend for each time point. In a similar study, Paschalis et al. (2008) measured position sense and joint reaction angle in 14 untrained females after completing maximal eccentric knee flexions (5x15 reps at 60°/s). Positional sense was measured at three different angles and revealed statistically significant impairment at extended positions immediately after and 1-day post-exercise for the eccentrically trained limb (-1-3°). The control limb did not exhibit statistically significant deviations at any time point for any position. There was a repeated bout effect observed for the second bout of exercise performing substantially better than the first bout at several time points and positions. The joint reaction angle was also assessed at three different angles and revealed statistically significant decreases 1-3 days post exercise for the eccentrically trained leg. A repeated bout effect was observed for the second bout as it performed significantly better 1-3 days post-exercise at some angles. The control limb only showed a statistically significant difference for one angle 2 days after exercise.

Impaired Strength

Eccentric Loading

Completing 110% eccentric only leg extensions, 25 recreationally active men only had a ($p < 0.01$) decrease in maximum voluntary isometric contraction (MVIC) immediately after exercise (Neltner et al., 2023). Surprisingly, the 24- and 48-hours post exercise MVIC measurements showed no statistically significant differences compared to baseline but attained lower values of strength. Twelve male physical education students completed 30 minutes of eccentric cycling and noticed significant decreases in knee extensor MVIC (0°/s) and isokinetic MVC at three different velocities (90, 180 and 300°/s) 20 minutes post exercise (Friden et al., 1983). Only 3 velocities were still statistically significant and weaker 72-hours post exercise. Peñailillo et al. (2013) also found a statistically significant decrease in knee extensor MVC strength immediately post, and 1-2 days post eccentric cycling compared to concentric cycling in untrained men. When comparing the first bout of eccentric cycling to the second bout, MVC strength was significantly decreased 1-4 days. Assessing MVC strength via maximal unilateral eccentric knee flexion in untrained women revealed a statistically significant decrease immediately after and up to 4 days post exercise (Paschalis et al., 2008). The second bout showed a statistically significant increased MVC values at 2- and 3-days post exercise. Assessing MVC strength after maximal eccentric knee flexion in untrained men ($n = 26$) showed a statistically significant decrease (-30%) immediately after exercise (Chen et al., 2023). MVC values were still lower (-15%) five days post-exercise. A repeated bout effect was observed with the second bout having substantially fewer decrements in MVC compared to the first bout. Brockett et al. (1997) found ($p < 0.001$) impaired MVC force and force modulation of the elbow flexors in the eccentric group in untrained adults ($n = 13$). Interestingly, MVC force decreased more for concentric only (-14%) compared to eccentric only (-10%). In terms of matching force modulation at 10% MVC, eccentric would produce less force (10%) while concentric only would produce more force (10%). This was completed by having the reference arm complete the 10% MVC force level and provided visual feedback to achieve such amount of force. Then the experimental arm was asked to match the same degree of force without visual feedback. This impaired force modulation remained statistically significant until 4 days after exercise. After completing eccentric forearm flexion, 12 untrained subjects were ($p < 0.01$) weaker in MVC 5 days post-exercise (Saxton et al., 1995). Chen et al. (2023) conducted two bouts of maximal eccentric elbow flexion in untrained men ($n = 26$) and observed a statistically significant decrease (-40%) immediately after exercise. Five days post exercise, MVC values were approximately -20% for the elbow. A repeated bout effect was observed with the second bout showing smaller decrements in MVC compared to the first bout.

Isokinetic Loading

Hyldahl et al. (2014) found a significant decrease in isokinetic leg extension strength 1-3 days post exercise in 14 untrained men following eccentric training. The eccentric condition performance was statistically significant and worse when compared to the concentric group in terms of isokinetic strength 2-3 days post exercise.

Rationale for impaired strength

A possible explanation for impaired strength performances may be due to kinematics. Kristiansen et al. (2022) noted the sticking region in the BP started lower and with a slower barbell velocity during 110% AEL in trained men. However, this finding may be a result of a methodological limitation as subjects were not allowed to bounce the bar off their chest. Merrigan et al. (2021) also stated that completing AEL BP between 100-120% may modify lifting mechanics and possibly impair performance. This statement was based on trained men and women who could BP their body weight. However, evidence has been provided by Montalvo et al. (2021) who used competitive power lifters (BP at least 1.5x BW) observed improvements in 1RM bench press using 105-125% AEL with a one second pause on the chest. Training experience and background most likely explains why Montalvo et al. (2021) found improvements in the BP using AEL with a pause, as powerlifters are required to pause during competition for the BP. The subject pool in Kristiansen et al. (2022) were just trained men, therefore, it can be assumed they do not have as much experience as powerlifters when it comes to paused BP.

Power Output

Acute AEL

Chae et al. (2023b) found two types of AEL weight releaser schemes (AEL5 and AEL2) created a 1-4% decrease in countermovement jump (CMJ) height in unloaded and loaded (20 kgs.) conditions compared to TRAD 25 minutes post exercise. For the unloaded CMJ condition, both AEL schemes were equal in decreased CMJ height post exercise. The loaded CMJ resulted in AEL5 having the biggest decrease.

Eccentric Loading

Only two studies have assessed power output after eccentric contractions. Friden et al. (1983) noted a statistically significant decrease in MVC at 300 °/s, 6 days after 30 minutes of eccentric cycling in 12 men. This may be a compensatory mechanism to avoid inducing more pain within the sore tissues (Cheung et al., 2003). Another study that measured changes in power output also used eccentric cycling (Peñailillo et al., 2013). The first bout of eccentric exercise elicited a statistically significant decrease (-7 to -12%) in CMJ height when compared to baseline. Comparison amongst groups showed that eccentric cycling was statistically significant and lower 1-2 days post when compared to concentric cycling, and 2-3 days post exercise when compared to the second bout of eccentric cycling. The squat jump (SJ) showed a statistically significant decrease (-17 to -22%) in the first eccentric cycling group immediately post and 1 day after compared to concentric, and significantly decreased (-12 to -14%) 1-2 days post for the second eccentric session. No statistically significant differences were observed between concentric cycling and the second bout of eccentric cycling for either CMJ or SJ.

Section Summary

The use of eccentric contractions can elicit peak soreness approximately 2 days after exercise and can last up to 5 days after. Friden et al. (1983) noted that the soreness may inhibit an individual's ability for fast movement and force production. Thus, a major concern for practitioners when utilizing AEL is limiting the degree of soreness, as expressed in a review by Douglas et al. (2017a). A review by Nicol et al. (2006) noted a bimodal trend for neural factors (EMG, short-latency amplitude, and stretch-reflex amplitude) after a fatiguing SSC task. Surprisingly, most of the neural factors reached premeasurement values 2 hours post exercise. This was believed to be a result of metabolic fatigue dissipating. However, all the neural factors returned to slightly better values than the immediate post time 24-48 hours post exercise. This follows the time course of when soreness is typically the highest. This leads to a review by Cheung et al. (2003), who noted DOMS can create consequential alterations in muscle coordination and segment motion (decreased joint ROM, shock attenuation, and peak torque), thus increasing the chance of injury if a premature return to sport occurs. Hody et al. (2019) recommend that explosive movements be avoided if athletes are experiencing DOMS, as there is a higher chance of tearing a muscle or ligament from improper muscle function and mechanical fragility. This can be important for practitioners in planning out their microcycles, with the most coordinated or powerful movements being completed when athletes are least fatigued or are suspected to have the least amount of DOMS. Perceptual efforts of AEL are lacking in trained individuals, but the current state of the literature indicates an initial elevation of RPE values. Interestingly, the use of eccentric exercise impairs coordination and joint ROM immediately after and up to five days post-exercise. The literature illustrates that individuals end up in a more extended joint angle after eccentric exercise compared to the target angle. Joint reaction angles can also be impaired in single joints 3-5 days after eccentric exercise (Chen et al., 2023). Eccentric contractions can create diminished strength capabilities lasting 3-5 days after exercise as well. Limited study has been completed dealing with power assessment after eccentric exercise, with the current data showing jumps and fast contraction velocities being affected up to 3 and 6 days after exercise, respectively. One consistent finding in all of these studies is a repeated bout effect, with the second eccentric session having less decrements on performance when compared to the first eccentric session.

AEL and Training Methodology

Accentuated Eccentric Loading (AEL) is a resistance training exercise type that may provide for psychological, physiological and performance enhancement beyond typical traditional (TRAD) forms of training (Chae et al., 2023a, 2023b; Wagle et al., 2017). However, the utility of AEL, as an exercise mode, must be considered in the context of the training process. Block periodization (BP) has been shown to be an efficacious training paradigm (Stone et al. 2022). Generally, over time, moves from less specific to more specific and from higher to lower training volume. Block Periodization consists of a “stage” which contains three periodization blocks (Stone et al. 2022). The periodization blocks are in sequential order: 1) Accumulation, 2) Transmutation and 3) Realization. Accumulation emphasizes alterations training in order to alter body composition and work capacity. During Transmutation, exercise becomes more specific as the volume is decreasing. Realization deals with further volume reductions (often a taper) and exercises becoming very specific in relation to those encountered during competition (Stone et al. 2022). Each periodization block can consist of fitness blocks or concentrated loads of about 4 weeks, designed to emphasize a specific aspect of fitness associated with the periodization block (Stone et al. 2022). Additionally, Hoffman (2011) stated that heavy eccentric training should be used within 4-6 week cycles for only a few sets per session to help minimize excessive muscle damage and the risks of overtraining or injury. Each block, if appropriately programed and sequenced, can potentiate adaptations for the next block as a result of residual effects (Stone et al. 2022). Appropriate programming is of paramount importance in order to produce the desired effects of the block. For example: during the accumulation block the early portion is typically a strength-endurance (S-E) fitness block. The S-E block is often of high volume and produces considerable accumulated fatigue. Based on acute observations (Chae et al., 2023a, 2023b), it may be possible to use AEL during the S-E block, produce equivalent or superior effects, but cause less training strain and accumulated fatigue. This effect may enhance the potentiating effect of the S-E block when training moves to a basic strength block.

Overall Summary

The rationale behind AEL producing superior results compared to TRAD appears sound for both the muscular and neuromuscular systems, however, training studies that utilize AEL appear to have contradictory results. Applying the physiological basis for these adaptations to performance measurements, AEL produces better upper and lower body improvements for strength and power compared to TRAD. In terms of hypertrophy, AEL is superior to TRAD for lower body, however no studies have measured upper body musculature. Transient release of anabolic hormones following AEL may also be part of the rationale as to why there are better performance boosts compared to TRAD. Lastly, AEL and eccentric training does induce weeklong decrements of joint coordination, joint reactions, force, power, soreness, and possibly perceptual efforts. However, these appear to occur for the first couple of sessions with AEL and eccentric training. Thus, it would be prudent to prescribe AEL when athletes are not in-season. Prescription of AEL intensities may differ slightly based off the goal of the individual. It appears that strength and power gains are superior in the AEL BP when using a 15-35% and 25-30%, respectively, higher eccentric intensity. However, it is important to consider the strength standard (>1.5x BW) of the individual in order to realize benefits in strength and power for the AEL BP. The literature for BS intensities is lacking consistency of findings and methodologies. For hypertrophy and hormonal responses, the literature suggests a 38-40% and 20-40%, respectively, higher eccentric phase. Assuming that AEL produces beneficial effects, AEL could potentially be integrated into different parts of the training process and produce superior outcomes. However, exactly how and where AEL would fit into the overall training process is unknown. Recently, evidence (Chae et al., 2023a, 2023b) indicates that AEL may reduce training strain. As the accumulation periodization block of training can have volume and produce considerable training strain and substantial stress, it may be possible to reduce training strain and subsequent stress by using AEL.

Chapter 3. Chronic Comparison Of Upper And Lower Body Muscle Soreness In Trained Individuals Completing Traditional Or Accentuated Eccentric Loading

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Abstract

The purpose of this study was to compare the effects of accentuated eccentric loaded (AEL) and traditional resistance training (TRAD) in terms of muscular soreness in the barbell bench press (BP) (anterior deltoid, triceps brachii, and pectoralis major) and back squat (BS) (vastus lateralis and gluteus maximus). A total of 18 recreationally active participants (Males: $n = 12$, age: 22.75 ± 4 years, BW: 89.42 ± 21.09 kg, BP 1RM: 104.67 ± 23.58 kg, relative BP 1RM: 1.19 ± 0.22, BS 1 RM: 140.75 ± 39.17 kg, relative BS 1RM: 1.59 ± 0.34, Females: $n = 6$, age: 23.6 ± 4.5 years, BW: 64.3 ± 10.8 kg, BP 1RM: 51.7 ± 13.4 kg, relative BP 1RM: 0.80 ± 0.13, BS 1 RM: 93.7 ± 18 kg, relative BS 1RM: 1.47 ± 0.30) completed 4 weeks of strength endurance training. Resistance training occurred 3 times a week (M, W, F), while speed and agility happened twice weekly (T & R). Participants completed the 10 cm palpation and movement visual analog scale (PVAS & MVAS, respectively) immediately before (PRE) and after (POST) every training session. The LB (lower body) musculature statistically decreased over time for the AEL group only for the MVAS ($p < 0.05$). The PVAS showed statistically significant lower LB scores in AEL compared to TRAD. We conclude that AEL training appears to create less soreness, specifically within the LB when compared to TRAD. Practitioners should not be concerned about excessive soreness when completing AEL training.

Keywords: Back squat, Bench Press, Eccentric, Tenderness

Introduction:

The use of accentuated eccentric loading (AEL) is an emerging training methodology topic in the literature. Comparing this training method to traditional resistance training (TRAD), has shown potential performance enhancements in strength (Brandenburg & Docherty, 2002; Cook et al., 2013; Doan et al., 2002; English et al., 2014; Friedmann-Bette et al., 2010; Norrbrand et al., 2008; Walker et al., 2016, 2017), power (Cook et al., 2013; Friedmann-Bette et al., 2010; Lates et al., 2020; Merrigan et al., 2020; Munger et al., 2022; Ojasto & Häkkinen, 2009a; Taber et al., 2021), hypertrophy (English et al., 2014; Norrbrand et al., 2008; Walker et al., 2017), and speed (Cook et al., 2013; Douglas et al., 2018). There has been relatively few studies demonstrating similar results from both training methods (AEL and TRAD) in regards to strength (Friedmann-Bette et al., 2010; Godard et al., 1998; Moore et al., 2007; Munger et al., 2022), power (Kristiansen et al., 2022; Moore et al., 2007; Munger et al., 2022; Taber et al., 2021; Wagle et al., 2018a; Wagle et al., 2018b), and hypertrophy (Godard et al., 1998). In fact, the use of AEL has achieved equal or superior increases in strength measures, except for a single study (Ojasto & Häkkinen, 2009b). Therefore, the use of AEL may be a promising novel stimulus for trained individuals to achieve a higher degree of performance (Pearcey et al., 2021).

There are some aspects that practitioners need to consider when implementing AEL. The primary concern would most likely be excessive soreness (Douglas et al., 2017a). This is due to AEL involving heavy eccentric contractions, which have been shown to induce a greater degree of soreness compared to concentric contractions (Brockett et al., 1997; Crenshaw et al., 1995; Eston et al., 2000; Friden et al., 1983; Hyldahl et al., 2014; Merrigan & Jones, 2021; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995; Yarrow et al., 2008). A systematic review and meta-analysis by Grainger et al. (2023) concluded that subjective measures of soreness were the best method to help assess fatigue after rugby union matches or training. Additionally, the use of self-report questionnaires was reported to be the most used monitoring tool in 84% of practitioners in New Zealand and Australia (Taylor et al., 2012). It was also reported that perceived soreness was the most common questionnaire response used to determine the recovery status of the athlete (Taylor et al., 2012). A high degree of soreness may also lead to decrements in strength (Chen et al., 2023; Friden et al., 1983; Hyldahl et al., 2014; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995) and power (Chae et al., 2023b; Friden et al., 1983; Peñailillo et al., 2013). Secondary concerns with the use of the eccentric contractions in AEL may involve impaired force modulation (Brockett et al., 1997), joint reactions (Chen et al., 2023), and coordination (Brockett et al., 1997; Byrne et al., 2004; Chen et al., 2023; Paschalis et al., 2008; Saxton et al., 1995). However, the previous listed studies were investigations of only eccentric contractions, currently, no studies have implemented assessments of AEL's effect on any of these variables. These factors, reflecting soreness and fatigue, are not ideal for training athletes who are in season and are required to perform optimally, especially in sports that require a great deal of coordination (Child et al., 1998).

A potential positive aspect of high degrees of soreness involves the repeated bout effect (RBE). This will lead to a decrease in soreness values the second time the same stimulus is applied. The recommended dosage required to induce the RBE, is 10 eccentric repetitions (Brown et al., 1997), while the time frame for the RBE to occur may take up to 5 days post exercise (Ebbeling & Clarkson, 1990). It has also been shown that the RBE adaptation can occur when a muscle is not fully recovered from the first bout of intense exercise (Ebbeling & Clarkson, 1990). It would be expected that athletes in strength training programs in which a relatively novel task is introduced would experience substantial muscle soreness. However, the soreness should be ameliorated relatively rapidly, via the RBE. This RBE has been shown to last up to 6 months after being exposed to the same intense exercise stimulus (Nosaka et al., 2001). Therefore, it is possible that by inducing soreness and subsequently a repeated bout, soreness could be reduced in exercises using a similar muscle mass for a substantial period of time. Thus, practitioners may prescribe the use of repeated bout exercise sessions to "protect" by reducing soreness in athletes prior to training camps, very demanding practices, or encountering a challenging season schedule.

The purpose of this study was to assess the degree of muscular soreness experienced in trained individuals over the course of a 4-week training program using either AEL or TRAD. The muscle soreness observed in the present study may give insight into upper and lower body differences for soreness with AEL weight releasers being used for the bench press (BP) and back squat (BS). Therefore, we hypothesized that AEL would create a higher degree of soreness compared to TRAD during the first week, and the RBE would be present for the remainder of the study duration.

Methods:

Experimental Approach to the Problem

This study was designed to compare the soreness values of specified muscles that were primary and secondary movers for the BS and BP. The exercise execution manner was the only difference between the 2 groups over the course of the study, as the AEL group implemented weight releasers every 2nd repetition, thus allowing participants to rest for 15 s before reattachment of the weight releasers. A visual analog scale (VAS) was used to determine the degree of soreness experienced using different training stimuli. There were two versions of the

VAS scale, one that involved self-palpation (PVAS) of the entire muscle itself, and the other involved taking the specified muscle through a full range of motion (MVAS) at a self-selected fast speed. The use of the VAS scale has shown similar values with the myometer pressure technique (Teague & Schwane, 1995).

Subjects

A total of 18 recreationally trained participants (mean ± SD; Males: *n* = 12, age: 22.75 ± 4 years, BW: 89.42 ± 21.09 kg, BP 1RM: 104.67 ± 23.58 kg, relative BP 1RM: 1.19 ± 0.22, BS 1 RM: 140.75 ± 39.17 kg, relative BS 1RM: 1.59 ± 0.34, Females: *n* = 6, age: 23.6 ± 4.5 years, BW: 64.3 ± 10.8 kg, BP 1RM: 51.7 ± 13.4 kg, relative BP 1RM: 0.80 ± 0.13, BS 1 RM: 93.7 ± 18 kg, relative BS 1RM: 1.47 ± 0.30) were pair matched, based on net relative strength (BS + BP) and the pairs randomly assigned to either a TRAD or AEL group for 4 weeks of training. All participants confirmed they trained the BP and BS movements regularly in their own training. Participants were admonished to refrain from exercise outside of the study.

Exclusion criteria included previous use of weight releasers over the past year, participants that missed >10% of total training or testing sessions, or if they had any obviating injuries prior to the start of the study. Prior to the start of data collection, all subjects signed a written informed consent that was approved by the institutions IRB committee (ETSU IRB ID # 0822.2f)

Procedures

Participants met with an investigator which explained the use of the soreness survey a week prior to training. The investigator introduced the format/instructions of the surveys to each participant. Then, using the survey, subjects completed the palpation visual analog scale (PVAS) first. Participants were instructed that the VAS scale ranges from 1-10, with 1 equivalent to no soreness at all and 10 is extreme soreness (see Figure 3.1). For the PVAS, participants were instructed to feel around the entire muscle a couple times before entering their value for the specified muscle. All measurements of soreness involved the right side of the body. The order of palpated muscles were: gluteus maximus (GM), vastus lateralis (VL), pectoralis major (PM), anterior deltoid (AD), and the triceps brachii (TB). Participants were instructed to complete the palpation and then record the value prior to moving onto the next muscle in the survey. After completing all of the muscles for PVAS, the survey then asked participants to complete the movement visual analog scale (MVAS) following the exact scale shown in Figure 1. The MVAS instructions had participants contract the same muscles in the same order through 3 different self-selected speeds in the order of slow, moderate, and fast. The MVAS may be more ecologically valid for assessing muscle soreness as sporting actions require different velocity movements. It may be possible that VAS limitations with soreness is related to muscle swelling or simply soreness, particularly at extremes of the range of motion (Saxton & Donnelly, 1996). The movements activated muscles through their full range of motion. Therefore, the GM required complete hip flexion to hip extension, the VL required complete knee flexion to knee extension, the PM required complete horizontal abduction to horizontal adduction, the AD required complete shoulder extension to shoulder flexion, and the TB required complete elbow flexion to elbow extension. The range of motion achieved was based on the max flexibility of the participant for that specified muscle. Participants were required to use one level of movement speed for a specified muscle and record that value prior to moving onto the next speed for the same muscle. These surveys were completed before warming up (PRE) and immediately after finishing the training session (POST) for every training session. Surveys were sent electronically to each participant’s email and were scheduled to be sent 10 minutes before the start of each session. Surveys were completed via Google Forms. A fac-simile of the PRE and POST questionnaires can be found at this link: https://forms.gle/ejDgTfNzciJQhKMA7 .

Figure 3.1: *The palpation and movement visual analog scale (PVAS and MVAS, respectively).*

Training Program

Accentuated eccentric loading (AEL) and TRAD completed the exact same training program (sets and repetitions). The study aimed to complete a target of 3x10 repetitions with 2 minutes of rest between sets. For a given training session both groups performed the same 3 exercises. The number of visits included 6 testing days (3 days for both pre- and post-testing) and 20 training days (12 resistance training and 8 speed and agility, Table 1). The only difference between groups was the use of weight releasers for the AEL group. Weight releasers were reattached every 2 repetitions, creating a total of 5 AEL repetitions per set. Participants were asked to rest for 15 s while investigators manually reattached the weight releasers to the bar. Attachment of the weight releasers was completed by using a second pair of weight clips to help consistently place the weight releasers in the same spot to help distribute and balance the bar. The weight releasers created a 110% eccentric intensity for the BS and BP, which were completed on Mondays and Fridays of each week. In terms of tempo, participants in both groups were told to complete the lift at their own speed, which resulted in ~1 s duration for both the eccentric and concentric portions. The training program is shown in Table 3.1. There were no weight releasers used on Wednesdays of each week, therefore AEL and TRAD completed the exact same workout on Wednesdays. Both groups completed the same standardized dynamic warmup (see Table 3.2) together but lifted in separate weight rooms under the supervision of experienced and certified strength and conditioning specialists (CSCS via NSCA). The warmups for BP and BS on Mondays and Fridays differed slightly between AEL and TRAD (see Table 3.3). After 2 weeks of training, the groups would switch weight rooms and supervising coaches to avoid any possible facility or coaching biases.

Table 3.1 Training program details

Training Intensities:

	TRAD:		**AEL:**		
Week	**M & W**	**F**	**M**	**W**	**F**
1	57.5%	50%	110%▲/57.5%	57.5%	110%▲/50%
2	62.5%	55%	110%▲/62.5%	62.5%	110%▲/55%
3	67.5%	57.5%	110%▲/65%	67.5%	110%▲/57.5%
4	52.5%	45%	110%▲/52.5%	52.5%	110%▲/45%

Exercise Selection and Order:

M	W	F
BS*, BP*, single arm overhead DB triceps extension	CG MTP, CG SLDL, BB row	BS*, BP*, single arm overhead DB triceps extension

*TRAD = traditional resistance training, AEL = accentuated eccentric loading, ▲ = eccentric intensity, M = Monday, W = Wednesday, F = Friday, BS = barbell back squat, BP = barbell bench press, DB = dumbbell, CG MTP = clean grip mid-thigh pull, CG SLDL = clean grip stiff leg dead lift, BB = barbell, * = AEL weight releasers*

Table 3.2 Warm up

Standardized General Warmup:
Light jog (400 m)
Elephant walks x 10 m
Quad pull x 10 m
Forward lunge with rotation x 10 m
Leg cradle x 10 m
Reverse lunge with reach x 10 m
Hamstring scoops x 10 m
Side lunge x 10 m

m = meters

Table 3.3 Resistance training warmup protocol

Bench Press and Back Squat Warmups on Mondays & Fridays:	
TRAD	AEL
1x5 at 25% 1 RM	1x5 at 25% 1 RM
1x5 at 50% 1 RM	1x5* at 50%▲/25%
1x1 at 80% 1 RM	1x2* at 80%▲/50%

▲ *= eccentric intensity, * = AEL was completed on the first repetition of the set, TRAD = traditional, AEL = accentuated eccentric loading*

Participants in both groups also completed speed, agility, and mid-section training on Tuesdays and Thursdays each week. Please refer to Table 3.4 for further details of speed, agility, and mid-section training. This makes the study more ecologically valid as athletes typically complete resistance training sessions and sprint etc. sessions within the same block of strength-endurance training.

Table 3.4: Speed, agility, and midsection training

Week:	Tuesday:	Thursday:
1	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x10 m Crunches 3x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x5 m 180° turn (exit 5 m to decel) 1x4x5 m
2	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x15 m Crunches 4x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x10 m 180° turn (exit 5 m to decel) 1x4x10 m
3	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x20 m Crunches 4x25	Buildups: 2x20 m Linear decel: 1x4x7.5 m Lateral decel: 1x4x7.5 m Sidestep cut (exit 5m to decel) 1x6x10 m 180° turn (exit 5 m to decel) 1x6x10 m
4	Buildups: 2x15 m, 2x25 m Crunches 2x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x5 m 180° turn (exit 5 m to decel) 1x4x5 m

m = meters, decel = deceleration

Training sessions occurred early in the morning (0600 hours), afternoon (1200 hours), or evening (1500 hours) sessions. Participants generally and consistently attended the same training time across the 4 weeks. If they switched training sessions, the survey would update to the correct time for that participant. Most training sessions, including warm-up, were completed in ≈ 50 minutes

Statistical Analysis

Data was collected in Google Forms initially and was then analyzed using the statistical software R (Version 4.3.2; R Core Team, Vienna, Austria). The statistical packages used include stringr, tidyr, ordinal, ggplot2, and rcompanion. Statistical significance was set with $\alpha \leq 0.05$. The soreness values were clustered to form upper body (UB: PM, AD, T) and lower body (LB: GM & VL) sections of each soreness measurement (PVAS & MVAS). The highest value of each body section each day was used for analysis and was differentiated between PVAS and MVAS. The PVAS and MVAS were run through their own separate statistical cumulative link mixed models fitted with the Laplace approximation, with the soreness rating serving as the independent variable and the subject as the random effect variable for the repeated measures. Dependent variables included group, day, time, and muscle. The time variable had two levels (PRE and IMM) and was dummy-coded with PRE set as the reference level (i.e. PRE=0). Group had two levels (AEL and TRAD) and also was dummy-coded with TRAD as the reference level (i.e. TRAD=0). Muscle with 2 levels of UB and LB was dummy-coded with UB as the reference level (UB=0). Pseudo R^2 indices (McFadden, Cox and Snell, and Nagelkerke) were computed to examine the fit of each model. Missing data was excluded from the analysis of each model. Both models were first computed as a saturated model with all of the aforementioned independent variables (i.e. all main effect and interaction effect terms). However, in order to manage the model complexity and avoid overfitting, the parsimonious approach was used by removing all independent variables that failed to show statistical significance for both the associated main effect and interaction effect(s). Hessian matrix and logistic link function were used for both models. The analysis was conducted as suggested by (Christensen, 2023). The critical alpha level was set at 0.05.

Results:

Palpation

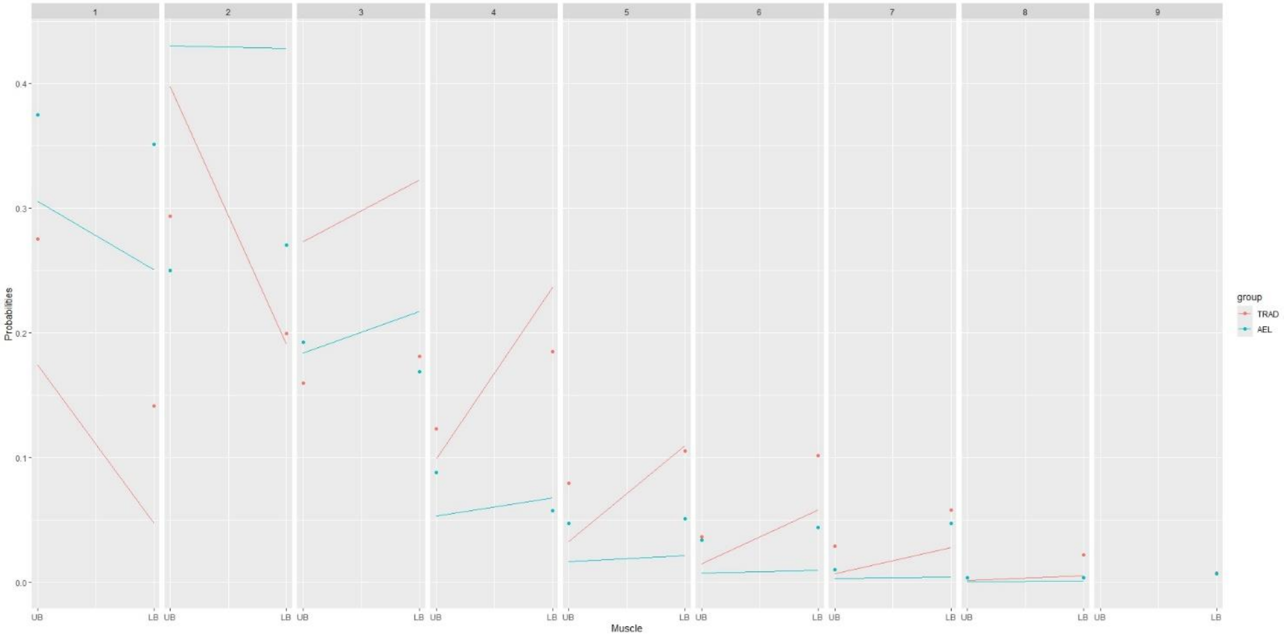
The random effects for the PVAS model achieved a variance of 3.66 (± 1.91). The final PVAS model remained the dummy variables for group and muscle and the interaction between these (Table 3.5). Threshold coefficients were as follows: -1.55 for scales 1 to 2, 0.28 for 2 to 3, 1.69 for 3 to 4, 2.82 for 4 to 5, 3.73 for 5 to 6, 4.77 for 6 to 7, 6.38 for 7 to 8, and 7.6 for 8 to 9. The model returned a Hessian matrix value of 1446.85. Please see Figure 3.2 for a visual of the interaction model of Group AEL:Muscle LB.

Table 3.5: PVAS Model Overview

Model	**Coefficient (β)**	***SE***	**P value (*p*)**	**Exponentiated Coefficients**
Group AEL	-0.732	0.917	0.424	0.480
Muscle LB	1.452	0.162	< 0.0001	4.272
Group AEL: Muscle LB	-1.179	0.225	< 0.0001	0.307

**Muscle LB = dummy variable with UB = 0 and LB = 1, Group AEL = dummy variable with TRAD = 0 and AEL = 1, and SE = standard error for coefficient*

Figure 3.2: Interaction model of Group AEL:Muscle LB for soreness

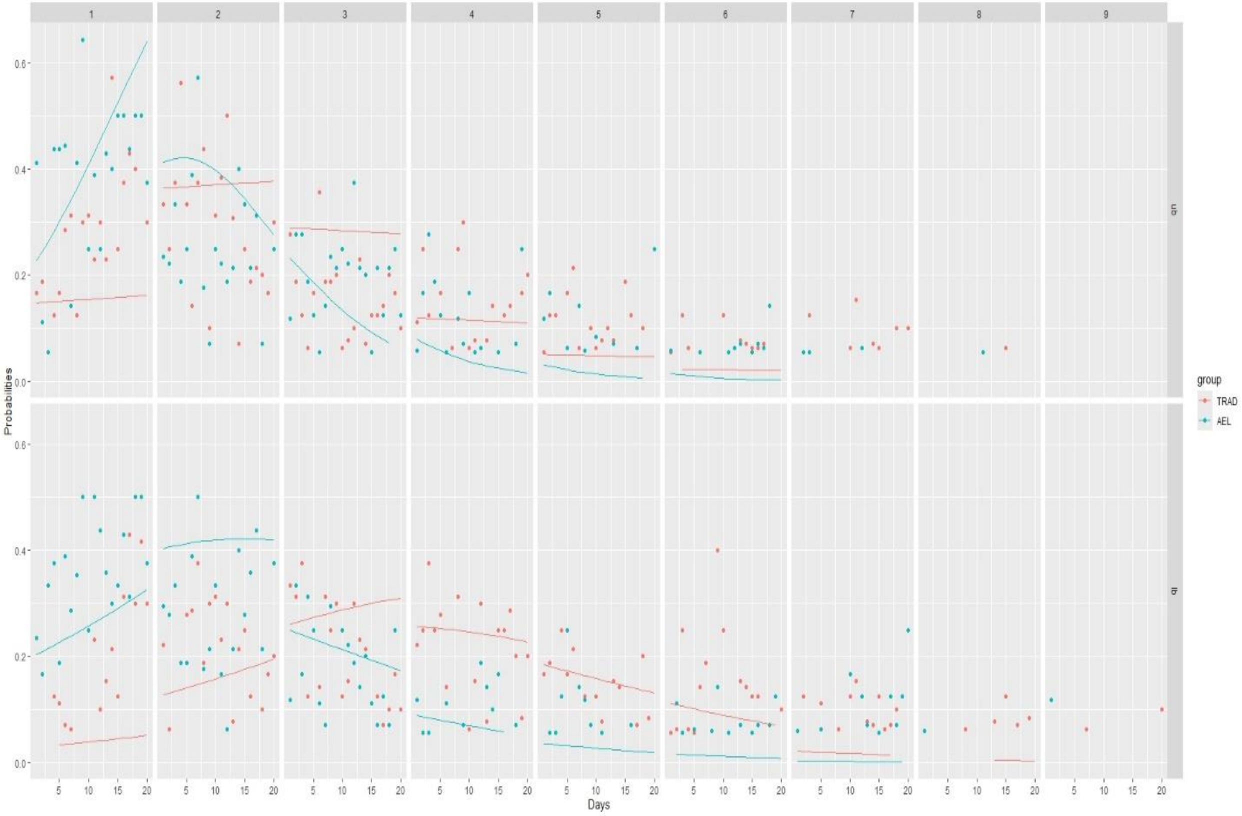


**UB = upper body (triceps brachii, anterior deltoid, pectoralis major), LB = lower body (gluteus maximus and vastus lateralis), AEL = accentuated eccentric loading group, TRAD = traditional resistance training group*

<u>Movement</u>

The variance of random effects for MVAS was 2.62 (± 1.61). The final model for MVAS included the dummy variables for group, muscle, and day, as well as the interaction between these. Threshold coefficients of MVAS were as follows: -1.75 for scales 1 to 2, 0.04 for 2 to 3, 1.38 for 3 to 4, 2.44 for 4 to 5, 3.52 for 5 to 6, 5.22 for 6 to 7, 6.67 for 7 to 8, and 8.49 for 8 to 9. A Hessian matrix value of 79822.98 was obtained. See Figure 3.2 for a visualization of the 3-way interaction (Day:Group AEL:Muscle LB).

Figure 3.3: 3-way Interaction of Day: Group AEL: Muscle LB for soreness



**UB = upper body (triceps brachii, anterior deltoid, pectoralis major), LB = lower body (gluteus maximus and vastus lateralis), AEL = accentuated eccentric loading group, TRAD = traditional resistance training group*

Table 3.6: MVAS Model Overview

Model	**Coefficient (*β*)**	**SE**	**P value (*p*)**	**Exponentiated Coefficients**
Day	-0.005	0.019	0.764	0.994
Group AEL	-0.441	0.827	0.594	0.643
Muscle LB	1.740	0.320	< 0.0001	5.699
Day: Group AEL	-0.088	0.029	0.002	0.915
Day: Muscle LB	-0.023	0.027	0.399	0.977
Group AEL: Muscle LB	-1.660	0.453	0.0002	0.190
Day: Group AEL: Muscle LB	0.084	0.040	0.034	1.087

**Muscle LB = Lower body muscles (gluteus maximus, vastus lateralis), AEL = accentuated eccentric loading group, SE = standard error*

Discussion:

The purpose of the current study was to examine whether there was likely to be differences in how delayed onset muscle soreness is experienced with respect to upper vs. lower body muscles, before vs. immediately after a session, and the time course of training. To assess delayed onset muscle soreness, we conducted palpation and also asked subjects to move their muscles at a self-selected fast speed. Such knowledge can have practical use when designing a resistance training program with special consideration to avoid soreness for some competitions, periods of high sport-specific practice volume, and effective fatigue management. The first primary finding of the current study is that, by palpation, the accentuated eccentric loading appears to have a tendency to cause less soreness particularly in the lower body musculature. The second finding of the study is that, by movement, both musculatures had a tendency of lower soreness in both groups over the course of the training study. However, AEL showed less soreness in the LB again when assessed via movement.

The accentuated eccentric loading appears to have a tendency to cause less soreness particularly in the lower body musculature when assessed via palpation. The first piece of evidence for this is the statistically significant coefficient of -1.17 for the group by muscle interaction effect in the palpation model (Table 3.5), suggesting different patterns of soreness between the two groups and between two musculatures. These different patterns are illustrated in Figure 3.2, which first shows that AEL has greater probabilities rating for soreness ratings 1 to 2 (no to minimal soreness) and lower probabilities for the higher ratings compared to TRAD regardless of the musculature. When comparing the two musculatures, it appears that the best fit line for TRAD appears much steeper than AEL. This observation suggests that the accentuated eccentric loading appears to produce similar soreness in both musculatures whereas the traditional resistance training appears to produce greater soreness in the lower body musculature. Thus, our results of lower soreness in the LB with AEL is surprising as the heavy eccentric component involved creates more soreness compared to concentric contractions (Brockett et al., 1997; Crenshaw et al., 1995; Eston et al., 2000; Friden et al., 1983; Hyldahl et al., 2014; Merrigan & Jones, 2021; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton & Donnelly, 1996; Yarrow et al., 2008). The closest comparison can be made to Merrigan & Jones (2021) who had trained men complete a 120% AEL on the first rep for sets of

5 or 3 in trained men for the BS. Merrigan & Jones, (2021) stated that soreness was statistically elevated 24 hours after baseline for the sets of 3 group only. Interestingly, in the current study, the most voluminous phase of training (strength endurance block) was completed and involved weaker participants (relative BS 1RM: 1.53 ± 0.34 vs 2 ± 0.3), but AEL experienced lower soreness for the LB compared to TRAD. Possible rationale might include the AEL intensity being 10% greater in Merrigan & Jones (2021) than the current study. Additionally, (Merrigan & Jones, 2021) only measured soreness at 24- and 48-hours post training, while the current study measured it for 4 weeks. Another AEL study conducted by Yarrow et al. (2008) had untrained participants complain of soreness in the first week of AEL training using the BS. While the previous authors did not provide information in regards to which body part, DOMS was not discussed for the remaining 3 weeks of training. While this is the only AEL study to have mentioned soreness during a month-long of training sessions involving the BP and BS, the results of the current study provide contrasting findings to what has previously been investigated (Merrigan & Jones, 2021; Yarrow et al., 2008). An interesting note is some studies have noted participants dropping out from eccentric device training or AEL due to soreness (Friedmann et al., 2004; Walker et al., 2016, respectively). The study by Walker et al. (2016) involved 2 trained individuals, while Friedmann et al. (2004) had 2 participants also drop out. No subjects dropped out due to soreness throughout the entire duration of the study in contrast to previous studies (Walker et al. 2016; Friedman et al. 2004). Additionally, our participant pool were trained individuals, which means they would most likely experience lower levels of soreness compared to untrained for high intensity exercise (Ertel et al., 2020). Rationale that may explain the finding of less soreness in the LB compared to the UB may involve differences in muscle architecture, muscle fiber composition, muscle size, muscle length changes during the eccentric, and daily

activity use of the muscles (Chen et al., 2023). Indirect evidence was completed by Chen et al. (2023) who noted elbow flexor soreness is quantiatively higher than knee flexors after the first and second eccentric exercise interventions. Thus, lower body muscle groups may be more resistant to soreness compared to upper body muscle groups when done via AEL.

Movement soreness shows a tendency of lower soreness values for the LB in the AEL group as the number of days increase. While the coefficient has a positive value for the 3-way interaction model (Day:Group AEL:Muscle LB: $\beta = 0.843$, $p = 0.034$), Figure 3.3 illustrates the soreness ratings between muscles over time. For the LB, ratings 1 to 2 (no to minimal soreness) increase throughout the duration of the study for both groups. Higher soreness ratings (3 to 7) is where the differences between groups can be observed, with AEL starting with a lower probability for soreness ratings 3 to 7 compared to TRAD at any time point in the study. This is an interesting note as our initial hypothesis of greater soreness within the first week of training failed, as TRAD started with higher soreness rating probabilities than AEL at the start of the study. Lastly, Figure 3.2 visualizes the probability discrepancy of AEL and TRAD for the UB and LB. The UB discrepancy between groups for ratings 4 to 6 are fairly close while the differences are much larger when comparing the same soreness ratings (4 to 6) for the LB. This almost replicates the PVAS UB and LB differences for ratings 4 to 7. The findings of the current study contrast what Merrigan & Jones (2021) found with elevated soreness within the LB muscles 24 hours after 120% AEL BS. In regards to time frames, the current results contrast what Yarrow et al. (2008) noticed in untrained participants complaining of soreness the first week of AEL BS. While the current study participant pool was trained, the AEL intensity was 10% greater for the first week compared to Yarrow et al. (2008) 100% AEL eccentric. Therefore, the results suggest the possibility of AEL creating less soreness within the LB compared to TRAD when measured via movement.

The physiological rationale for no differences in combined soreness scores could be related to the RBE. The RBE protection appears to take place after a single eccentric bout (Ebbeling & Clarkson, 1990). However, a more robust RBE effect can occur after several training interventions (Croisier et al., 1999; Hody et al., 2011). Brown et al. (1997) proposed that 10 repetitions create an RBE stimulus. Ebbeling & Clarkson (1990) suggested that RBE is greatest when the second bout is performed within 2 weeks of the first bout. Even if the second bout of exercise stimulus was done before complete recovery (5 days post), it appears to not create a recovery setback (Ebbeling & Clarkson, 1990). Thus, the training intervention of AEL fulfilled the number of reps to offer an RBE protection and the time frame of not creating setbacks. This follows what Yarrow et al. (2008) noted, their subjects experienced DOMS the first week of training only. Soreness was not discussed for the remaining 3 weeks (Yarrow et al. 2008), suggesting that the RBE occurred. Another potential physiological rationale for no soreness differences may be due to the participant pool being trained. An example of this was Merrigan & Jones (2021) who used well trained subjects. While the protocol for Merrigan & Jones (2021) only included 3x5 with a 120% eccentric and 65% concentric and 3x3 at a 120% eccentric and 80% concentric, the authors stated that subjects on average did not exceed a mild level of soreness. Thus, the lower volumes in well trained subjects were not likely to create a high degree of soreness with only one AEL repetition being completed per set. Completing cluster sets of AEL (5 AEL repetitions per set) during a strength endurance block (sets of 10) failed to create any spikes in soreness values in the current study. While the cutoff values for PVAS and MVAS have never been listed, the results of the current study would suggest a rating of 3 to be mild soreness. This rating also appears to be what separates AEL and TRAD in regards to UB and LB ratings.

An interesting observation was found with AEL having lower soreness ratings on day 1 compared to TRAD. An argument could be made that AEL did not have higher soreness on day 1 because it was completed via cluster sets with a 15 s rest every 2 repetitions while TRAD had to complete straight sets. This argument is in contrast with the findings of (Teague & Schwane (1995), who noted no statistical differences in soreness between 10 continuous eccentric contractions or 15 s breaks between each eccentric contraction. Teague & Schwane (1995) only found statistical differences in VAS scores of the biceps between 10 continuous reps and a repetition every 5 minutes. However, it does fit anecdotal evidence from the current laboratory. Based on discussions with athletes and subjects using cluster training versus traditional, authors of the current study have noted that individuals using cluster training subjectively reported quantitatively less soreness and agrees with that observed by others 24 hours after exercise (Api et al., 2023; Varela-Olalla et al., 2020). Geohegan-Poe et al. (2018) found that pressure tolerance recovered faster at the 72-hour time point for the eccentric cluster set condition compared to TRAD. Thus, the previous authors concluded that decreasing metabolic strain may create a different time course in soreness (Geohegan-Poe et al., 2018). Another argument could be made that the participant pool was stronger in the AEL group, thus making them more trained compared to the TRAD group. The average total relative strength of the BP and BS combined for AEL was 2.6 while TRAD was 2.77, making this argument invalid. The last argument that could potentially explain why AEL did not suffer from greater soreness than TRAD on day 1 could be related to the accentuated eccentric load intensity being 110%. While this is 10% lower than Merrigan & Jones (2021), it might be possible that the eccentric intensity was enough to elicit an

RBE without creating extreme soreness as it was a novel stimulus for each participant in the AEL group.

The findings of the current study also contrast with review of the literature and the suggestion by Douglas et al. (2017a) that soreness is the primary concern for AEL implementation. There are other aspects of AEL implementation that should be investigated due to the high eccentric nature of the training method, such as acutely decreased strength (Chen et al., 2023; Friden et al., 1983; Hyldahl et al., 2014; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995), power (Chae et al., 2023b; Friden et al., 1983; Peñailillo et al., 2013), force modulation (Brockett et al., 1997), joint reactions (Chen et al., 2023), and coordination (Brockett et al., 1997; Byrne et al., 2004; Chen et al., 2023; Paschalis et al., 2008; Saxton et al., 1995). The previously listed factors are all important variables for peaking for sports performance, yet it has been suggested that AEL be used in-season to maintain power and strength (Suchomel et al., 2019b). Therefore, further examination of AEL training should be warranted before implementing in-season or peaking.

Of course, the current study has some limitations. This included inconsistency amongst soreness survey submissions. While participants were asked to fill out PRE prior to warming up and submit IMM after completing the session, some failed to completely submit the survey. The number of missing data points for the PRE and POST MVAS responses for 18 participants over 20 days was 20.83% (150 missing responses / 720 possible responses). The number of missing data points for the PRE and POST PVAS responses for 18 participants over 20 days was 20.69% (149 missing responses / 720 possible responses). This amount of missing data may have resulted in different statistical findings and provided different conclusions. A possible argument could be made that participants palpated the UB and LB muscles differently, thus resulting in score differences. Ertel et al. (2020) noted that VAS may not be a good measure of perceived soreness in participants with no experience of using the VAS or no experience of muscle soreness from exercise. However, the participants of the current study completed a thorough familiarization session with an investigator prior to the start of training and are considered trained individuals. Furthermore, participants were not told to apply equal pressure to each muscle. Thus, differences in muscle palpation pressure may have resulted in the current results.

To summarize the current study, LB soreness scores of AEL appear to decrease more compared to TRAD over time when assessed via movement. Palpation does indicate lower LB scores as well for AEL throughout the entire duration of the study. Both groups did notice a decrease in soreness (UB and LB) via palpation and movement over time.

Practical Application:

The current study suggests that AEL creates lower soreness scores of the LB compared to TRAD. In regards for the UB, there were no differences in palpation or movement for either group, however, soreness scores were quantitatively lower for AEL. Thus, the results of the current study suggest no concern of soreness with AEL training, in fact there will be less soreness for the LB specifically. For future soreness monitoring, we recommend only completing the fast speed for MVAS as that speed most likely mimics sporting and exercise actions and allows for easier data management. Additionally, coaches who want to monitor soreness closely prior to a season or in-season should implement fast MVAS as they will be able to monitor it more closely than palpation.

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Chapter 4. Chronic Comparison Of Short Recovery Stress Scale In Trained Individuals Completing Traditional Or Accentuated Eccentric Loading

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Abstract

The purpose of this study was to compare and monitor psychological stress induced by accentuated eccentric training (AEL) compared to traditional resistance training (TRAD). The only difference between groups was AEL utilized weight releasers for the bench press and back squat every 2 repetitions with 15 s of rest. Recreationally trained participants (Males: $n = 12$, age: 22.75 ± 4 years, BW: 89.42 ± 21.09 kg, BP 1RM: 104.67 ± 23.58 kg, relative BP 1RM: 1.19 ± 0.22, BS 1 RM: 140.75 ± 39.17 kg, relative BS 1RM: 1.59 ± 0.34, Females: $n = 6$, age: 23.6 ± 4.5 years, BW: 64.3 ± 10.8 kg, BP 1RM: 51.7 ± 13.4 kg, relative BP 1RM: 0.80 ± 0.13, BS 1 RM: 93.7 ± 18 kg, relative BS 1RM: 1.47 ± 0.30) completed 4 weeks of strength endurance training. Resistance training occurred three times per week (M, W, F) and speed and agility were trained twice per week (T & R). Participants completed the short recovery stress scale (SRSS) prior to their warmups every single day of training. Results showed a statistical significance for an interaction of muscular stress between groups over days ($p < 0.05$). Physical performance capability and overall recovery increasing over days while overall stress decreasing in both groups. We conclude that AEL does not create any major differences compared to TRAD when assessed via the SRSS. Practitioners can use AEL to obtain certain qualities without the expense of greater stress and somewhat lower recovery rates compared to TRAD.

Keywords: Perceptual responses, Psychological fatigue, Monitoring, Fatigue assessment, Self-Report

Introduction:

Accentuated eccentric loading (AEL) involves the use of a heavier eccentric load compared to the concentric load. This training methodology has shown some promising results in several physical performance factors such as strength (Brandenburg & Docherty, 2002; Cook et al., 2013; Doan et al., 2002; English et al., 2014; Friedmann-Bette et al., 2010; Norrbrand et al., 2008; Walker et al., 2016, 2017), power (Cook et al., 2013; Friedmann-Bette et al., 2010; Lates et al., 2020; Merrigan et al., 2020; Munger et al., 2022; Ojasto & Häkkinen, 2009; Taber et al., 2021), hypertrophy (English et al., 2014; Norrbrand et al., 2008; Walker et al., 2017), and speed (Cook et al., 2013; Douglas et al., 2018). However, other studies using AEL and TRAD have shown no statistically significant differences in strength (Friedmann-Bette et al., 2010; Godard et al., 1998; Moore et al., 2007; Munger et al., 2022), power (Kristiansen et al., 2022; Moore et al., 2007; Munger et al., 2022; Taber et al., 2021; Wagle et al., 2018a; Wagle et al., 2018b), and hypertrophy (Godard et al., 1998). To the author's knowledge, there has only been one observation that resulted in statistically lower maximum strength with the use of AEL compared to TRAD (Ojasto & Häkkinen, 2009b). However, the majority of studies tend to reveal an equal or slightly advantageous performance boost for specific physiological and performance variables with the use of AEL.

Like any training methodology, there are some potential drawbacks with the implementation of AEL. Because of the extra work performed, the use of AEL could increase the total amount of recovery time needed. The term recovery represents restorative physiological or psychological processes in a time dependent manner (Kellmann et al., 2018). A review by Nässi et al. (2017) suggested that monitoring fatigue should involve surveys that compare both psychological and physiological components to attain a better idea of how that athlete is reacting to a training program. A single parameter of physiological or psychological components only focuses on a specific aspect of recovery or fatigue, thus multivariate methods should be utilized (Kellmann et al., 2018). Heidari et al. (2019) has suggested the addition of social aspects to help gauge the athlete's overall recovery. Currently, there have been no acute or chronic studies assessing psychological recovery via surveys with AEL training to the authors' knowledge. However, perceptual efforts, such as rating of perceived exertion (RPE) have been examined with the implementation of AEL. Yarrow et al. (2008) found statistically significant higher RPE values in untrained individuals in the bench press (BP) and back squat (BS) for the first four sessions in the AEL group only. Coincidentally, this time frame was associated with AEL participants experiencing substantial delayed onset muscle soreness (DOMS). A very recent acute study by Chae et al. (2023b) compared RPE values in trained men between two different AEL programming styles (AEL2: reattaching weight releasers every 5 reps, AEL5: reattaching weight releasers every 2 reps). The use of AEL5 resulted in statistically significant higher RPE later in the BS workout compared to TRAD and AEL2. While not a resistance training study, Peñailillo et al. (2013) provided seemingly contrasting evidence, as concentric cycling obtained statistically significant higher RPE values compared to two bouts of eccentric cycling in untrained men. However, the cycling intensity for both contraction types were prescribed at the same relative intensity (percent) of maximum concentric power. So, the eccentric work was accomplished at a much lower load in relation to the maximum eccentric power output. While the RPE values observed in AEL are limited, the current data indicates that AEL elicits higher RPE values when athletes start utilizing this training methodology with eccentric intensities >110% of the concentric 1RM value. The use of the SRSS may provide practitioners with a deeper understanding of what athletes are experiencing overall from the stress of the training program. Therefore, it may be recommended that practitioners do not prescribe the use of AEL when athletes are in-season, when fatigue is already high and optimal performance is required.

The use of questionnaires is more practical for monitoring recovery and fatigue, as other monitoring tools such as maximal sport-specific tests would be deemed counterintuitive for athletes who are insufficiently responding to a training program (Kellmann et al., 2018; Taylor et al., 2012). Taylor et al. (2012) noted that self-report questionnaires were the most commonly used monitoring tool among 84% of practitioners in New Zealand and Australia. Of the questionnaires practitioners implemented, 80% stated they used custom reports and did not use common evidence-based questionnaires as they are too long for athletes to complete and the staff to analyze (Taylor et al., 2012). However, a great advantage for the SRSS is the fact that it consists of 8 questions and can be completed within 40-60 seconds (Henze et al., 2024), thus not interfering with time constraints (Taylor et al., 2012). Other common subjective questionnaires, such as the profile of mood states or the recovery stress questionnaire for athletes require individuals to recall what their past week or 3 days have been like, respectively (Saw et al., 2016). However, in order to create adjustments to training, it is recommended that questionnaires should be completed frequently (Saw et al., 2016). Thus, the SRSS has several advantages due to it being brief, financially practical, and a noninvasive tool for monitoring muscular stress and recovery (Henze et al., 2024; Kölling et al., 2020). A concern that some practitioners may have with the SRSS is the possible language barrier of it being translated from German to English, however, Kölling et al. (2020) has confirmed construct validity with the questionnaire in English speaking athletes. It has been proposed in the literature that psychological reactions are more sensitive than physiological markers when assessed via resistance training load (Nässi et al., 2017; Saw et al., 2016). However, real world constraints and athlete monitoring may modify this finding. Therefore, the use of light continuous monitoring via psychological surveys may help identify athletes struggling to adapt to training programs and possibly prevent non-functional overreaching or overtraining from occurring (Heidari et al., 2019). Lastly, a systematic review revealed subjective measures are superiorly better in terms of sensitivity and consistency when compared to objective measures (Saw et al., 2016).

A training study that did not complete AEL methodology but utilized the SRSS showed a nearly perfect correlation of the negative emotional state question to creatine kinase in trained weightlifters (Perkins et al., 2022). Additionally, biochemical markers related to training stress showed a positive trend with the stress items of the SRSS but a negative relationship for the recovery items in the SRSS (Perkins et al., 2022). Henze et al. (2024) also found similar results with creatine kinase levels having a strong positive relationship with stress items of the SRSS (muscular stress and overall stress only) and a strong negative relationship with recovery items of the SRSS (physical performance capacity and overall recovery only) in elite handball athletes. By contrast, observations by Perkins et al. (2022) indicated the relationship of SRSS recovery items (physical performance capability and emotional balance) showed statistically significant negative moderate associations for jump performance. This led Perkins et al. (2022) to state that athlete’s perceptions of SRSS values do not always equate to performance values.

The purpose of this study is twofold: 1) to assess psychological recovery responses between AEL or TRAD training and 2) to monitor perceptual responses over a strength-endurance training block. For the first purpose, we hypothesize that AEL would create higher scores of stress scale items and lower scores of recovery scale items compared to TRAD in the initial 2 weeks but would reach TRAD values for the remainder of the study duration.

Methods:

Experimental Approach to the Problem

Use the short recovery stress scale (SRSS) to monitor psychological stress and recovery of participants over the course of 4 weeks with AEL or TRAD. The only difference between groups was the use of weight releasers being implemented on the BS and BP exercises. The weight releasers were reattached after every 2 repetitions, thus allowing participants to rest for 15 s. The SRSS survey entails recovery items (physical & mental performance capability, emotional balance, and overall recovery) and stress items (muscular stress, lack of activation, negative emotional state, and overall stress) questions that equate to how recovered or stressed the individual may be. Thus, the SRSS allows for the subjective comparison of which training methodology is more stressful.

Subjects

This study had a total of 18 recreationally trained participants (mean ± SD; Males: n = 12, age: 22.75 ± 4 years, BW: 89.42 ± 21.09 kg, BP 1RM: 104.67 ± 23.58 kg, relative BP 1RM: 1.19 ± 0.22, BS 1 RM: 140.75 ± 39.17 kg, relative BS 1RM: 1.59 ± 0.34, Females: n = 6, age: 23.6 ± 4.5 years, BW: 64.3 ± 10.8 kg, BP 1RM: 51.7 ± 13.4 kg, relative BP 1RM: 0.80 ± 0.13, BS 1 RM: 93.7 ± 18 kg, relative BS 1RM: 1.47 ± 0.30). Participants were randomly pair matched based off net relative strength (BS + BP), to complete either 4-weeks of TRAD or AEL. All participants confirmed they trained the BP and BS movements regularly in their own training. Participants were told to abstain from exercising outside of the study.

Participants were excluded if they had previous use of weight releasers over the past year, missed >10% of total training or testing sessions, or if they had any injuries prior to the start of the study. All participants completed an approved informed consent form via the institutions IRB committee (ETSU IRB ID # 0822.2f) prior to the start of testing.

Procedures

During the familiarization week, an investigator explained the SRSS to each participant through the SRSS once. This entailed a full description of each question, the scoring, and addressing any confusion that the participant might have had. Participants were asked to answer the questions based on how they felt at that exact moment of completing the survey, as this would allow observance of a rapid shift in training stress (Meeusen et al., 2013). Additionally, chronic use of this survey may lead some participants to repeat remembered answers from previous days. Thus, questions were randomly ordered each day requiring all participants to fully read each question every time they completed the survey. So, the randomization of question order was carried out to avoid response distortion of the same questions being constantly used over the course of a month (Meeusen et al., 2013). The SRSS uses a Likert-type rating scale of 0-6 (0 = does not apply at all, 6 = fully applies). The questions that contributed to recovery scale items were physical performance capability, mental performance capability, emotional balance, and overall recovery. The remaining 4 questions asked about the stress scale items: muscular stress, lack of activation, negative emotional state, and overall stress. In a systematic review by Saw et al. (2016) it was suggested that acute psychological monitoring should focus on subscales of vigour/motivation, physical symptoms/injury, non-training stress, fatigue, physical recovery, general health/well-being, and being in shape. The SRSS survey fulfills most of these suggested subscales. Table 4.1 provides an example of the questions that each individual was asked everyday throughout the duration of the study. The SRSS surveys were sent electronically to each participant’s email and were scheduled to be sent 10 minutes prior to the start of each training session. Prior to warming up, participants were asked to complete the SRSS. Surveys were completed via Google Forms. A fac-simile of the SRSS survey questionnaires can be found at this link: https://forms.gle/1nKoUqxLtEUaF7VX7).

Table 4.1 SRSS Survey Example

SRSS Survey	
Physical Performance Capability (e.g. strong, physically capable, energetic, full of power)	4
Mental Performance Capability (e.g. attentive, receptive, concentrated, mentally alert)	5
Emotional Balance (e.g. satisfied, balanced, in a good mood, having everything under control, stable, pleased)	5
Overall Recovery (e.g. recovered, rested, muscle relaxation, physically relaxed)	3
Muscular Stress (e.g. muscle exhaustion, muscle fatigue, muscle soreness, muscle stiffness)	5
Lack of Activation (e.g. unmotivated, sluggish, unenthusiastic, lacking energy)	1
Negative Emotional State (e.g. feeling down, stressed, annoyed, short-tempered)	2
Overall Stress (e.g. tired, worn-out, overloaded, physically exhausted)	4

Training Program

Both training groups (TRAD & AEL) completed the same training program (sets and repetitions), which entailed 3x10 repetitions with a rest duration of 2 minutes. Each training session of each unique day involved the same 3 exercises. The duration of the study required a total of 6 testing days (pretesting: 3 days, post testing: 3 days) and 20 training days (12 weight training and 8 speed, agility, and mid-section). The use of weight releasers in the AEL group was the only difference between groups. Reattachment of the weight releasers occurred every 2 repetitions, thus a total of 5 AEL reps were completed per set. Participants were asked to rest for 15 s while investigators would manually place the weight releasers onto the bar. A second pair of weight clips was used to help consistently place the weight releasers in a proper spot for balance and distribution of the load. Attachment of the weight releasers created a 110% eccentric intensity in BS and BP exercises, which were executed on Mondays and Fridays. Participants in both groups were told to complete the lift at their own speed, resulting in a ~1 s duration of both eccentric and concentric phases. A more detailed explanation of the training program can be found in Table 4.2. Every Wednesday did not use weight releasers, thus AEL and TRAD completed the exact same training session. Prior to each session, both groups performed the same standardized dynamic warmup (see Table 4.3) together, but resistance trained in different weight rooms under the supervision of experienced and certified strength and conditioning specialists (CSCS via NSCA). Warmups for the BP and BS slightly differed between groups (see Table 4.4). Both groups would switch weight rooms and supervising coaches after 2 weeks to avoid any possible facility or coaching biases.

Table 4.2 Training program details

<table>
<tr><th colspan="6">Training Intensities:</th></tr>
<tr><th></th><th colspan="2">TRAD:</th><th colspan="3">AEL:</th></tr>
<tr><th>Week</th><th>M & W</th><th>F</th><th>M</th><th>W</th><th>F</th></tr>
<tr><td>1</td><td>57.5%</td><td>50%</td><td>110%▲/57.5%</td><td>57.5%</td><td>110%▲/50%</td></tr>
<tr><td>2</td><td>62.5%</td><td>55%</td><td>110%▲/62.5%</td><td>62.5%</td><td>110%▲/55%</td></tr>
<tr><td>3</td><td>67.5%</td><td>57.5%</td><td>110%▲/65%</td><td>67.5%</td><td>110%▲/57.5%</td></tr>
<tr><td>4</td><td>52.5%</td><td>45%</td><td>110%▲/52.5%</td><td>52.5%</td><td>110%▲/45%</td></tr>
<tr><th colspan="6">Exercise Selection and Order:</th></tr>
<tr><td colspan="2">M</td><td colspan="2">W</td><td colspan="2">F</td></tr>
<tr><td colspan="2">BS*, BP*, single arm overhead DB triceps extension</td><td colspan="2">CG MTP, CG SLDL, BB row</td><td colspan="2">BS*, BP*, single arm overhead DB triceps extension</td></tr>
</table>

*TRAD = traditional resistance training, AEL = accentuated eccentric loading, ▲ = eccentric intensity, M = Monday, W = Wednesday, F = Friday, BS = barbell back squat, BP = barbell bench press, DB = dumbbell, CG MTP = clean grip mid-thigh pull, CG SLDL = clean grip stiff leg dead lift, BB = barbell, * = AEL weight releasers*

Table 4.3 Warm up

Standardized General Warmup:
Light jog (400 m)
Elephant walks x 10 m
Quad pull x 10 m
Forward lunge with rotation x 10 m
Leg cradle x 10 m
Reverse lunge with reach x 10 m
Hamstring scoops x 10 m
Side lunge x 10 m
m = meters

Table 4.4 Resistance training warmup protocol

Bench Press and Back Squat Warmups on Mondays & Fridays:

TRAD	AEL
1x5 at 25% 1 RM	1x5 at 25% 1 RM
1x5 at 50% 1 RM	1x5 at 50%▲/25%
1x1 at 80% 1 RM	1x2 at 80%▲/50%

▲ *= eccentric intensity, TRAD = traditional, AEL = accentuated eccentric loading*

On Tuesdays and Thursdays, both groups also completed speed, agility, and mid-section training. Please see Table 5 for further details. The combination of resistance training and sprinting would deem this study more ecologically valid as athletes commonly complete both training aspects in the same block of strength-endurance training.

Table 4.5 Speed, agility, and midsection training

Week:	Tuesday:	Thursday:
1	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x10 m Crunches 3x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x5 m 180° turn (exit 5 m to decel) 1x4x5 m
2	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x15 m Crunches 4x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x10 m 180° turn (exit 5 m to decel) 1x4x10 m
3	Buildups: 2x15 m, 2x25 m Acceleration: 4x4x20 m Crunches 4x25	Buildups: 2x20 m Linear decel: 1x4x7.5 m Lateral decel: 1x4x7.5 m Sidestep cut (exit 5m to decel) 1x6x10 m 180° turn (exit 5 m to decel) 1x6x10 m
4	Buildups: 2x15 m, 2x25 m Crunches 2x25	Buildups: 2x20 m Linear decel: 1x4x5 m Lateral decel: 1x4x5 m Sidestep cut (exit 5m to decel) 1x4x5 m 180° turn (exit 5 m to decel) 1x4x5 m

m = meters, decel = deceleration

The time that training sessions were held was early in the morning (0600 hours), afternoon (1200 hours), or evening (1500 hours). Participants primarily attended the same training time over the course of the study. In the case that a participant switched training session times, the SRSS survey would update to the correct time for that participant. Most training sessions, including warm-up, were completed in ≈ 50 minutes.

Statistical Analyses

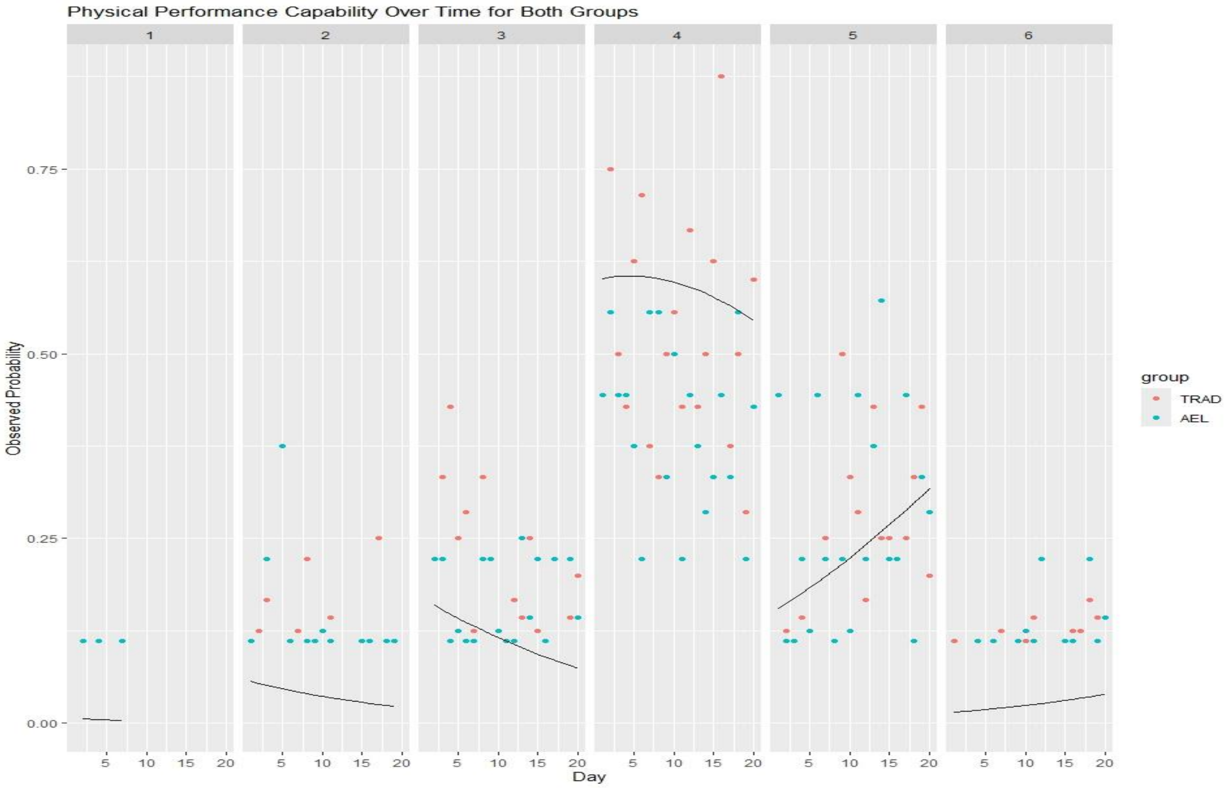
Data was initially collected in Google Forms and was then analyzed using the statistical software R (Version 4.3.2; R Core Team, Vienna, Austria). The statistical packages used include stringr, tidyr, ggplot2, rcompanion, and ordinal. Statistical significance was set with $\alpha \leq 0.05$. Each question of the SRSS was processed through its own statistical cumulative link mixed-effects model fitted with the Laplace approximation, acting as the dependent variable. The independent categorical variable was group. Day was quantified from 1-20, representing each separate day throughout the entire duration of the training program. The group variable was dummy coded (i.e., group: AEL was assigned 1 while TRAD was assigned 0). The interaction of day by group was also examined. Given the nature of repeated measurements, the subjects were used as the random effect variable for the intercept. All models were first computed as a saturated model with all of the aforementioned independent variables (i.e. all main effect and interaction effect terms). However, in order to manage the model complexity and avoid overfitting, the parsimonious approach was used by removing all independent variables that failed to show statistical significance for both the associated main effect and interaction effect(s). R Pseudo R^2 indices (McFadden, Cox and Snell (ML), Nagelkerke (Cragg and Uhler)) were calculated to quantify the fit of each final model. Missing data was excluded from analysis of each SRSS model. Additionally, Hessian matrix was run. For reference, Christensen (2023) suggests that models are ill defined if the Hessian values are larger than 10^{4-6}.

Results:

Recovery

The final model for physical performance capability (PPC) reached statistical significance for day only ($\beta = 0.052$, $SE = 0.019$, $p = 0.006$). The threshold coefficients for PPC were as follows: -5.07 for scales 1 to 2, -2.65 for 2 to 3, -1.16 to 3 to 4, 1.63 for 4 to 5, and 4.24 for 5 to 6. The PPC model obtained a Hessian matrix of 3477.36. Please see Figure 4.1 below for a visual of the predicted and observed probabilities of PPC over the number of days.

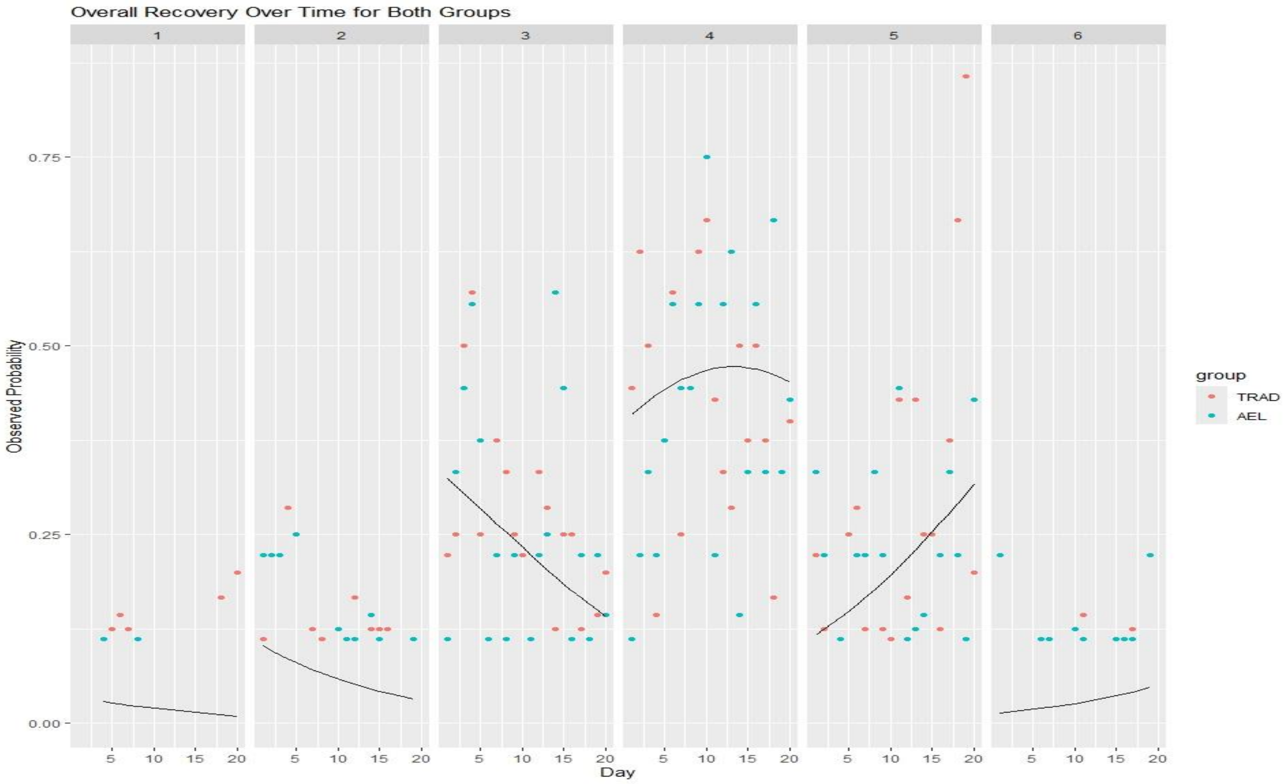
Figure 4.1: Predicted and observed probabilities of PPC over days



**PPC = physical performance capability. Note: Values closer to 6 mean that participants were representing the SRSS description of PPC (strong, physically capable, energetic, full of power). Values closer to 0 mean participants did not represent any of these descriptive terms.*

Overall recovery (OR) final model reached statistical significance for day only ($\beta = 0.071$, $SE = 0.018$, $p < 0.001$). The threshold coefficients for OR were as follows: -3.23 for scales 1 to 2, -1.76 for 2 to 3, -0.08 for 3 to 4, 1.96 for 4 to 5, and 4.35 for 5 to 6. Hessian matrix value of 2442.14 was obtained for the OR model. Please see Figure 4.2 below for a visual of the predicted and observed probabilities of OR over the number of days.

Figure 4.2: Predicted and observed probabilities of OR over days



**OR = overall recovery. Note: Values closer to 6 mean that participants were representing the SRSS description of OR (recovered, rested, muscle relaxation, physically relaxed). Values closer to 0 mean participants did not represent any of these descriptive terms.*

The remaining questions for the recovery section of the SRSS (MPC and EB) did not reach statistical significance for any of the variables in the saturated model. None of the statistically significant models under the recovery section exceeded the recommended Hessian matrix value proposed by Christensen (2023).

Table 4.6: SRSS Models statistics

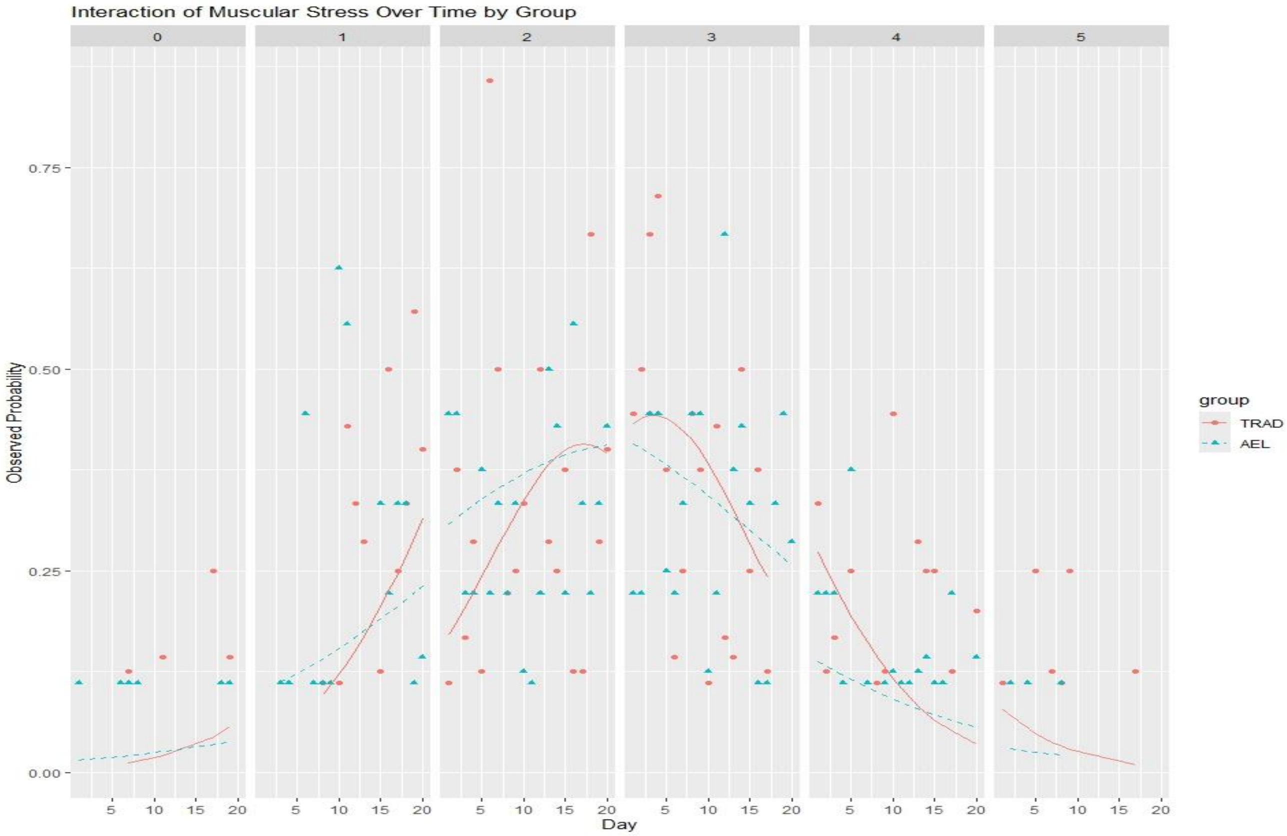
SRSS Models					
Model	**Variance of Random Effects (± SD)**	**Coefficient (β)**	***SE***	***P* value (*p*)**	**Exponentiated Coefficients**
PPC (day)	2.32 ± 1.52	0.052	0.019	0.006	1.05
OR (day)	0.66 ± 0.81	0.071	0.018	< 0.001	1.07
MS (day)		-0.132	0.027	< 0.001	0.875
MS (group)	0.758 ± 0.87	-1.056	0.592	0.074	0.347
MS (day*group AEL)		0.077	0.036	0.032	1.08
OS (day)	1.71 ± 1.3	-0.035	0.018	0.052	0.965

**PPC = physical performance capability, OR = overall recovery, MS = muscular stress, OS = overall stress, AEL = accentuated eccentric loading, SE = standard error for coefficient*

<u>Stress</u>

The muscular stress (MS) final model showed statistical significance for interaction of day *group (*β* = 0.077, *SE* = 0.036, *p* = 0.032). Threshold coefficients for MS were as follows: -5.32 for scales 0 to 1, -3.14 for 1 to 2, -1.41 for 2 to 3, 0.48 for 3 to 4, and 2.33 for 4 to 5. Hessian matrix value of 8203.75 was obtained for the MS model. Please see Figure 4.3 below for a visual of the predicted and observed probabilities of MS between groups over time.

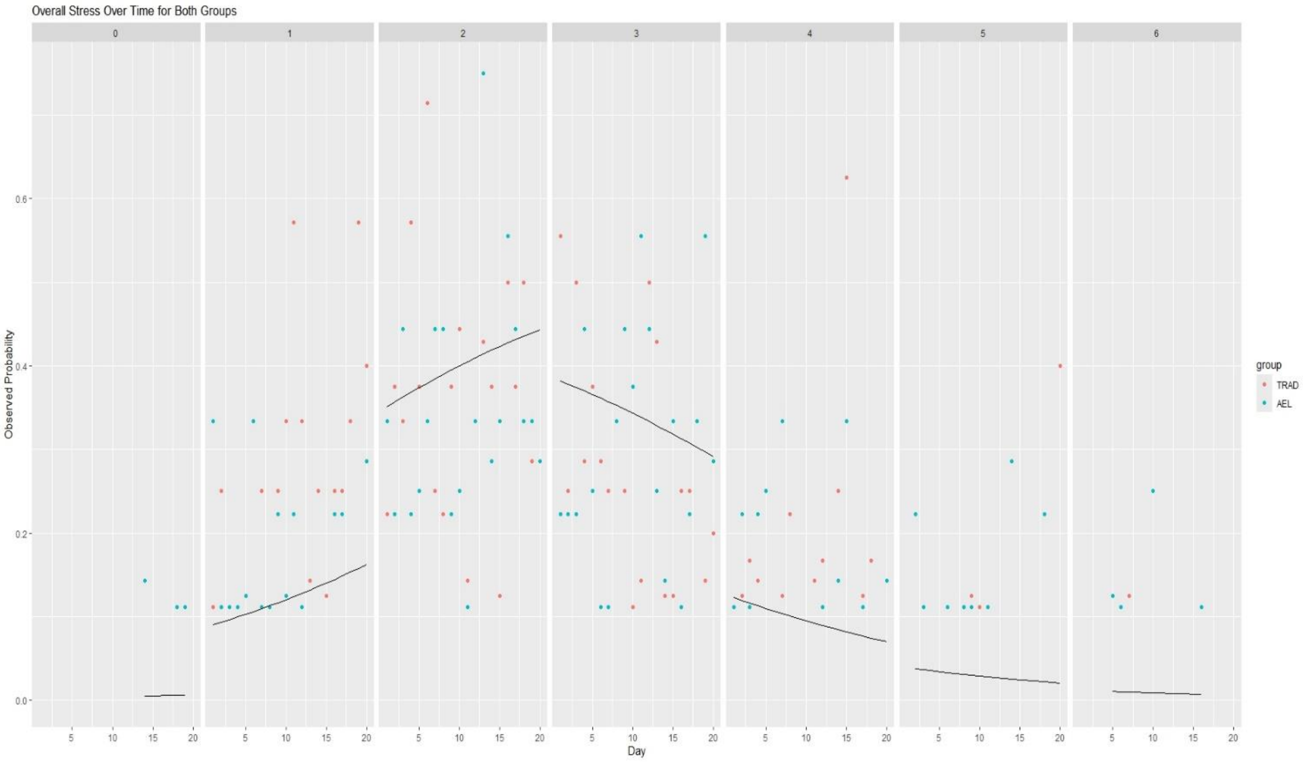
Figure 4.3: Predicted and observed probabilities of MS between groups over days



**MS = muscular stress. Note: Values closer to 6 mean that participants were representing the SRSS description of MS (muscle exhaustion, muscle fatigue, muscle soreness, muscle stiffness). Values closer to 0 mean participants did not represent any of these descriptive terms.*

The final model for overall stress (OS) reached statistical significance for day (*β* = -0.035, *SE* = 0.018, *p* = 0.052). Threshold coefficients for OS were as follows: -5.79 for scales 0 to 1, -2.3 for 1 to 2, -0.25 for 2 to 3, 1.52 for 3 to 4, 2.89 for 4 to 5, and 4.38 for 5 to 6. The final model for OS obtained a Hessian matrix value of 3772.61. Figure 4.4 illustrates the predicted and observed probabilities of OS ratings over the study in both groups.

Figure 4.4: Predicted and observed probabilities of OS over days



**OS =overall stress. Note: Values closer to 6 mean that participants were representing the SRSS description of OS (tired, worn-out, overloaded, physically exhausted). Values closer to 0 mean participants did not represent any of these descriptive terms.*

The remaining stress questions in the SRSS (LA and NES) did not reach statistical significance. None of the statistically significant models under the stress section exceeded the recommended Hessian matrix value proposed by Christensen (2023).

Discussion:

The first purpose of the current study was to examine psychological recovery and stress responses between two different training methods. The second purpose was to illustrate psychological recovery and stress responses over a strength-endurance training block. The primary finding in regards to the first purpose of the study was that traditional resistance training had higher values of perceived muscular stress scores at the start of the study, and then they tapered off at a faster rate at the end. The finding for the second purpose of the study was an increase in perceptual physical performance and recovery and a decrease in perception of overall stress as the number of days increase.

Accentuated eccentric loading has a tendency to create a slower taper of higher MS scores. This was noted via the statistically significant coefficient of 0.077 for the group by day interaction effect in the MS model (Table 4.6), suggesting that MS scores were slightly higher in AEL as the study progressed. This is illustrated in Figure 4.3, which shows that AEL having higher MS scores (3-4) than TRAD around the last week of the training period (around day 15). Therefore, our data suggests that MS scores obtain better values (*i.e.*, does not fully apply) for TRAD at the end of a strength-endurance block. This might reflect upon the deload week for the AEL group being relatively more demanding compared to the TRAD group's training. The closest comparison can be made to Hitzschke et al. (2017), who monitored SRSS scores during a shock-microcycle that used eccentric overload in the BP and BS movements in trained athletes. The 11 training sessions completed within 5 days resulted in an increase of MS values throughout the training week (Hitzschke et al., 2017). This is the opposite of what the current study found, but it was most likely due to differences in programming and the intentions of the study. While AEL was completed during the most voluminous phase of training (strength-endurance block), it appears to not be that intensive to create an increase in MS values at any time point. While MS values were highest at the start of the study, they never increased as the study progressed, suggesting that both training groups were adapting to their training program. Indirect comparisons can be made with other authors who used RPE with AEL training. Yarrow et al. (2008) found statistically higher RPE values in BP and BS AEL in untrained individuals during the first couple sessions. The results of the current study do not suggest an increase in either recovery or stress scale items at the start of the study for AEL. However, AEL has a slower taper of the MS scores the last week of the training period. Additionally, Yarrow et al. (2008) had untrained participants while the current study had trained individuals, thus resulting in possible differences when using AEL. Another AEL study that did use trained participants was by Chae et al. (2023b). This study used the same AEL programming techniques (reattaching the weight releasers every 2 reps for a set of 10 reps) and showed statistically higher RPE values in the BS compared to TRAD and AEL 2 (reattaching weight releaser after 5 reps for a set of 10 reps). While this study had a stronger participant population (relative BS 1RM: 1.9 ± 0.4) and the exact same AEL programming, only the MS SRSS question suggests slightly higher stress during the last week of training compared to TRAD. Overall comparison to previous literature shows disagreement with studies that monitored training via the SRSS (Hitzschke et al., 2017), but this is most likely due to program design. Furthermore, there is disagreement of the current study when comparing AEL studies that implemented RPE (Chae et al., 2023b; Yarrow et al., 2008). Therefore, the SRSS and RPE may provide practitioners with different data and monitoring of the athlete, in part, depending upon the training process model used.

A properly programmed strength-endurance block has a tendency to increase PPC and overall recovery (OR) and decrease overall stress (OS) in both training groups. This is supported by the coefficients of 0.052, 0.071, and -0.035 for PPC, OR, and OS, respectively (Table 4.6). Visually, Figures 4.1 (PPC) and 4.2 (OR) follow similar trends with rating 5 increasing as the study progresses. Figure 4.3 (OS) on the other hand illustrates an increase in ratings 1 and 2 as the number of days increases. These results contrast that of Hitzschke et al. (2017) who had opposing results. However, this was during a shock microcycle composed of 11 strength training sessions within 5 days, that also used eccentric overload in the BP and BS in trained participants.

Thus, the results of the current study suggests that proper programming was applied and that both groups were able to recover and decrease stress induced via the resistance training program. Hitzschke et al. (2017) also investigated athletes completing high intensity interval training in a shock microcycle and found similar trends of a decrease in PPC and OR and an increase in OS. While the speed and agility part of the current study was not isolated for analysis, there were never any visible spikes of any SRSS question throughout the duration of the study. Additionally, the speed and agility programming was not the same as high intensity interval training. However, the results of the current study highlight that overall scales (OR and OS) and physical scales (PPC and MS) show the biggest shifts in physical stress and align with the similar results by Hitzschke et al. (2017).

An interesting observation within the SRSS questions involves the psychological questions (MPC, EB, LA, and NES). None of these questions resulted in statistical significance. This is interesting considering that psychological reactions are apparently more sensitive than physiological markers for resistance training load (Nässi et al., 2017; Saw et al., 2016). Additionally, the physical aspects of the SRSS (PPC, OR, MS, and OS) showed statistical significance. PPC and OR increased and OS decreased throughout the study duration in both groups, while MS decreased at different rates depending on the group. Thus, it appears that the physical factors within the SRSS are more sensitive to resistance training load than the psychological questions. It could be argued that training was not that hard in either group due to PPC and OR increasing and OS and MS decreasing over time, thus failing to elicit any reactive shift in the psychological aspects of the SRSS. However, this was during a strength-endurance block which requires the greatest amount of volume load to be completed, which follows the sensitivity of psychological reactions with resistance training load. Also, Hitzschke et al. (2017)

noticed no shifts in the psychological questions during a shock microcycle. Lastly, there is the possibility of participants engaging in the athlete undoing hypothesis (Lautenbach & Zajonz, 2023). This involves participants completing activities that promote positive emotions that could decrease their psychosocial stress levels, thus possibly improving their overall recovery (physical, psychological, and social components) (Heidari et al., 2019; Kellmann et al., 2018). However, none of the psychological questions reached statistical significance in the current study. Lautenbach & Zajonz (2023) also measured physiological recovery and found no statistical significance with the undoing hypothesis but stated to use caution due to a small sample size. Thus, psychological questionnaires may give practitioners insight into everything an athlete might be doing outside of their sport, not just the training program.

Limitations of the study included inconsistent SRSS submissions. A total of 38 missing responses for the SRSS occurred over 20 days for the 18 involved participants. This resulted in 10.5% of missing data (38 missing responses / 360 possible responses). While the participants were told to complete the 1-minute survey prior to warming up, some participants failed to completely submit the survey. The amount of missing data may have resulted in different statistical findings and may have led to more insight into the possible statistical significance for other SRSS questions. Lastly, Hitzschke et al. (2017) stated that the SRSS cannot accurately identify athletes who may be in an under recovered or recovered state. Work done by Perkins et al. (2022) noted that correlations of SRSS items to physical performances were opposite of what would be expected. Thus, the sole use of SRSS used in the current study may not be enough to diagnose the current state of an athlete or give insight into how an athlete might perform the day of. Therefore, it is recommended to combine both psychological and physiological monitor tools together (Halson, 2014; Hitzschke et al., 2017).

In summary, the use of AEL training only resulted in statistical differences in MS values of the SRSS compared to TRAD. It appears that AEL has a slower decrease in MS values over time compared to TRAD, which has a steeper increase in lower MS values (0-2) over time. Additionally, PPC and OR increased and OS decreased in both training groups as the study progressed. Physical questions of the SRSS (PPC, OR, MS, and OS), not psychological (MPC, EB, LA, and NES) appeared to be the most sensitive to high volume loads in a strength endurance block for AEL or TRAD training. While this is the first study of its kind to measure SRSS values over 4 weeks in AEL training, comparisons to previous literature are hard to make. Thus, more research is warranted on examining the differences between AEL and TRAD on subjective measures such as the SRSS.

Practical Applications:

The SRSS identified a difference in MS values between AEL and TRAD. Specifically, AEL had a slower decrease in MS values while TRAD had a faster decrease. The PPC and OR statistically increase and OS decreased as the study progressed. This highlights proper programming for a strength-endurance block. Lastly, the remaining 4 questions of the SRSS did not result in any differences over time, group, or interaction. Thus, we conclude that SRSS monitoring between AEL and TRAD training during a strength endurance block resulted in no major changes in the recovery or stress aspects. The only change involved the MS question, which resulted in different rating responses between groups for lower values during the last week of training. Additionally, no psychological questions of the SRSS (MPC, EB, LA, and NES) were reactive to either condition, rather the physical questions (PPC, OR, MS, and OS) were. Thus, practitioners may consider using AEL if they desire certain training qualities without the expense of greater stress and somewhat lower recovery rate compared to TRAD. Practitioners should also consider using both subjective (e.g. SRSS) and objective measures of training strain and recovery.

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Chapter 5. Summary and Directions for Future Research

Conclusion of the previous two studies provides useful information about the soreness and perceptual responses of stress and recovery of accentuated eccentric loading (AEL) during a strength-endurance (S-E) block compared to traditional resistance training (TRAD). This knowledge helps practitioners implement AEL or TRAD training methodology with a better understanding of the possible soreness and perceptual recovery and stress consequences.

A month of resistance S-E training included sets of 10 repetitions to accumulate high volume 3 days per week and subjects also completed speed and change of direction training 2 days per week to make the format of the study intervention more ecologically valid for strength-power athletes. The resistance training program included compound movements, such as the bench press (BP) and the back squat (BS). The AEL group used 110% eccentric weight releasers in a cluster set format (1 repetition with weight releaser, 1 repetition with no weight releaser, rack the bar and rerack the weight releasers), equating to a total of 5 AEL reps per set for both compound movements. During reattachment of the weight releasers, participants rested 15 seconds before initiation of the next cluster set. Every day of training (1-20 days), participants filled out surveys asking about palpation and movement visual analog scales for soreness (PVAS and MVAS, respectively) and perceptual responses of recovery and stress which was assessed via the short recovery stress scale (SRSS). All 3 surveys were completed immediately before warming up, and only the PVAS and MVAS were completed immediately after finishing the training session.

The results of the current studies showed that AEL produced a statistically significant decrease in lower body (LB) musculature over time compared to TRAD when monitored via the MVAS ($p = 0.034$). The AEL group also showed statistically significantly lower PVAS scores of the LB compared to TRAD ($p < 0.0001$). These results are surprising due to eccentric movements typically creating higher degrees of soreness compared to concentric (Brockett et al., 1997; Crenshaw et al., 1995; Eston et al., 2000; Friden et al., 1983; Hyldahl et al., 2014; Merrigan & Jones, 2021; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton & Donnelly, 1996; Yarrow et al., 2008). The closest analogy can be made to Merrigan & Jones (2021) who had participants of similar strength levels, but completed 120% AEL eccentric intensity for 1 AEL repetition during sets of 5 repetitions in the BS. The participants reported statistically elevated soreness 24 hours post exercise for the AEL group only and reported that soreness did not exceed mild levels (Merrigan & Jones, 2021). Thus, the current study possibly had an AEL intensity that was too low to elicit a degree of soreness but offered better repeated bout effects (RBE) when compared to TRAD over time. Additionally, the methodology of the current study may explain the results of lower soreness in the AEL group due to their cluster set nature. Other studies that used cluster sets for the BS noted quantitatively lower soreness values for the LB compared to TRAD (Api et al., 2023; Varela-Olalla et al., 2020).

Monitoring of perceptual responses illustrated that AEL and TRAD reported similar values for all the SRSS questions, except for one (muscular stress (MS)). The MS question reported a statistically significant interaction of group and day with AEL showing a slower decay of higher MS values ($\beta = 0.077$, $SE = 0.036$, $p = 0.032$). The specific time frame appears to be around day 15 for when TRAD reported lower probabilities of reporting higher MS values than AEL. Additionally, a properly programmed AEL or TRAD S-E block should result in statistical increases in overall recovery (OR) ($\beta = 0.071$, $SE = 0.018$, $p < 0.001$), physical performance capability (PPC) ($\beta = 0.052$, $SE = 0.019$, $p = 0.006$), and decreases in overall stress (OS) ($\beta = -0.035$, $SE = 0.018$, $p = 0.052$). Hitzschke et al. (2017) is the closest analogy to the current study that completed a shock-microcycle with overloaded eccentrics in the BP and BS. The SRSS questions that reported the largest changes and statistical significance were the physical (PPC and MS) and overall questions (OS and OR) (Hitzschke et al., 2017). The results of the current study contrast the reported values of the physical and overall questions by Hitzschke et al. (2017), but this is most likely due to differences in the methodology and purpose. Lastly, the physiological questions of the SRSS (lack of activation (LA), emotional balance (EB), mental performance capability (MPC), and negative emotional state (NES)) did not report any statistical differences in the current study and similar studies (Hitzschke et al., 2017). Therefore, the physical and overall questions of the SRSS appear to be more sensitive than the psychological, which contrasts the suggestions of psychological factors being sensitive to resistance training volume load (Nässi et al., 2017; Saw et al., 2016) .

An issue for comparing AEL to TRAD is the possible implementation of eccentric intensities and cluster sets. The use of the current study using 110% AEL intensity might have resulted in the RBE without creating any increase in soreness as observed by Merrigan & Jones (2021). Additionally, a 15 second break seems to report quantitatively lower values compared to straight sets (Api et al., 2023; Varela-Olalla et al., 2020). However, Teague & Schwane (1995) noted no differences in soreness for eccentric biceps contractions with 15 seconds of rest but noticed statistical significance when a 5 minute break between repetitions was applied. Therefore, future research should compare AEL cluster sets to TRAD cluster sets. This is based off the finding of the current study that AEL cluster sets reported statistically significantly lower LB scores compared to straight set TRAD. Additionally, the current study suggests an AEL intensity of 110% may be light enough to create an RBE without any drawbacks, while 120% may create elevated soreness compared to TRAD (Merrigan & Jones, 2021). There are other physical aspects (strength (Chen et al., 2023; Friden et al., 1983; Hyldahl et al., 2014; Neltner et al., 2023; Paschalis et al., 2008; Peñailillo et al., 2013; Saxton et al., 1995), power (Chae et al., 2023b; Friden et al., 1983; Peñailillo et al., 2013), force modulation (Brockett et al., 1997), joint reactions (Chen et al., 2023), coordination (Brockett et al., 1997; Byrne et al., 2004; Chen et al., 2023; Paschalis et al., 2008; Saxton et al., 1995)) that should be investigated prior to the prescription of AEL in-season or for peaking (Suchomel et al., 2019b). The perceptual responses showed similar values between groups and reflected what properly programmed S-E block should represent. Previous research has shown that the SRSS questions do not accurately depict the true state of the athlete completing physical tests (Hitzschke et al., 2017; Perkins et al., 2022). Thus, it is recommended to combine both physiological and psychological monitoring tools together (Halson, 2014; Hitzschke et al., 2017). Future SRSS monitoring research should be combined with physiological monitoring over a chronic period to identify which questions possibly correlate best with performance.

To conclude the current studies, AEL appears to create less soreness in the LB over time when assessed via MVAS. The PVAS shows lower LB soreness for AEL as well throughout the duration of the study. The SRSS only showed a difference in MS for the last week of training, with AEL having higher reported values. Lastly, PPC and OR increase and OS decrease in a properly programmed S-E block. If practitioners use AEL, their athletes or clients should expect lower soreness levels for the LB compared to TRAD. Perceptual responses showed no major differences, except for AEL having a slower taper of MS values. Therefore, practitioners should consider the other potential benefits of using AEL over TRAD, as there appears to be no major drawbacks with less soreness and similar perceptual recovery and stress responses.

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