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General Sport Skills Performance Following the Combined Use of Accentuated Eccentric Loading and Cluster Sets During a Strength-Endurance Training Phase

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ABSTRACT

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The purpose of this study aimed to evaluate the efficacy of resistance training with accentuated eccentric loading (AEL) and cluster sets (CS) versus traditional resistance training (TRAD) on general sports skills and power performance in recreationally trained individuals. Seventeen subjects (11 males, 6 females; mean age 23.2 ± 4.1 years; body mass 81.3 ± 22.2 kg; height 172.1 ± 10.0 cm; relative 1 RM back squat 1.5 ± 0.3) were randomly assigned to AEL ($n = 9$) or TRAD ($n = 8$) groups. After an initial familiarization and baseline testing, both groups underwent a four-week strength-endurance training regimen. The AEL group incorporated AEL in a CS format every other repetition for back squat and bench press. Pre- and post-intervention assessments included accelerative sprint (10- and 20-meter split time), change of direction (505), COD deficit (CODD), countermovement jump height, and peak power. Statistical significance was set at $p \leq 0.05$. Both groups showed significant improvements in 505 and CODD ($p < 0.01$), with the AEL group demonstrating a greater effect size than TRAD for 505 (g: -0.90; and -0.45, respectively) and CODD (g: -0.87; and -0.26, respectively). No other measures showed significant changes ($p > 0.05$). These data suggest that a strength-endurance training block can enhance change of direction ability, with potential added benefits from AEL with CS, although further research is warranted to confirm these effects.

DEDICATION

I would like to dedicate this dissertation to my wife, Caitlyn Nelson, and to my parents Dave and Dawn Nelson. Without your unwavering support, encouragement, and steadfast love this journey would not have been possible.

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Chapter 1. Introduction

Arguably, two of the most important aspects of sport performance is the ability to produce large amounts of force quickly and ensuing high power outputs, both of which are largely determined by an athlete's muscular strength (G. G. Haff & Nimphius, 2012; M. H. Stone et al., 2002, 2003; T. J. Suchomel et al., 2016; Young, 2006). In fact, athletes of higher playing levels and abilities demonstrate significantly greater strength, power and explosive strength compared to their less elite counterparts (M. H. Stone et al., 2002; T. J. Suchomel et al., 2016). It has been established that resistance training effectively enhances these qualities, further supporting sport specific performance (Deschenes & Kraemer, 2002; Hakkinen et al., 1988; Kraemer et al., 1998; McGuigan et al., 2012; M. Stone et al., 2002; M. H. Stone et al., 1991; T. J. Suchomel et al., 2016). Unsurprisingly, since the 1970's resistance training has been a foundational aspect of the overall training program for athletes and is a fundamental means of physical preparation utilized by most strength and conditioning professionals (Durell et al., 2003; Kraemer et al., 1998). Importantly, successful employment of resistance training into the physical preparation of athletes constitutes that the training means must demonstrate reasonable transfer to improvements in sporting actions such as sprinting, jumping, and change of direction (COD) ability. Regarding this transfer of training effect, significant improvements in strength and power output from resistance training show accompanying improvements in sprint, jump and COD performance (Comfort et al., 2012; Cormie et al., 2010; McBride et al., 2002). While the effectiveness of resistance training for athletes has much support, continued long-term improvements in sport performance depend on the successful organization of training means across multiple levels of an athlete's career (DeWeese et al., 2015a, 2015b).

Through the use of periodization, the effectiveness of resistance training for sport performance can be further enhanced (G. G. Haff, 2004; G. G. Haff et al., 2004). Periodization is the macro-management of the training process achieved through logically sequencing and manipulating training means to increase the potential to achieve specific performance goals (Cunanan et al., 2018; M. H. Stone et al., 2021). Although several periodization models currently exist (Mujika et al., 2018), one effective and well-studied variant is block periodization (M. H. Stone et al., 2021). Specifically, block periodization attempts to optimize the potential to reach peak performance by logically sequencing phases of highly concentrated workloads thereby taking advantage of residual training effects and planned variation (V. Issurin, 2008; V. B. Issurin, 2016; M. H. Stone et al., 2021). Current research suggests that block periodization is both effective at enhancing sport performance and often produces superior results compared to other periodization variants (Carroll et al., 2019; Hartmann et al., 2009; V. B. Issurin, 2014; Painter et al., 2012). Within a stage of a block periodized program there exists three blocks of training, each consisting of one or more concentrated loads of unidirectional, or semi-unidirectional, training typically lasting for 2-8 weeks (V. Issurin, 2008). Each block aims to potentiate performance in subsequent higher-intensity and more specific blocks of training, leading to a cumulative performance peak prior to competition. To build the capacity for higher quality training in later blocks, the first, and often longest, "accumulation" block typically targets qualities with the longest training residuals (V. Issurin, 2008; M. H. Stone et al., 1982). For example, within the accumulation block coaches may prescribe two, high-volume, concentrated loads such as strength-endurance and basic strength to build the foundation for long-term performance enhancement (DeWeese et al., 2015a, 2015b). Previous research provides evidence supporting that an accumulation-style block of training is effective in producing the specific qualities that underpin further adaptive potential (Andersen & Aagaard, 2000; McGee et al., 1992; McMillan et al., 1993; Pierce et al., 1993; M. H. Stone et al., 1983, 2021). Regardless of the block of training, appropriate micro-management of the training plan, or programming, is essential at each level of the periodization model to direct the training towards the desired response.

Programming entails appropriately prescribing and manipulating training factors such as exercise selection, load prescription and intensity factors, volume of the training stimulus, etc. (Cunanan et al., 2018; M. Stone et al., 2022). Fundamental to the successful use of resistance training to improve the principal fitness qualities supporting athletic performance and effectively transferring that training to improvements in sport form is proper exercise selection and load prescription. Machine based and free-weight exercises, single-joint and multi-joint exercises, weightlifting exercises and their derivatives, and plyometrics are just a few resistance training methods that are at a coaches disposal when considering exercise selection (T. J. Suchomel et al., 2018). Regardless of the method and specific exercise selected, at its most fundamental level resistance training exercise demands attention be paid to the loading strategy employed. Most commonly, traditional resistance training methods, such a free-weight multi-joint exercises, prescribes the same load for lifting, or concentric, and lowering, or eccentric, portions of the selected exercise. However, given that eccentric muscle actions are capable of producing as much as 50% more force than concentric actions (Hollander et al., 2007; Jorgensen, 1976; Katz, 1939; Westing et al., 1988), traditionally loaded resistance exercises constrict the loading potential to that of an athlete's concentric strength. It logically follows that practitioners and researchers alike are now directing their attention to eccentric overload training to capitalize on the evident force production discrepancy between eccentric and concentric muscle actions (T. J.

Suchomel et al., 2019a). Application of eccentric overload training can now be found in several training methods such as tempo training, eccentric only exercises, flywheel inertial training, plyometrics, and accentuated eccentric loading (AEL) (McNeill et al., 2019; T. J. Suchomel et al., 2019a). Several reviews on the topic suggest eccentric overload training may potentially result in superior improvements in strength, power, explosive strength, and sport specific performance variables compared to traditionally loaded resistance training methods (Chaabene et al., 2018; Cowell et al., 2012; Douglas et al., 2017a; McNeill et al., 2019; Roig et al., 2009; T. J. Suchomel et al., 2019a, 2019b; Wagle et al., 2017).

Despite the potential benefits of this contraction-specific training method, coaches must also carefully consider the specificity of the exercises selected and loading strategy used in the context of the sporting actions performed in the competitive environment to ensure optimal transfer of training effects (Suarez, Wagle, et al., 2019). For example, given that isolated muscular actions rarely occur in the competition setting, the degree of transfer from eccentric training may be limited. Strength and conditioning professionals would therefore benefit from a loading strategy that delivers an adequate eccentric stimulus while still adhering to the specific regime of muscular work that typifies athletic movements. Accentuated eccentric loading (AEL) is a modified method of eccentric training that offers practitioners an answer to this loading strategy conundrum by providing an eccentric overload under the constraints of stretch-shortening cycle muscular actions. Specifically, AEL allows an athlete to perform typical resistance training movements that require coupled eccentric and concentric muscle actions with minimal disruption to the natural mechanics of the exercise while still prescribing eccentric loads in excess of the concentric load (Wagle et al., 2017). Current research on AEL has shown it to be a training method with promise for potentially improving performance both acutely and chronically. Acutely, AEL may enhance force production, power output, jump performance, and throwing actions (Aboodarda et al., 2013; Doan et al., 2002; J. Sheppard et al., 2007; J. M. Sheppard & Young, 2010). The acute performance enhancing effect of AEL may be explained by the unique neural characteristics associated with eccentric training such increased neural drive, selective recruitment of fast-twitch fibers, reflex inhibition, and SSC utilization (Douglas et al., 2017a, 2017b; Wagle et al., 2017). Likewise, superior improvements in maximal strength, reactive strength, sprint speed, and agility performance have been demonstrated following long-term use of AEL compared to traditional resistance training (Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; Walker et al., 2016). Such chronic performance improvements may be the result of the unique morphological adaptations associated with eccentric training such as increased fascicle lengthening, superior hypertrophy of fast twitch fibers, and a shift to a more explosive muscle phenotype (Douglas et al., 2018; T. J. Suchomel et al., 2019a; Wagle et al., 2017; Walker et al., 2020).

Given the current research on AEL, it appears potentially more advantageous than traditional resistance training methods for enhancing sport specific skills performance. However, there is currently a paucity of research on the chronic effects of AEL on these training variables. Additionally, to the author's knowledge there is currently no research examining the chronic effects of AEL on jump, sprint and change of direction performance when implemented into an accumulation-style block of training typically used by athletes. It is therefore the purpose of this study to comparatively examine the effects of two simultaneous training programs of traditional training and AEL training typical of that employed during an accumulation block on changes in jump, sprint, and change of direction performance.

Chapter 2. Review of the Literature

Introduction

Resistance training is a well-established component of athletic training programs, significantly enhancing muscular strength, power, and sport specific performance (Comfort et al., 2012; Cormie et al., 2010; Deschenes & Kraemer, 2002; Hakkinen et al., 1988; Kraemer et al., 1998; McBride et al., 2002; McGuigan et al., 2012; M. H. Stone et al., 1991, 2002; T. J. Suchomel et al., 2016). Traditional resistance training uses the same absolute load for both the eccentric and concentric phases of the movement. However, this strategy is limited by an individual's concentric strength since human muscles can produce significantly more force during eccentric contractions (Hollander et al., 2007; Jorgensen, 1976; Katz, 1939; Westing et al., 1988). Consequently, traditional resistance training may not adequately enhance the upper limit of force production in human muscle.

Various training methodologies have been developed to exploit the greater force production during eccentric actions (T. J. Suchomel et al., 2019a). Evidence suggests that eccentric training can lead to superior performance enhancements compared to traditionally loaded resistance training (Chaabene et al., 2018; Cowell et al., 2012; Douglas et al., 2017a; McNeill et al., 2019; Roig et al., 2009; T. J. Suchomel et al., 2019a, 2019b; Wagle et al., 2017). However, many eccentric training methods lack practical relevance or accessibility in typical training environments (Merrigan et al., 2022; Wagle et al., 2017). Additionally, for resistance training to effectively improve sport performance, it must adhere to the principle of specificity (Goodwin & Cleather, 2021; Suarez, Wagle, et al., 2019). Accentuated eccentric loading (AEL) can meet this requirement by applying eccentric overload through practical and accessible methods that quantify the overload while maintaining high sport specificity.

AEL is distinguished by three key factors, making it a highly promising form of eccentric load training. First, it involves prescribing eccentric loads that exceed concentric loads. Second, when properly applied, it minimally disrupts the natural mechanics of the movement. Third, it uses stretch-shortening cycle (SSC) muscle contractions, where an eccentric action is rapidly followed by a concentric contraction (Harden et al., 2022; T. J. Suchomel et al., 2019a; Wagle et al., 2017). These last two points contribute to AEL's sport-specific nature. Research indicates that AEL can effectively enhance force production and power output (Brandenburg & Docherty, 2002; English et al., 2014; Friedmann et al., 2004; Walker et al., 2016), both of which are crucial for athletic performance (G. G. Haff & Nimphius, 2012; T. J. Suchomel et al., 2016; Young, 2006).

Studies on AEL's acute and chronic effects have shown potential benefits in jump height, power output, sprint speed, and change of direction ability (Aboodarda et al., 2013; Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; J. Sheppard et al., 2007). Despite these promising findings, research on the effects of AEL on these specific sport skills is limited. Specifically, there is little research on the effects of AEL when integrated into typical athletic training programs using practical and readily available means. Therefore, this literature review consolidates existing knowledge on AEL using practical and readily available means and its impact on sprinting, change of direction, and jump performance. It provides a comprehensive overview of AEL's efficacy in enhancing these skills specifically compared to traditional training. This review summarizes: 1) loading strategies and the relationship to muscular strength, 2) the acute effects of AEL on general sport skills, and 3) the chronic effects of AEL on general sport skills.

Literature Search Methods

The search for relevant literature was conducted in March 2024 using the databases Google Scholar, PubMed, and SPORTDiscus. No limitations were set regarding the publication date. The search terms included "accentuated eccentric load", "augmented eccentric load", "enhanced eccentric load", and "eccentric overload". The focus was on AEL methodologies involving multi-joint exercises with free-weights, as these are the most practical and accessible for typical training environments. The search yielded no current research on acute performance enhancement in sprinting and change of direction. Consequently, flywheel training studies were included to examine the acute effects of eccentric overload on these performance metrics. Flywheel training was initially excluded due to the difficulty in quantifying the eccentric load. The initial search identified 13 studies. With the inclusion of relevant flywheel training studies, and additional five studies were added. The results from flywheel training studies are discussed briefly due to the specific requirements of AEL and limitations of this training methodology. All included works are peer-reviewed, and full access to the publications was available.

AEL Methodology and the Relationship to Strength

Investigations of the effects of AEL on general sport skills performance covers various eccentric loading intensities and methodologies. Previous reviews have started to distinguish practical methods of delivering AEL from those unsuitable for typical training environments (Merrigan et al., 2022; Wagle et al., 2017). Eccentric training may be categorized as isoweight, isokinetic, and isoinertal (Franchi & Maffiuletti, 2019). While inertial eccentric training with flywheel technology is becoming more accessible, it often fails to produce eccentric forces greater than the concentric forces (Harden et al., 2022; T. J. Suchomel et al., 2019a). Similarly, isokinetic variations of AEL diminish its sport-specific nature, as human movement in sports and training rarely occurs at fixed velocities (Goodwin & Cleather, 2021; Newton et al., 1996). Thus, practical and readily available AEL primarily utilizes isoweight eccentric methods, such as free-weights, weight-releasers, manual unloading, or dropping an additional eccentric load at the end of the eccentric phase. As previously mentioned, AEL prescribes eccentric loads in excess of the concentric load for a given exercise (Harden et al., 2022; T. J. Suchomel et al., 2019a; Wagle et al., 2017). AEL can be categorized into supramaximal, maximal, and submaximal, where the eccentric load exceeds, equals, or is less than the concentric one repetition maximum (1RM), respectively (Merrigan et al., 2022). A primary reason studies using flywheel eccentric overload are excluded is due to incomparable loading methods.

The submaximal, or “augmented” eccentric, loading methodology is generally found to be more effective for acute enhancements in sport skills performance than supramaximal loading (Wagle et al., 2017). Most research focuses on jump performance, showing that eccentric loads less than ~30% of body mass can improve acute jump performance and power output (Aboodarda et al., 2013; Bridgeman et al., 2017; Lloyd et al., 2022; J. Sheppard et al., 2007). However, not all studies report improvements (Aboodarda et al., 2014; Godwin et al., 2021), and loads exceeding this threshold consistently fail to enhance jump performance (Godwin et al., 2021; Moore et al., 2007; Tseng et al., 2021).

Chronic AEL studies typically employ greater absolute eccentric loads and exercises not directly related to the sports skills tested. One study on chronic submaximal AEL reported significant jump performance and power output improvements when applied to countermovement jumps (J. Sheppard et al., 2007). This was supported by a case study in rugby athletes using submaximal AEL applied to drop jumps (Bridgeman et al., 2020). Both investigations demonstrated greater improvements using submaximal AEL compared to traditional loading methods. More extensive evidence exists for chronic AEL using variations of the squat exercise, with loads ranging from 90% to 115% of concentric 1RM. This range appears equally effective at improving general sport skills performance compared to traditional training. However, the use of submaximal loads tend to outperform traditional training (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; Douglas et al., 2018).

Enhancements in sport skills following AEL seem to align with increases in strength, which is crucial for sprinting, change of direction, jumping, and power output (T. J. Suchomel et al., 2016). For example, studies showing more pronounced improvements in these skills with AEL compared to traditional training also report larger strength improvements (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; Friedmann-Bette et al., 2010; N. Munger et al., 2022). Additionally, the effectiveness of AEL in enhancing performance may depend on an individual's muscular strength (Merrigan et al., 2022; Wagle et al., 2017). Therefore, it may be that a more effective strength stimulus because of using AEL is responsible for comparably greater gains in sport skills performance.

Acute Enhancement of General Sport Skills With AEL

The literature concerning the acute effects of AEL for enhancing general sport skills performance is limited. Most of the literature focuses on the acute performance enhancement of AEL with plyometric exercises, such as countermovement and depth jumps, and the associated kinetic variables. There is considerably less evidence on the acute effects of AEL on sprinting and change of direction tasks. Potential mechanisms for acute performance enhancement with AEL are derived from studies on traditional strength training exercises, like squats and bench presses, as well as plyometric exercises. These mechanisms may include increased neural drive, enhanced preload, selective recruitment of fast-twitch fibers, reflex inhibition, and improved utilization of the SSC (Doan et al., 2002; Douglas et al., 2017b; Munger et al., 2017; J. Sheppard et al., 2007; Wagle et al., 2017). Although there is strong evidence supporting these mechanisms, some authors disagree (Aboodarda et al., 2013; Lloyd et al., 2022), suggesting instead that changes in movement strategy may explain performance improvements.

Jumps and Power Output

Two early studies examining the acute effects of AEL on jump performance reported contradictory findings (Moore et al., 2007; J. Sheppard et al., 2007). Sheppard et al. observed that elite male volleyball players achieved significantly higher jump heights and peak power output in block jumps when using a 20 kg load during the eccentric phase, compared to bodyweight jumps. Conversely, Moore et al. found that additional eccentric loads of 20%, 50%, and 80% of 1RM in jump squats did not significantly affect peak velocity or power output compared to traditional jump squats in resistance-trained men. Although Moore et al. did not directly measure jump height, the lack of change in peak velocity suggests similar results for jump height (McMahon et al., 2018). This discrepancy likely stems from differences in movement selection and eccentric loads used. The block jump likely involved a smaller range of motion than the jump squat (Lobietti, 2009; Moore et al., 2007). Additionally, the 20 kg load in the block jumps likely represents less than 20% of back squat 1RM. Therefore, the larger range of motion and higher eccentric loads in the jump squats likely lengthened the amortization phase, limiting elastic energy usage and possibly explaining the differences (Wagle et al., 2017).

Similar acute performance enhancements have been observed with AEL applied to countermovement jumps (CMJ) (Aboodarda et al., 2013). Aboodarda et al. found significantly greater jump heights and power output when performing CMJs with an additional eccentric load of 30% body mass via elastic bands compared to bodyweight jumps. They also observed that

20% of body mass added during the eccentric phase improved jump height but not power output. This suggests a specific loading strategy may be most effective for acute power output enhancements. While most literature attributes acute jump performance improvements leading to better utilization of the SSC, Aboodarda et al. observed no change in leg stiffness. Instead, the improved jump height is likely due to a significantly greater concentric impulse resulting from prolonged movement duration.

However, not all research agrees on the potentiating effect of AEL on CMJ performance (Godwin et al., 2021; Tseng et al., 2021). Godwin et al. found no change in jump height with 20% or 40% of body mass applied during the eccentric phase of CMJs compared to bodyweight only. However, the authors observed significantly increased power output despite no change in jump height. The authors suggested the lack of CMJ performance improvement with AEL might be due to participants' insufficient strength levels to achieve a potentiating effect. Tseng et al. (2021) conducted an acute AEL intervention with male collegiate volleyball players using AEL half squats with an additional eccentric load of 105% 1RM paired with 80% 1RM concentric loads. Subjects were tested on the CMJ at 10 minutes, 24 hours, and 48 hours post-intervention. The authors observed no change in CMJ height at any time point compared to baseline. However, methodological issues with AEL application may partially explain the lack of potentiation. To achieve the desired AEL stimulus, weight was manually removed from the bar at the bottom position of the half squat, likely affecting the natural mechanics of the movement and thus the acute potentiating effect (Wagle et al., 2017).

Several studies have also examined the acute effects of AEL on drop jump performance (Aboodarda et al., 2014; Bridgeman et al., 2017; Lloyd et al., 2022). In a follow-up study, Aboodarda et al. (2014) observed no improvements in drop jump performance across three different heights with an additional eccentric load of 20% or 30% of body mass. AEL likely reduced reactive strength performance, as participants may have lacked the strength necessary to benefit from the accentuated eccentric loads (Wagle et al., 2017). Stronger individuals are better at storing and utilizing elastic energy and generally have shorter amortization phases (Beattie et al., 2017).

In contrast, Bridgeman et al. (2017) found that AEL drop jumps with an additional load of 20% body mass significantly improved subsequent CMJ height and peak power at 2- and 6-minutes post-intervention but not at 12 minutes. Interestingly, there was little improvement during the drop jump itself compared to bodyweight jumps. This suggests a time-dependent window for the acute potentiating effects of AEL on jump performance, along with specific loads.

Adolescent rugby athletes showed significantly improved jump height during drop jumps with an additional eccentric load of 15% body mass from a standardized height of 30 centimeters compared to traditional drop jumps (Lloyd et al., 2022). However, no improvement in power output was observed. The authors suggested mechanisms for the acute enhancement of drop jump performance include increased neural drive and a higher active state at the start of the concentric phase, leading to greater concentric impulse and jump heights. The application of AEL to drop jumps also resulted in acute changes in jump strategy. Participants displayed significantly longer contraction time due to the additional eccentric load. This likely explains the improvement in concentric impulse and jump height. Ultimately, while AEL may not be the most effective resistance training modality for enhancing the SSC, it appears effective for improving force generation capabilities.

The acute effects of AEL on jump performance and power output show mixed results. While some studies demonstrate significant improvements in jump height and/or power output with AEL (Aboodarda et al., 2013; Bridgeman et al., 2017; Godwin et al., 2021; Lloyd et al., 2022; J. Sheppard et al., 2007), others report no change or only specific enhancements based on load and movement type (Aboodarda et al., 2014; Godwin et al., 2021; Moore et al., 2007; Tseng et al., 2021). Variability in participant strength levels, eccentric load magnitudes, and movement mechanics likely contribute to these discrepancies. Despite these mixed findings, AEL appears to offer potential benefits for enhancing concentric impulse and force generation capabilities, though it may not be universally effective for optimizing the SSC (Aboodarda et al., 2013; Lloyd et al., 2022). Further research is needed to identify optimal loading strategies and protocols to maximize the acute performance benefits of AEL.

Change of Direction and Sprint Performance

To the author's knowledge, no literature currently examines the acute effects of AEL on change of direction (COD) and sprint performance using practical and readily available methods. However, research does exist on the acute effects of flywheel-inertial training (FIT). Although FIT does not provide a true accentuated eccentric stimulus, it offers coupled eccentric-concentric actions, is capable of providing an enhanced eccentric load, and has been historically used for eccentric overload training (T. J. Suchomel et al., 2019a; Wagle et al., 2017). This review will briefly discuss research on FIT, though a comprehensive review of FIT training for acute enhancements of sport skill performance is beyond its scope.

Several studies on FIT across various exercises – including COD-specific exercises, leg extension, and bilateral and unilateral half squats – have found that eccentrically overloaded exercises performed before a COD task significantly enhance subsequent COD performance and related kinetic variables (Beatoet al., 2021a; Beato et al., 2021b; De Hoyo et al., 2014). It is important to note that these studies did not include other training methods, making it difficult to compare FIT's acute effects to traditional training methods on COD performance. Beato et al. (2021b) found no difference between general and specific exercises in subsequent COD performance. Similarly, De Hoyo et al. (2014) compared only to a control group completing a general five-minute warm-up. Thus, it could be argued that any resistance training exercise performed before COD tasks may acutely improve performance, rather than specifically eccentrically overloaded exercises.

Similar acute results have been observed in sprint performance studies. FIT may effectively enhance short sprint performance, though this likely depends on the individuals maximal strength and may not offer additional benefits over traditional training (De Hoyo et al., 2014; Kale et al., 2023; Sañudo et al., 2020). However, Kale et al. (2023) noted significant acute improvements in step rate following flywheel training, which were not observed with traditional isoweight exercises. Velocity is a product of step rate and step length; an increase in one variable will result in higher velocities, provided the other variable does not decrease (Hunter et al., 2004). Kale and colleagues (2023) observed no change in step length while step rate increased, indicating a positive performance-enhancing effect on sprint performance from eccentric training.

In summary, while flywheel training has been investigated for its acute effects on COD and sprint performance, it is not the most effective form of AEL due to its limited ability to produce a true accentuated eccentric stimulus. The existing research lacks robust comparative evidence against traditional training methods, diminishing its evidential power. However, theoretically, there is some indication that eccentric overload training may acutely enhance COD and sprint performance, suggesting potential benefits that warrant further exploration.

Chronic Enhancement of General Sport Skills With AEL

Previous reviews have explored the potential mechanisms behind performance enhancement from the chronic implementation of AEL, suggesting both positive neural and morphological adaptations (Douglas et al., 2017a; Merrigan et al., 2022; T. J. Suchomel et al., 2019a; Wagle et al., 2017). Performance enhancement from AEL is likely driven by several mechanisms, both neural and morphological. Chronic AEL can improve neuromuscular efficiency by increasing agonist voluntary activation and decreasing antagonist coactivation, enhancing motor unit recruitment – especially high-threshold units, improving rate coding, and fostering intermuscular coordination (Douglas et al., 2017a; Merrigan et al., 2022). Morphological adaptations from chronic AEL include superior hypertrophy of type 2 fibers compared to traditional training, increasing fascicle length for greater contraction velocities, a shift towards a more explosive muscle phenotype, and increased tendon stiffness for improved SSC performance through better force transmission (Douglas et al., 2017a; Merrigan et al., 2022; Wagle et al., 2017). Given this promising mechanistic support, the chronic application of AEL warrants consideration for enhancing both short-term and long-term performance.

Jumps and Power Output

The literature on the chronic effects of AEL on jump performance and power output indicates its efficacy in enhancing these abilities (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; Munger et al., 2017; J. Sheppard et al., 2008). However, only one study provides evidence that AEL is significantly more effective than traditional training in enhancing jump performance and power output (J. Sheppard et al., 2008). Most literature shows traditional training to be equally effective in improving these qualities.

In a follow-up to an acute study on AEL's effects on jump performance, Sheppard et al. (2008) demonstrated that 5 weeks of AEL training improved jump height and power output in a CMJ test more than traditional training in high-level volleyball players. However, the only difference between the training groups was an additional eccentric load of 20 kg or 10 kg, for males and females respectively, applied to CMJs for the AEL group during the same power-focused training block.

It is possible that the superior results from AEL may, in part, stem from increased training variation rather than an inherent superiority of AEL as a "specific" training method. Bridgeman et al. (2020) partially supported this possibility showing a trend towards AEL-induced superior improvement in peak eccentric and concentric force, CMJ, and squat jump (SJ) performance after 4 weeks of a training program that included either AEL drop jumps with an additional eccentric load equivalent to 20% of body mass or traditional drop jumps with no additional load. However, a lack of robust statistical analysis between groups weakened the evidence for AEL as a superior training method for chronic improvements in jump performance.

More literature shows equivocal findings when comparing the chronic effects of AEL and traditional training on jump performance. For example, two studies examining the chronic effects of AEL applied to traditional squat exercises found no differences in jump performance or power output between AEL and traditional training groups (Chakshuraksha & Apanukul, 2021; Munger et al., 2022). In these studies, Munger et al. and Chakshuraksha & Apanukul used supramaximal eccentric loads for back squats and half squats, respectively. Munger and colleagues showed that 5 weeks of AEL at eccentric loads ranging from 105 to 115% 1RM and traditional training both improved jump height, with no differences between groups. Similarly, Chakshuraksha & Apanukul observed no differences in power output during a jumping task after 6 weeks of combined AEL, using 105% 1RM eccentric loads, or traditional training with plyometric training.

There is evidence that at times AEL might be less effective at improving jump performance. Douglas et al. (2018) found that 4 weeks of tempo AEL squats using submaximal eccentric loads (92% to 98% 1RM) did not change drop jump performance in rugby athletes, while the traditional training group showed a small improvement. An additional 4 weeks of AEL using supramaximal loads (106% to 110% 1RM) had the same effect on jump height, but likely improved contact time. The traditional group's additional 4 weeks of training did not further benefit drop jump performance. One proposed mechanism for chronic AEL's utility is improved SSC utilization through increased connective tissue stiffness. The authors observed likely increased leg stiffness in the AEL group only after the final 4 weeks of training, possibly supporting the improvement in contact time during the drop jump task. Notably, the final 4 weeks also included AEL drop jumps in addition to AEL back squats, suggesting that AEL drop jumps likely contributed to the improvement in leg stiffness and contact time due to training specificity.

The literature on the chronic effects of AEL on jump performance and power output suggests that while AEL can enhance these abilities, it is not consistently more effective than traditional training. Only one study shows AEL to be superior, while most research indicates traditional training is equally or, at times, more effective. The variability in findings is likely due to differences in training protocols and the specificity of exercises used. Overall, while AEL has potential benefits, it's superiority over traditional methods for enhancing jump performance and power output remains inconclusive.

Sprinting and Change of Direction Performance

Several studies have evaluated the chronic effects of AEL on sprint performance. Research indicated that AEL can lead to favorable morphological adaptations related to sprint performance. For instance, there is evidence of increased fascicle lengthening after 10 weeks of AEL, unlike traditional training which showed no such differences (Walker et al., 2020). However, there is also evidence of no changes in fascicle length following AEL (Douglas et al., 2018). Despite this, the potential for AEL to enhance sprint performance remains, given the strong correlation between increased fascicle length and sprint performance (Abe et al., 2000, 2001; Kumagai et al., 2000).

Douglas et al. (2018) conducted one of the most comprehensive and ecologically valid comparative examinations of AEL and traditional training on sprint performance. The authors found that 4 weeks of controlled eccentric tempo AEL using the half squat exercise at near maximal eccentric loads (92-98% 1RM) resulted in possible improvements in 40-meter sprint performance. However, no significant differences were noted for 10- or 20-meter sprints. Similarly, maximal velocity, contact time and step rate, showed likely improvements. Effect size comparisons with a traditional training group suggested a possibly superior training effect for the AEL group in these variables. Conversely, an additional 4 weeks of AEL with supramaximal loads (106-110% 1RM) had the opposite effect. Sprint performance at 10-,20-, and 40-meters likely declined compared to the initial four weeks of AEL. Sprint variables were either unchanged or decreased. Effect size comparisons with the traditional group showed no difference after the subsequent 4 weeks. The authors proposed that improvements in maximal velocity and sprint time were likely due to increased lower body strength. Indeed, increases in squat 1RM likely favored the AEL group. Sprint performance shows strong correlations to maximal strength (T. J. Suchomel et al., 2016) and improvements in strength likely underpin increases in sprint speed (Comfort et al., 2012), suggesting that greater strength gains may have led to greater sprint speed improvements.

The differences between the initial and subsequent four weeks were attributed to prolonged periods of substantial eccentric loading. This likely required longer recovery than traditional training before a supercompensation effect could be observed. Additionally, previous research suggests that submaximal AEL may be superior for enhancing explosive performance (Merrigan et al., 2022; Wagle et al., 2017), and the shift to supramaximal intensities could explain the lack of further sprint performance improvements.

Most literature shows mixed results when comparing the effects of AEL and traditional training on sprint performance. Both methods appear equally effective. For instance, after 5 weeks of AEL or traditional training applied to the back squat, significant improvements in 20-meter sprint performance were found for both groups, averaged over 5-, 10-, and 20-meter splits (Munger et al., 2022). Supporting the idea that strength improvements underline enhancements in general sport skills, both groups showed significant increases in eccentric back squat 1RM. Similarly, rugby players performing 6 weeks of either AEL or traditional training combined with plyometric training showed significant improvements in 40-meter sprint performance, with no evident between group differences (Chakshuraksha & Apanukul, 2021). Additionally, a 4-week intervention of either AEL or bodyweight drop jumps showed positive trends in 10- and 30-meter sprint performance (-2.2% and -2.0%, respectively) for the AEL group but not for the traditional training group (Bridgeman et al., 2020). However, the lack of traditional statistical null hypothesis testing limits the inferential power of the results in comparing AEL and traditional training.

To the author's knowledge, only two studies have examined the effects of AEL using free weights on change of direction (COD) performance. Bridgeman et al. (2020) compared 4 weeks of five sets of six repetitions of AEL drop jumps with an additional eccentric load of 20% of body weight to traditional bodyweight drop jumps. Both groups demonstrated an improvement in COD performance during the 505 COD test. Although no robust statistical analysis was performed, the AEL group showed a larger magnitude of improvement in COD performance (-5.6%) compared to the traditional training group (-2.5%). Similarly, 6 weeks of combined AEL and plyometric training significantly enhanced agility performance in the T-test (Chakshuraksha & Apanukul, 2021). Subjects in the AEL group performed four sets of four repetitions of the half squat exercise at 90% of 1RM with an additional eccentric load of 105% 1RM using weight releasers. This was combined with 12 repetitions of countermovement jumps, with a 30-second rest interval for each set. The control group performed the same program, but the half squat load remained at 90% 1RM for both the eccentric and concentric phases. The study reported a significant group-by-time effect, indicating greater improvements in agility performance for the AEL group compared to the traditional group. Similar findings were noted for relative back squat strength, suggesting a greater training effect for dynamic lower body strength in the AEL group. The improvement in agility performance may have been underpinned by a larger increase in relative back squat strength as lower body dynamic strength is well correlated with COD and agility performance (T. J. Suchomel et al., 2016).

COD performance is influenced by multiple factors, including straight-line sprint speed, reactive strength, and both concentric and eccentric force production capabilities (Chaabene et al., 2018). Distinguishing performance improvements in COD tasks that require straight-line sprinting – whether due to enhanced sprint performance or actual improvements in COD ability – can be challenging (Nimphius et al., 2016). The current literature suggests both AEL and traditional training are likely equally effective for improving sprint performance. Similar results have been noted with reactive strength (Douglas et al., 2018). However, more research reports AEL to be an effective method for improving both concentric and eccentric force production capabilities, often to a greater degree than traditional training (Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; Ersöz et al., 2022; Friedmann-Bette et al., 2010; Munger et al., 2022; Walker et al., 2016). Taken together, it is likely greater improvements in COD performance using AEL compared to traditional training are likely due to better gains in concentric and eccentric lower body strength.

Research on the chronic effects of accentuated eccentric loading (AEL) on sprint and change of direction (COD) performance presents mixed results. Studies indicate that AEL can enhance sprint performance, particularly through increased fascicle length and lower body strength, although these benefits are inconsistent across different training protocols. While some research shows significant improvements in sprint metrics with AEL, other studies find no substantial difference when compared to traditional training methods. Additionally, AEL may be more effective in improving COD performance due to greater gains in concentric and eccentric force production. However, more comprehensive and consistent statistical analyses are needed to confirm these findings.

Conclusion and Direction of Future Research

The existing literature has demonstrated that AEL can effectively enhance sport skill performance, specifically in areas such as jump height, power output, sprinting, and change of direction (COD). AEL provides a potent stimulus for both acute and chronic adaptations. Acute improvements in sport skills following AEL are primarily linked to enhancements in total force generation capabilities. Which may be the result of unique neural responses or changes in movement strategy. Chronic benefits appear to stem from increased neuromuscular efficiency and morphological adaptations. However, the superiority of AEL over traditional training methods remains inconclusive, with several studies indicating that traditional training methods may offer comparable benefits. Importantly, the efficacy of AEL likely depends on the individual's strength levels, as performance improvements and effective accentuated loads likely require a prerequisite level of strength. Furthermore, studies where AEL training outperformed traditional training typically showed greater strength gains in the AEL group, suggesting that these improvements might be due to a more effective strength stimulus.

Future research should focus on elucidating the optimal loading strategies and protocols for AEL to maximize its benefits for sport skills performance. Additionally, future research should examine the acute effects of AEL using practical and readily available means on sprint and change of direction performance. Comparative studies between AEL and traditional resistance training when incorporated into a training program typical of athletic populations are essential to determine its practical effectiveness. Longitudinal studies examining the long-term effects of AEL on athletic performance when incorporated into logically sequenced phases of training with different training goals are also warranted.

To translate the benefits of AEL into practical training programs, it is crucial to develop accessible and scalable methods for implementing AEL into the typical training environment. Emphasis should be placed on integrating AEL into existing training regimens with minimal disruption to primary performance outcomes being targeted. For example, how would AEL training effect outcomes from different training paradigms (phases) within periodized training processes. Coaches and practitioners should consider the individual athlete characteristics, such as strength levels and training age, before considering the implementation of AEL. Additionally, combining AEL with other training modalities, such as plyometrics and other traditional resistance training exercises, could potentially further enhance overall sport skills performance. By addressing these areas, future research can contribute to the optimization of training programs and the broader application of AEL in sport performance.

Chapter 3. Effects of Accentuated Eccentric Loading on General Sport Skills and Power Performance Following a Four-Week Block of Strength-Endurance Training

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Abstract

The purpose of this study aimed to evaluate the efficacy of resistance training with accentuated eccentric loading (AEL) and cluster sets (CS) versus traditional resistance training (TRAD) on general sports skills and power performance in recreationally trained individuals. Seventeen subjects (11 males, 6 females; mean age 23.2 ± 4.1 years; body mass 81.3 ± 22.2 kg; height 172.1 ± 10.0 cm; relative 1 RM back squat 1.5 ± 0.3) were randomly assigned to AEL ($n = 9$) or TRAD ($n = 8$) groups. After an initial familiarization and baseline testing, both groups underwent a four-week strength-endurance training regimen. The AEL group incorporated AEL in a CS format every other repetition for back squat and bench press. Pre- and post-intervention assessments included accelerative sprint (10- and 20-meter split time), change of direction (505), COD deficit (CODD), countermovement jump height, and peak power. Statistical significance was set at $p \leq 0.05$. Both groups showed significant improvements in 505 and CODD ($p < 0.01$), with the AEL group demonstrating a greater effect size than TRAD for 505 (g: -0.90; and -0.45, respectively) and CODD (g: -0.87; and -0.26, respectively). No other measures showed significant changes ($p > 0.05$). These data suggest that a strength-endurance training block can enhance change of direction ability, with potential added benefits from AEL with CS, although further research is warranted to confirm these effects.

Introduction

Resistance training effectively improves the qualities that underlie general athletic performance skills (Deschenes & Kraemer, 2002; Kraemer et al., 1998; McGuigan et al., 2012; M. H. Stone et al., 1991; T. J. Suchomel et al., 2016). Consequently, it has become integral to the physical preparation of athletes (Durell et al., 2003; Kraemer et al., 1998). Evidence also shows that resistance training enhances general sport skills like sprinting, jumping, and change of direction (Comfort et al., 2012; Cormie et al., 2010; McBride et al., 2002). Traditional resistance training typically uses the same load for both the concentric (lifting) and eccentric (lowering) portions of exercises (McMaster et al., 2009). However, this approach limits the loading potential to an individual's concentric strength, because eccentric muscle actions producing up to 50% more force (Hollander et al., 2007; Jorgensen, 1976; Katz, 1939; Westing et al., 1988). To address this discrepancy, various eccentric overload training methods have been studied, including tempo training, eccentric-only exercises, flywheel-inertial training, specialized devices, plyometrics, and accentuated eccentric loading (AEL) (Harden et al., 2022; McNeill et al., 2019; T. J. Suchomel et al., 2019a; Wagle et al., 2017). Recent reviews suggest that eccentric overload training can improve athletic qualities and sport skills (Chaabene et al., 2018; Cowell et al., 2012; Douglas et al., 2017a; McNeill et al., 2019; Roig et al., 2009; T. J. Suchomel et al., 2019a, 2019b; Wagle et al., 2017). However, practitioners must consider the specificity of eccentric overload training methods to ensure effective transfer to sport performance (Goodwin & Cleather, 2021; Suarez, Wagle, et al., 2019).

AEL seems to address this concern by allowing resistance training with eccentric loads exceeding the concentric load while maintaining normal movement mechanics (Harden et al., 2022; T. J. Suchomel et al., 2019a; Wagle et al., 2017). This approach enhances specificity and potential transfer to competitive performance while providing eccentric overload (Goodwin & Cleather, 2021; Suarez, Wagle, et al., 2019). Research indicates that AEL can improve performance both acutely (potentiation) and chronically. For example, AEL may acutely enhance kinetic and kinematic variables and specific performance in training and sporting tasks (Aboodarda et al., 2013; Beato et al., 2021; Doan et al., 2002; Lloyd et al., 2022; Patus, 2021; Sheppard et al., 2007; Sheppard & Young, 2010). Chronic AEL implementation also shows favorable improvements in these variables (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; De Hoyo et al., 2016; Douglas et al., 2018; Fiorilli et al., 2020; Friedmann-Bette et al., 2010; Munger et al., 2022; O Brien et al., 2020; Sheppard et al., 2008; Tous-Fajardo et al., 2016; Walker et al., 2016). However, there is limited evidence on the chronic effects of AEL using practical and readily available methods that could be effectively employed in a team sport training environment (Harden et al., 2022; Merrigan et al., 2022). Therefore, although AEL appears potentially advantageous for enhancing general sport skills, more research on its chronic use in ecologically valid settings is needed to assist practitioners in designing training programs.

Regardless of the method used, effective resistance training for sport performance is enhanced when logically organized and sequenced into a long-term plan (DeWeese et al., 2015a, 2015b; G. G. Haff, 2004; G. G. Haff et al., 2004). One such effective, and well-studied, method of organizing the training process is block periodization (Carroll et al., 2019; Hartmann et al., 2009; V. B. Issurin, 2014; Painter et al., 2012; M. H. Stone et al., 2021). Within this organizational system, athletes typically spend the majority of the training plan leading up to competition focusing on building the foundation for long-term performance enhancement by employing semi-unidirectional training targeting qualities with the longest training residuals (DeWeese et al., 2015a, 2015b; V. Issurin, 2008; M. H. Stone et al., 1982). This period of training typical employs high volumes of general physical preparation while targeting the specific sport skills that are manifested during competition are often deemphasized (Bompa & Buzzichelli, 2019; DeWeese et al., 2015a, 2015b; V. Issurin, 2008; M. H. Stone et al., 1982, 2021). With respect to block periodization such a period of training often begins with a strength-endurance training phase which attempts to develop special work capacity and possibly favorable adaptations in body composition (DeWeese et al., 2015b, 2015a; M. H. Stone et al., 2021; T.

Suchomel et al., 2017). Recent acute studies comparing AEL and traditional training during a strength-endurance paradigm highlight AEL's potential efficacy (Chae, 2023b, 2023a). Chae et al. (2023a, 2023b) used practical methods, specifically cluster sets with weight releasers, to acutely apply high-volume AEL. They found that AEL provided a greater training stimulus with lower acute stress and similar perceptual responses compared to traditional training. Thus, AEL may be advantageous in general preparatory phases by allowing greater training stimulus accumulation with lower physiological stress.

Currently, no evidence compares the effects of AEL and traditional training on general sport skills during a high-volume phase where these skills are not primarily targeted. Moreover, this has not been examined using the practical and readily available means employed by Chae et al. (2023a, 2023b). This study aimed to examine the effects of traditional training versus AEL with cluster sets during a strength-endurance phase. Comparisons between groups include changes in sprinting, change of direction, and jumping performance. The results should provide practitioners with evidence on the efficacy of AEL in general preparation training for improving general sport skills.

Methods

Experimental Approach to the Problem

Resistance trained, college-aged, individuals were recruited to comparatively examine the effects of AEL resistance training versus traditional resistance training (TRAD), within a strength-endurance block of training, on accelerative sprint, change of direction, and jump performance. A between group repeated measures design was used where subjects were pair matched based on initial strength levels then randomly allocated to one of two resistance training groups, performing either accentuated eccentric loading [AEL] (n = 9) or traditional resistance training [TRAD] (n = 8). This study took place over 7 weeks, including one week of familiarization, one week of pre-testing, four weeks of a resistance training program of either AEL or TRAD training protocols, and one week of post-testing. During the training intervention period of the study, all subjects performed five training sessions each week comprised of three non-consecutive days (M, W, F) of resistance training and two non-consecutive (T, TH) days of sprint, change of direction, and midsection work. The primary difference between the two groups was the load used during the eccentric phase of specific traditional resistance training exercises and the set configuration during these exercises. All other elements of the resistance training program and field-based training were the same between the two groups. Accelerative sprint, change of direction, and jump performance were measured at two time points during the length of the study period, pre-testing (week 2) prior to the training program intervention and post-testing (week 7) after the training program intervention.

Subjects

Eighteen resistance-trained, college-aged, individuals initially volunteered to participate in the current investigation. Following attrition due to missed training sessions (n = 1), a final sample of 17 subjects (mean ± SD; male = 11, female = 6, age = 23.2 ± 4.1 years, body mass = 81.3 ± 22.2 kg, height = 172.1 ± 10.0 cm, relative back squat 1 repetition maximum [1 RM] = 1.5 ± 0.3) completed the entire 7-week study duration. All subjects had at least one year of resistance training experience. Subjects were excluded from the study if they had previous experience with accentuated eccentric loading using weight releasers, missed more than 10% of the total training sessions, missed any testing sessions, or had any training obviating musculoskeletal injuries during the previous six months. Subjects were given an overview of the study procedures and informed of any potential risks or benefits of participation before the study commenced. All subjects read and signed an institutionally approved informed consent document. Study procedures were approved by East Tennessee State University's Institutional Review Board (ETSU IRB ID# 0822.2f).

Procedures

Familiarization. The week prior to the baseline testing session all subjects underwent five days of familiarization for the testing protocols and training conditions. On day 1 subjects were familiarized with the one 1RM testing protocol for the back squat and bench press exercises as per previously established methodology (Wetmore et al., 2020). The next day subjects returned to the laboratory for familiarization with the incrementally loaded countermovement jump (CMJ) testing protocol and 20-meter sprint testing protocol. Following Day 2, barbell displacement for the back squat exercise was determined for each subject. The vertical distance from the end of the barbell to the floor with the subjects descended to a position with the top of the thigh parallel to the ground in the back squat exercise was considered squat displacement. Following determination of squat displacement, subjects were familiarized with the AEL back squat exercise using weight releasers (Rogue, Columbus, Ohio). The next day, subjects returned to the laboratory for familiarization with the 505 change of direction task. On the fifth, and final, day of familiarization barbell displacement for the bench press exercise was determined for each subject. The vertical displacement from the end of the barbell to the floor with barbell in contact with the subject's chest was considered barbell displacement for the bench press exercise. Following determination of bench press displacement, subjects were familiarized with the AEL bench press exercise using weight releasers (Rogue, Columbus, Ohio)

Testing. Subjects underwent two testing sessions, one following the initial week of familiarization with the study protocol (Pre) and one following the 4-week training intervention

(Post). The first day of testing included CMJ testing. Following a day of complete rest, subjects returned to the laboratory for sprint and change of direction testing. For both testing sessions subjects arrived at the laboratory and were initially tested for adequate hydration status via urine specific gravity using a refractometer (Atago CO., LTD, Tokyo, Japan). Following confirmation of adequate hydration status, subjects proceeded with the rest of the days testing protocol.

Countermovement Jump. The incrementally loaded CMJ assessment was performed in accordance with previous literature (Carroll et al., 2019; Wetmore et al., 2020). Following the completion of a standardized warm-up (Kraska et al., 2009), subjects performed a series of CMJs on dual force plates (Rice Lake Weighing Systems, Rice Lake, WI, USA) sampling at 1,000 Hz. CMJ testing was performed in unweighted (<1 kg PVC pipe) and weighted conditions. The only difference in the current testing protocol from the previously cited literature was subjects performed weighted jumps with increasing loads of 10 kg up to 60 kg following the unweighted condition. The use of a PVC pipe or barbell was used to eliminate the use of an arm swing during jumps, in accordance with previous methods (Carroll et al., 2019). Subjects were allowed to descend to a self-selected depth and were instructed to jump as “high and fast as possible”. At each load subjects initially performed two warm-up attempts, one at 50% and one at 75% of perceived maximal intensity, before performing a minimum of two maximal effort attempts. Subjects continued to perform maximal effort attempts at each load until achieving two attempts that were within 2 centimeters of jump height, as calculated by flight time, or when five maximal attempts had been performed. Between all jump trials, subjects were given approximately 30-60 seconds of rest. Jump testing was terminated following the 60 kg loaded jump condition or when the average jump height of the two top trials at a particular load was less than 10 centimeters. If a subject was unable to achieve the 10 centimeters of jump height cut-off value that condition was not included in the analysis. All jump variables were calculated using a custom computer program (LabVIEW, ver. 2010, National Instruments, Austin, TX). The average jump height and peak power from the two unweighted condition trials with the highest jump height were considered for analysis. Previous research form our laboratory has demonstrated excellent (ICC = 0.991) reliability for unweighted jump height and peak power (Wetmore et al., 2020).

20-Meter Sprint Testing. Subjects performed sprint testing on the same lane of the same indoor synthetic track for both testing sessions. Sprint data was recorded using the Microgate Witty Wireless Training Timer (Microgate USA, Mahopac, NY) including one handheld Witty Timer connected to a laptop computer and three photocells with corresponding reflectors and tripod stands, collectively referred to as timing gates. Timing gates were positioned at 0 (55 cm tall), 10 (75 cm tall), and 20 (90 cm tall) meters from the designated starting line. Following a standardized warm up including jogging, dynamic stretching, and submaximal 20-meter sprint efforts at 75, 85, and 95% of self-selected maximal intensity, subjects completed two maximal 20-m sprints separated by approximately 3 minutes of rest (Douglas et al., 2018). Subjects began the test at a designated starting position in a split stance with their preferred front foot positioned 30 centimeters behind the initial timing gate (0 m). Subject were instructed to provide maximal effort and "run through" the final timing gate, rather than beginning to decelerate prior to crossing the final timing gate. Split times (10 and 20) were collected using the timing Witty Wireless Training Timer. Previous research has indicated 10- and 20-meter split times collected using timing gates show high reliability (ICC = 0.87 and 0.96, respectively) (Gabbett et al., 2008).

5-0-5 Change of Direction Task. Immediately following the 20-meter sprint tests, subjects performed change of direction (COD) testing using the 5-0-5 COD test, per established methods

(Sheppard & Young, 2006), on the same lane of the same indoor synthetic track for both testing sessions. COD performance was recorded using the Microgate Witty Wireless Training Timer (Microgate USA, Mahopac, NY) including one handheld Witty Timer connected to a laptop computer and one photocell with corresponding reflector and tripod stands (height = 75cm), collectively referred to as timing gates. A single timing gate was positioned 10 meters from the designated starting line. Subjects began the test using the same starting methodology as the 20-meter sprint testing. Subjects initially performed two submaximal warm up attempts on each leg at 75% and 90% of self-selected maximal intensity. Subjects then performed 4 maximal effort trials, separated by 3 minutes of rest, which included two maximal effort trials where the turnaround line was touched with the right hand and foot then two maximal effort trials where the turnaround line was touched with the left hand and foot. Subjects were instructed to sprint through the timing gates to the turnaround line and touch it with the designated hand then as quickly as possible turn around and sprint back through the starting line. Additionally, subjects were instructed to "run through" the starting line with special attention paid to not begin to decelerate until they have fully passed the timing gates. If subjects failed to touch the turnaround line with the designated hand the trial was not counted for analysis, and they were instructed to complete another trial. The side with the fastest mean time was considered the "preferred" side, while the other side was considered the "non-preferred" side (Nimphius et al., 2016). The average of the fastest trials for the preferred side and non-preferred side was calculated and considered for analysis (505). Previous research has indicated that 505 times collected from timing gates display high reliability (ICC = 0.78 – 0.90) (Gabbett et al., 2008; Nimphius et al., 2016). Finally, as described in previous literature (Nimphius et al., 2016), COD deficit (CODD) was calculated as 505 time minus 10-meter sprint time.

Training Intervention. All subjects completed a combination of resistance training and skill-based track sessions every week. Subjects were pair matched based on initial relative strength levels then randomly allocated to one of two resistance training groups, performing either accentuated eccentric loading [AEL] (n = 9) or traditional resistance training [TRAD] (n = 8). All subjects completed 4 weeks of high-volume resistance training. Subjects performed five training sessions each week for four weeks including resistance, midsection, sprint, and change of direction training. Resistance training sessions were completed three times a week (M, W, F) while skill-based and mid-section training was performed two times a week (T, TR). Subjects were prescribed the same number of exercises, sets and repetitions of each exercise, and rest between exercises and training sessions. For resistance training sessions, the AEL group incorporated eccentrically overloaded repetitions during the 1st, 3rd, 5th, 7th, and 9th repetitions of each set (Figure 1) of the back squat and bench press exercises using weight releasers. AEL group subjects were given 15 seconds of intra-set rest between clusters of repetitions separated by AEL repetitions. All subjects were given 2 minutes of inter-set rest. See Tables 1-4 for an overview of the training intervention and resulting volume loads.

Table 3.1

Resistance Training Protocol

T1						
		TRAD		AEL		
Week	Sets x Reps	Day 1 & 3	Day 5	Day 1	Day 3	Day 5
1	3 x 10	57.5%	50%	110*/57.5%	57.5%	110*/50%
2	3 x 10	62.5%	55%	110*/62.5%	62.5%	110*/ 55%
3	3 x 10	67.5%	57.5%	110*/67.5%	67.5%	110*/57.5%
4	3 x 10	52.5%	45%	110*/52.5%	52.5%	110*/45%
T2						

Intensity = %1RM

AEL = Accentuated Eccentric Loading, TRAD = Traditional Resistance Training

Day 1: Monday, Day 3: Wednesday, Day 5: Friday

** Indicates AEL Repetitions*

Table 3.2

Resistance Training Exercise Selection

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

BS = Back Squat, BP = Bench Press, CG = Clean Grip, MTP = Mid-Thigh Pull, SLDL = Stiff Legged Deadlift, BOR = Bent Over Row, DB = Dumbbell

Day 1: Monday, Day 3: Wednesday, Day 5: Friday

** Indicates exercise performed with AEL repetitions by the AEL group*

Table 3.3

Acceleration, Change of Direction and Midsection Training Overview

Week	Day 2 (Tuesday)	Day 4 (Thursday)
1	BU: 2 x 15m, 2 x 25m ACC: 4 x 4 x 10m Crunches: 3 x 25	BU: 2 x 20m COD: Half to ¾ Speed Linear Decels – 1 x 4 x 5m Lateral Decels – 1 x 4 x 5m Accel to Sidestep Cut (45° - exit 5m to decel) 1 x 4 x 5m Accel to Turn (135° - exit 5m to decel) 1 x 4 x 5m
2	BU: 2 x 15m, 2 x 25m ACC: 4 x 4 x 15m Crunches: 4 x 25	BU: 2 x 20m COD: ¾ + Speed Linear Decels – 1 x 4 x 5m Lateral Decels – 1 x 4 x 5m Accel to Sidestep Cut (45° - exit 5m to decel) 1 x 6 x 5m Accel to Turn (180° - exit 5m to decel) 1 x 6 x 5m
3	BU: 2 x 15m, 2 x 25m ACC: 4 x 4 x 20m Crunches: 4 x 25	BU: 2 x 20m COD: Full Speed Linear Decels – 1 x 4 x 5m Lateral Decels – 1 x 4 x 5m Accel to Sidestep Cut (45° - exit 5m to decel) 1 x 6 x 5m Accel to Turn (180° - exit 5m to decel) 1 x 6 x 5m
4	BU: 2 x 15m, 2 x 25m ACC: 4 x 2 x 20m Crunches: 2 x 25	BU: 2 x 20m COD: ¾ + Speed Linear Decels – 1 x 4 x 5m Lateral Decels – 1 x 4 x 5m Accel to Sidestep Cut (45° - exit 5m to decel) 1 x 4 x 5m Accel to Turn (180° - exit 5m to decel) 1 x 4 x 5m

BU = Build Ups, ACC – Acceleration, COD = Change of Direction, Decel = Deceleration

Table 3.4

Volume Loads (Back Squat + Bench Press)

Group	VL_d/Body Mass	VL_d/ Relative Strength
AEL	408.54 ± 79.96	12,102 ± 3679
TRAD	341.93 ± 104.18	11,572 ± 4133

VL_d = Volume load displacement (total reps x kg x barbell displacement in meters)

VL_d/Relative Strength = VL_d/(Relative Back Squat 1RM + Relative Bench Press 1RM)

Statistical Analyses

All statistical analyses were performed using R, an open-source statistics software (Version 4.3.2; R Core Team, Vienna, Austria). Descriptive statistics using means and standard deviation were calculated. Multiple 2x2 (group x time) mixed-model analysis of variance (ANOVA) were conducted to determine statistically significant differences between pre and posttest values. Data were initially screened for independence of error, normal distribution of residuals, and homoscedasticity. Alpha level was set at $p \leq 0.05$. Within-group effect sizes along with 95% confidence intervals were calculated for pre and post measures using Hedge's *g* to assess practical significance. Effect size magnitudes were interpreted using the following scale: 0.0 – 0.2 (trivial); 0.2 – 0.6 (small); 0.6 – 1.2 (moderate); 1.2 – 2.0 (large); 2.0 – 4.0 (very large); 4.0 - ∞ (nearly perfect) (Hopkins et al., 2009). If the 95% confidence interval incorporated both positive and negative effects the within-group change was deemed unclear (Batterham & Hopkins, 2006; Hopkins et al., 2009). Descriptive statistics using mean, standard deviation, and confidence interval limits can be found in Table 5.

Table 3.5

Descriptive Statistics using mean ± SD (Upper and Lower Limit of 95% CI)

	AEL		TRAD	
	Pre-Testing	Post-Testing	Pre-Testing	Post-Testing
20-m Sprint				
10 m (s)	1.932 ± 0.117 (1.834 - 2.031)	1.972 ± 0.172 (1.873 - 2.071)	1.919 ± 0.138 (1.820 - 2.018)	1.909 ± 0.111 (1.810 - 2.008)
20 m (s)	3.355 ± 0.210 (3.197 - 3.512)	3.362 ± 0.255 (3.204 - 3.52)	3.316 ± 0.246 (3.158 - 3.475)	3.283 ± 0.178 (3.124 - 3.441)
505 COD Task				
505 (s)*	2.620 ± 0.183 (2.507 - 2.732)	2.535 ± 0.148 (2.423 - 2.648)	2.575 ± 0.162 (2.463 - 2.688)	2.531 ± 0.116 (2.419 - 2.644)
CODD (s)*	0.692 ± 0.112 (0.625 - 0.760)	0.572 ± 0.109 (0.505 - 0.639)	0.651 ± 0.087 (0.583 - 0.72)	0.613 ± 0.065 (0.545 - 0.682)
Countermovement Jump				
Jump Height (cm)	28.51 ± 8.18 (23.48 - 33.54)	29.14 ± 5.95 (24.11 - 34.17)	32.39 ± 6.74 (27.36 - 37.42)	33.17 ± 5.99 (28.14 - 38.2)
Peak Power (W)	3742 ± 872 (3157 - 4327)	3626 ± 799 (3040 - 4211)	4523 ± 1419 (3938 - 5109)	4626 ± 1547 (4040 - 5212)

** Indicates statistically significant main effect of time ($p \leq 0.05$)*

Results

20-Meter Sprint

ANOVA revealed no statistically significant effects for either of the sprint variables analyzed ($p > 0.05$). Both groups demonstrated trivial effect sizes for within-group changes in 20-meter sprint time compared to pre-intervention testing, although with differing directionality of the effect (Table 5). However, the opposite effect was observed for 10-meter sprint time.

Compared to baseline the AEL group demonstrated a small reduction in 10-meter sprint performance, while the TRAD group again demonstrated a trivial positive effect (Table 6).

505 Change of Direction

ANOVA revealed a statistically significant main effect of time for both 505 ($p < 0.01$) and CODD ($p < 0.01$). The significant main effect came from an improvement in both 505 ($\Delta = -0.064$) and CODD ($\Delta = -0.079$) from pre to post testing. No other statistically significant main effects or interaction effects were observed ($p > 0.05$). Within-group effect sizes demonstrated a moderate effect of the training intervention on the AEL group for both 505 and CODD (Table 6) with 95% confidence intervals that were compatible with values greater than a small effect. On the contrary, the TRAD group demonstrated only small improvements in both 505 and CODD following the intervention (Table 5) with 95% confidence intervals that were not compatible with at least a small effect.

CMJ

ANOVA revealed no statistically significant effects for jump height ($p > 0.05$). However, ANOVA revealed a statistically significant main effect of group for peak power ($p < 0.001$). Within-group effect sizes demonstrated similar non-significant improvements in jump height for both groups (Table 5). Following the training intervention, the AEL group demonstrated a small reduction in peak power, while the TRAD group demonstrated a small improvement (Table 6).

Table 3.6

Within Group Effect Size (95% CI)

	AEL	TRAD
20-m Sprint		
10 m (s)	0.34 (-0.21 - 0.88)	-0.08 (-0.61 - 0.45)
20 m (s)	0.04 (-0.49 - 0.57)	-0.19 (-0.72 - 0.35)
505 COD Task		
505 (s)*	-0.90 (-1.48 - -0.3)	-0.45 (-0.96 - 0.08)
CODD (s)*	-0.87 (-1.44 - -0.28)	-0.26 (-0.76 - 0.25)
Countermovement Jump		
Jump Height (cm)	0.19 (-0.35 - 0.72)	0.22 (-0.32 - 0.76)
Peak Power (W)	-0.30 (-0.84 - 0.25)	0.26 (-0.29 - 0.79)

** Indicates statistically significant main effect of time ($p \leq 0.05$)*

Discussion

The purpose of this investigation was to comparatively examine the effects of AEL resistance training with cluster sets to traditional resistance training (TRAD) on accelerative sprint, change of direction (COD), and jump performance during an accumulation-style training block. To the authors' knowledge, this is the first study to examine AEL using practical and accessible methods versus traditional resistance training on general sport skills in a typical general preparatory training block for athletes. The main findings of the current investigation are a strength-endurance fitness block of training typical of an Accumulation Block (general preparatory phase) for athletes 1) improves COD performance using AEL or traditional resistance training, though AEL may offer slight advantages, 2) shows no substantial positive or negative differences in sprint or jump performance outcomes between AEL and traditional training although the directionality of the effect differed between groups, and 3) doesn't meaningfully impact sprint or jump performance when performed using AEL or traditional training.

Previous research on chronic eccentric overload training suggests it may yield better improvements in general sport skills compared to traditional training (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; De Hoyo et al., 2016; Douglas et al., 2018; Fiorilli et al., 2020; Friedmann-Bette et al., 2010; N. Munger et al., 2022; O Brien et al., 2020; J. Sheppard et al., 2008; Tous-Fajardo et al., 2016). However, much of this research did not use practical methods, did not quantify the eccentric load, or employed mechanically "augmented" rather than "accentuated" eccentric loading (Harden et al., 2022; Merrigan et al., 2022; T. J. Suchomel et al., 2019a; Wagle et al., 2017). For instance, previous studies often used flywheel-inertial training, which is impractical in team sport settings and incapable of applying consistent quantifiable eccentric loads (Suchomel et al., 2019a). Other studies used impractical methods (Friedmann-Bette et al., 2010), or did not employ eccentric loads exceeding maximal concentric abilities (Bridgeman et al., 2020; J. Sheppard et al., 2008). Thus, direct comparisons with this investigation are challenging. This discussion primarily focused on studies examining AEL using practical methods compared to more traditional training (Harden et al., 2022; Merrigan et al., 2022; Wagle et al., 2017).

The results of the current investigation suggest that COD performance can improve after a strength-endurance block with either AEL or traditional training in moderately trained subjects. Although no interaction effect was observed, the 95% confidence interval for the magnitude of the training effect on COD performance in AEL group only was compatible with values greater than a small effect (Batterham & Hopkins, 2006; Buchheit, 2016; Rhea, 2004). Along with a larger magnitude of effect, these data suggest a possibly greater training effect for the AEL group. These findings agree with those of previous studies using similar methodology on the dynamics of COD performance. For example, rugby athletes showed improved agility performance after 6 weeks of AEL or traditional training combined with plyometric training (Chakshuraksha & Apanukul, 2021). The authors of this study also observed a significant group by time effect, demonstrating a superior improvement in agility performance for the AEL group compared to traditional training Similarly, a case study on rugby athletes observed a trend favoring AEL for COD performance, although without robust statistical analysis (Bridgeman et al., 2020). Eccentric strength is crucial for COD performance (Chaabene et al., 2018), and previous research shows significant correlations between eccentric strength and COD performance (Jones et al., 2009; Spiteri et al., 2014). AEL may improve eccentric strength more effectively than traditional training (Hortobagyi et al., 2001; N. Munger et al., 2022), possibly explaining the larger magnitude of improvement in COD performance for the AEL group . While not tested in the current investigation, it is possible both groups improved eccentric strength leading to improvements in COD performance following the intervention.

The results of the current investigation indicate no statistically significant between group differences following the intervention in sprint or jump performance, supporting previous literature (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; N. Munger et al., 2022). While no interaction effect existed, the current investigation demonstrates AEL and traditional training when incorporated into a strength-endurance block may have differing directionality of effects on jump performance and power output. A slightly favorable improvement was noted when using traditional training compared to AEL. This finding supports the work of Douglas et al. (2018) who demonstrated a larger between-group effect favoring traditional training for both jump height and peak power following 4 and 8 weeks of training, respectively. Although previous research indicated 5 weeks of AEL training was more effective than traditional training for improving jump height and power output (Sheppard et al., 2008), the results of the current investigation do not support this contention. This is most likely explained by specificity of both training (high-volume) and the task tested. The only difference between the AEL and traditional group for the Sheppard et al. (2008) study was additional eccentric loading on CMJs during training compared to using bodyweight, the exact exercise task that was tested before and after the intervention. Furthermore, the exercise selection of both groups was heavily targeted at improving explosive performance whereas the current investigation employed AEL into more general training typical of an accumulation stage. Finally, the application of AEL by Sheppard and colleagues (2008) can be considered "augmented", or submaximal, eccentric loading as opposed to "accentuated", or supramaximal, eccentric loading which employs eccentric loads in excess of the maximal concentric load that could be achieved (Harden et al., 2022; Wagle et al., 2017). It has been previously noted that submaximal eccentric loading is generally more effective at improving explosive performance (Wagle et al., 2017). It is likely that a combination of high-volume Accumulation phase training, supramaximal eccentric loads, and the requirement of a transfer of training effect to a non-trained sporting task explains why the current investigation failed to replicate the results of Sheppard et al. (2008).

Along with no between-group differences in sprint, jump, or power performance the current investigation also suggests no observable changes in these metrics when using AEL or traditional training following 4 weeks of strength-endurance training. This is supported by the work of Douglas et al. (2018) who observed equally trivial changes in sprint, jump, and power performance for both AEL and traditional groups following 4 weeks of training. Furthermore, previous evidence suggests that improved sprint performance might be delayed multiple weeks following an accumulation block of training (Moir et al., 2007), indicating potential enhanced residual effects (M. H. Stone et al., 2021). However, evidence exists that both AEL and traditional training are equally effective at improving sprint, jump and power performance (Chakshuraksha & Apanukul, 2021; N. Munger et al., 2022). For example, when averaged over multiple splits, Munger et al. (2022) found a significant improvement in mean 20-meter sprint performance following 5 weeks of either AEL or traditional training. Likewise, the authors also noted significant improvements in jump height for both AEL and traditional training. Similarly, Chakshuraksha & Apanukul (2021) also found a significant improvement in 40-meter sprint performance following 6 weeks of either AEL or traditional training. These authors also observed AEL and traditional training to be equally effective at improving power output during jumping tasks. The results of the current investigation failed to replicate these results. There are a few possible explanations for the discrepancies between the sprint, jump, and power performance observed in the current study and those of the previous studies. First the total volume load of the previous studies was substantially lower than that of the current investigation. Although attempts were made in the current investigation to mitigate the deleterious effects of fatigue using heavy and light days and an unload week, it is common to observe short-term reductions in performance of sport specific qualities following high training volumes (M. H. Stone et al., 2019; Verkhoshanksy, 1988; Verkhoshansky & Siff, 2009). For example, substantial reduction in explosive strength (rate of force development) and vertical jump variables have been observed following volumes of training typical of a strength-endurance phase during an accumulation block (Hornsby et al., 2017; Stone et al., 2019; Suarez et al., 2019). In fact, sprint performance is likely limited by the ability to produce high rates of force development over limited contact periods (Weyand et al., 2010). It is possible that improvements in sprint performance were masked by the accumulated fatigue resultant of high training volumes in the current investigation. Likewise, the development of explosive strength (RFD) and sport associated variables impacted by RFD such as jump height and sprint performance are likely better targeted using explosive and ballistic exercises (Cormie et al., 2011; G. G. Haff & Nimphius, 2012). The current investigation employed no direct power or explosive training outside of the sprinting done twice per week. However, previous studies finding a main effect of time for improvements in sprint performance following AEL or traditional training devoted the majority of their training volume towards ballistic training (Chakshuraksha & Apanukul, 2021). These differences also likely explain why the current investigation failed to substantially improve jump performance or power output for either group. For example, Munger et al. (2022) only had subjects train twice a week, included no additional training typical of athletes, and accumulated much less total volume load each session. Despite substantially lower volume, the loads employed consisted of lower average concentric intensities compared to the current investigation. Lower concentric training intensities can be more effective at improving unloaded jump performance in the short term (McBride et al., 2002; Swinton et al., 2023). It is likely an interplay of lower total volume for the traditional group and lower concentric intensities for the AEL group worked in tandem to produce a main effect for improvements in jump performance that were not replicated by the current investigation. Additionally, alterations in 1 RM squat (McDowell, 2024), while increasing somewhat in both groups were not markedly different between groups. Thus, it is doubtful that alterations in 1RM squat strength impacted these results.

In summary, the impact of AEL using cluster sets was compared to traditional resistance training on athletic performance during a preparatory phase, focusing on accelerative sprint, COD, and jump performance. A strength-endurance block of training successfully improves COD performance using either AEL or traditional training, but these improvements might favor AEL. However, no statistically significant difference in sprint or jump performance were observed when using either AEL or traditional training. Previous research suggested AEL might be superior, particularly with generally impractical methods like flywheel-inertial training, but this study employed more accessible means, making direct comparisons to existing literature difficult. Although no statistically significant interaction was noted, the potential for a greater training effect from AEL on COD is supported by literature. The lack of a meaningful difference in sprint and jump outcomes also echoes existing studies. Discrepancies with prior findings that showed benefits from AEL may be due to variations in training volume, specificity, and general training intervention methodology. Overall, the current investigation indicates that while AEL could offer marginal benefits in COD, both AEL and traditional methods do not substantially differ in their effects on sprint, jump, and power output after a strength-endurance phase of training.

Practical Applications

Evidence exists that that AEL may produce more favorable adaptations in change of direction, sprint, and jump performance when applied both acutely (Aboodarda et al., 2013; Beato, Madruga-Parera, et al., 2021; Doan et al., 2002; Lloyd et al., 2022; Patus, 2021; J. Sheppard et al., 2007; J. M. Sheppard & Young, 2010) and chronically (Bridgeman et al., 2020; Chakshuraksha & Apanukul, 2021; De Hoyo et al., 2016; Douglas et al., 2018; Fiorilli et al., 2020; Friedmann-Bette et al., 2010; N. Munger et al., 2022; O Brien et al., 2020; J. Sheppard et al., 2008; Tous-Fajardo et al., 2016) compared to traditional training. Yet, limited research has been carried out on the chronic application of AEL compared to traditional training on these performance metrics during training typical of an athlete. The findings of the current investigation suggest AEL is generally not more effective than traditional training at improving general sport skills during an accumulation-style block of training. AEL with cluster sets can be integrated into strength-endurance blocks to potentially enhance COD abilities. Given that COD is critical in many sports, coaches could consider AEL to possibly achieve marginal gains over traditional methods. This could be beneficial when athletes are in the preparatory phase of training, aiming to establish a foundation for more specialized skills such as agility (G. Haff & Triplett, 2021). However, given the logistical concerns of employing AEL on a team sport training scale, practitioners may consider more practical means of improving eccentric ability required during change of direction tasks by specifically targeting deceleration abilities (Lockie et al., 2014). When considering the programming of training to improve these abilities coaches should note that AEL's impact may be more pronounced when applied to the specific exercise task being tested (Bridgeman et al., 2020; De Hoyo et al., 2016; J. Sheppard et al., 2008; Tous-Fajardo et al., 2016) and when incorporated into phases of training typical of improving power or strength performance (Chakshuraksha & Apanukul, 2021; Munger et al., 2017; J. Sheppard et al., 2008). Finally, if practitioners choose to employ AEL careful attention should be paid to managing acute fatigue and the expected time-course of a supercompensatory response in performance. It has been noted elsewhere that neuromuscular performance recovery following eccentric training likely requires more time than traditional training, possibly up to 8 weeks (Douglas et al., 2017a, 2018). Coaches should therefore appropriately plan for a possible transient reduction in sport specific skills following high volumes of AEL. In conclusion, AEL employed during a strength-endurance block may provide possible specific benefits in COD performance but is not a preferrable training method to improve sprint or jump performance compared to traditional training methods.

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Chapter 4. Summary and Directions of Future Research

The current study was an examination of the effects of four weeks of Accentuated Eccentric Loading (AEL) and cluster sets (CS) during a strength-endurance (SE) phase on general sport skills performance. The results provide practitioners with evidence for the dynamics of general sport skills performance following this training methodology. The findings indicated that AEL did not yield superior enhancements in general sport skills performance compared to traditional training. Specifically, both training groups improved change of direction (COD) performance, with no significant changes observed in sprinting or jump variables.

The lack of improvement in sprint and jump performance can be attributed to the high training volumes, which likely negatively impacted rate of force development. This phenomenon aligns with previous research suggesting that high training volumes can hinder explosive performance (Suarez, Mizuguchi, et al., 2019) and that sprint performance can be difficult to enhance through traditional resistance training alone (Swinton et al., 2023). Moreover, the use of a 110% 1RM eccentric load in AEL might have been excessive for improving general sport skills, as submaximal AEL has been shown to be more effective in enhancing explosive performance (Bridgeman et al., 2020; Douglas et al., 2018; J. Sheppard et al., 2008; Wagle et al., 2017).

The observed improvements in COD performance can be linked to the necessity for both absolute eccentric and concentric strength (Chaabene et al., 2018), which may have been enhanced during the training intervention. Additionally, a potential learning effect from concurrent COD training could have contributed to these improvements. Previous research supports that enhancements in general sport skills following AEL are often accompanied by increases in lower body absolute force production capabilities (Chakshuraksha & Apanukul, 2021; Douglas et al., 2018; McDowell, 2024; Munger et al., 2022).

The study also demonstrated that AEL successfully achieved greater volume loads. Volume is the most modifiable factor in training, with significant evidence-based impacts on performance (Figueiredo et al., 2018). AEL, as an advanced methodology, provides a viable means to increase training volume without compromising training density or time allocation. This is particularly beneficial in scenarios where athletes must balance multiple fitness components within limited training periods. The ability to handle greater volumes while still improving COD performance suggests that AEL could support further improvements in more sport-specific skills, such as agility, later in the training process if integrated into a well-organized training program (G. Haff & Triplett, 2021; M. H. Stone et al., 2021). Importantly, AEL allowed for greater training volumes without detrimental effects on sport skills performance. Maintaining sport skills performance is crucial, especially in team sports, where athletes cannot afford prolonged reductions in these skills due to time constraints and competitive demands.

Future research should focus on determining the optimal loading strategies for enhancing general sport skills when incorporating AEL into traditional resistance training programs. Investigations should aim to identify the most effective eccentric loads and methods to balance training volume and intensity. Additionally, research should explore the logical sequencing of AEL across different training phases with varying goals within a periodized training plan. Longer-duration studies, extending beyond the four-week period used in this study, are necessary to fully understand the long-term effects of AEL. Notably, specific improvements in general sport skills following high-volume or AEL training may require more than 4 weeks to manifest

(Douglas et al., 2018; Moir et al., 2007). For instance, examining the transition from strength endurance to basic strength to power phases, with different exercises and loading methods, could provide valuable insights. Consistent application of typical athletic training volumes and loading strategies will enhance the comparability of future studies and contribute to a more robust understanding of AEL's efficacy. Overall, future research should strive to develop comprehensive guidelines for AEL implementation, ensuring that it effectively supports sport-specific performance enhancements while considering practical application in diverse athletic settings.

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