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The Effects of Accentuated Eccentric Loading on Barbell and Trap Bar Loaded Countermovement Jumps

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ABSTRACT

This study examined effects of accentuated eccentric loading (AEL) on barbell and trap bar loaded countermovement jumps (LCMJ). Twenty-one subjects (16 male, 5 female; Age: 23.5 ± 1.8 years; Body mass: 81.4 ± 10.6 kg; Height: 176.9 ± 7.2 cm; Training age: 7.1 ± 2.6 years) participated in this study. Upon establishing one repetition maximum and baseline jumping conditions, three experimental loading sessions were completed in random order. Barbell and trap bar LCMJ were performed with a spectrum of fixed loads from 20-50 kg during control conditions and with additional AEL loads of 10, 20, or 30 kg for experimental conditions. According to coefficients of variation (<10%), jump height, modified reactive strength index (mRSI), force, impulse, and duration measures were considered reliable across conditions. Mixed effect models analyzed effects of AEL against fixed loading in trap bar and barbell LCMJ ($p < 0.05$). Compared to the control condition, AEL produced negligible reductions in jump height during barbell LCMJ and small reductions during trap bar LCMJ. Modified reactive strength indexes were reduced by AEL during barbell LCMJ but not trap bar LCMJ. Average braking forces were greater in AEL conditions, while propulsive impulse was lower in the AEL conditions. The barbell LCMJ with AEL resulted in longer propulsive durations and unchanged braking durations, while propulsive and braking durations were lower during trap bar LCMJ with AEL compared to control conditions. This investigation revealed that use of AEL increases eccentric braking forces but decreases propulsive phase outputs, which subsequently may result in negligible to small acute decreases in LCMJ height. Implementing AEL during LCMJ may be an effective strategy to improve deceleration / eccentric abilities. Future research should explore longitudinal power and deceleration adaptations, while concomitantly improving acutely altered movement mechanics from AEL.

Keywords: Weight Releasers; Strength Training; Plyometrics

INTRODUCTION

Maximal power, strength, and speed of eccentric and concentric actions are key physical abilities sought after in competitive sports as these characteristics underpin sport specific actions such as decelerating, change of direction, and jumping ability.[1,2] Previous research has demonstrated that maximal power output may discriminate between athletes of different levels as well as starters and non-starters on the same team.[3] Therefore, in some sports, developing key performance indicators such as maximal power output and eccentric / horizontal decelerating ability are crucial for an athlete's success.[1,2,4] Multiple methods exist for developing muscular power outputs such as strength training, weightlifting movements, plyometrics, and sprinting. To develop eccentric and horizontal deceleration abilities, some have suggested improving braking force control and enhanced technical ability to apply braking forces (e.g., developing rapid deceleration force capabilities).[4,5] As athletes develop throughout their career, new and varied methods must be employed to drive neuromuscular adaptations and elicit concomitant improvements in muscular power and eccentric braking capabilities (e.g., stable and rapid decelerations).

One emerging method for developing muscular power, strength, hypertrophy, and eccentric control is the use of accentuated eccentric loading (AEL).[6–19] The AEL method involves applying more weight during the eccentric (or braking subphase) portion of the movement compared to the concentric (or propulsive) portion while attempting to elicit little to no disruptions in natural movement mechanics.[11,18] Due to most training methods using a concentric focused exercise prescription, the use of AEL may enable greater recruitment of motor units during the eccentric phase and subsequently potentiate concentric performances.[11,18,20] Specifically, heavy (i.e., eccentric overloading or AEL) and/or fast (i.e., greater velocities or shorter durations of < 2 seconds) eccentrics may improve maximal power output, horizontal deceleration, landing from jumps, and stretch-shortening cycle abilities which are important for many sport performances and injury risk.[4,5,11] To date, researchers have demonstrated benefits of AEL for the development of concentric strength, eccentric strength, muscle architecture, and rapid force production,[11,18] but more research is warranted due to the many confounding factors that influence the efficacy of AEL such as the movement type, loading patterns, and prior training history.

Previous investigations have shown benefits of AEL for acute strength and power development, but have primarily investigated common strength training exercises such as the back squat and bench press.[11–13,17,18] However, many coaches use AEL in conjunction with vertical jumping exercises to concomitantly build eccentric capabilities and help develop maximal muscular power.[9,11,19] Previous studies have employed AEL by having subjects hold then release dumbbells or resistance bands after completing the eccentric phase to improve jumping ability.[7–9,16,21] For example, AEL with 20kg dumbbells improved jump height (4.3%), power (9.4%), velocity (3.1%), and force (3.9%) of countermovement and block jumps of trained volleyball players compared to jumps without AEL.[16] In professional football players, AEL with 20% and 40% of body mass did not influence countermovement jump height or velocity, but did improve peak power likely as a result of the additional forces from the AEL.[7] Others have employed AEL with 20 or 30% of the subject's body mass via elastic bands and found improved propulsion ground reaction forces, power output, net impulse and jump height in the countermovement jump but not the depth jump.[21,22] Evidence has been presented that AEL incorporating dumbbells and elastic bands can improve jumping performance as long as the jump type and load employed is appropriate.[16,21–23] Collectively, the evidence has suggested that AEL with external loads ranging from 10–30% of body mass can improve performances, but this may be dependent on the combination of jump type, loads employed, and training experience. For example, the results from AEL with resistance bands may be influenced by the changes in band tension which is greatest at the top and decreases throughout the eccentric phase before the bands are released.[11,24] Thus, resistance banded AEL can be difficult to compare across exercises with varied movement lengths (i.e., drop jump v. countermovement jump) and to fixed loading strategies (i.e., dumbbell or barbell). Since research of AEL during jumping tasks is limited,[11] and in support of recent literature review conclusions,[9] continued research is warranted to investigate employing AEL with increased eccentric and concentric loads during jumping-based movements.

Currently, with increased research on AEL, coaches are using various jump types with barbells and trap bars in conjunction with AEL to drive performance in training without established training prescription guidelines or supporting evidence. Thus, it is important to begin scientific investigation on AEL during loaded jumping tasks via barbell or trap bar which will help inform coaches. Since the drop or depth jump is already a high intensity plyometric exercise and squat jump does not involve an eccentric phase, the loaded countermovement vertical jump (LCMJ) should be explored. The LCMJ has also shown to improve neuromuscular performance capabilities including strength and power,[25] which may be exacerbated with AEL. Furthermore, no studies have examined weights greater than 30% of bodyweight to implement AEL during jumping exercises. Therefore, the purpose of this study is to determine the efficacy of various AEL concentric and eccentric loading schemes during barbell and trap bar LCMJ. Specifically, various AEL combinations will be used in conjunction with several fixed barbell and trap bar loads to examine their interactions. We hypothesize the AEL will increase eccentric braking impulse and force with unchanged braking durations while subsequently increasing jump height during barbell and trap bar LCMJ. We further hypothesize that the barbell and trap bar LCMJ will respond similarly to AEL, but that AEL efficacy will be dependent on a combination of weight used on the barbell or trap bar and AEL weight releasers.

METHODS

Experimental Approach to the Problem

A randomized counterbalanced within-subject design was employed to examine the effects of AEL on barbell and trap bar LCMJ. Subjects reported to the laboratory for five separate testing sessions consisting of a baseline maximal strength session, a baseline control (no-AEL) session, and three randomly assigned experimental loading sessions (AEL with 10, 20, and 30 kg). Each session occurred five to seven days apart at the same time of the day under the same ambient conditions (22°C). Subject were required to have not trained a minimum of 48 hours before each testing session to prevent the potential influence of fatigue on the experimental session performances.

Subjects

Twenty-one subjects volunteered for this study. Detailed demographics can be found in Table 1. All subjects regularly engaged in resistance training, were between 18 and 35 years of age, and were familiar with the back squat, trap bar deadlift, and countermovement jumps. Subjects were excluded if they had sustained a lower extremity injury within the past three months that prevented them from completing lower body resistance training or had any history of major medical conditions including metabolic or cardiovascular disease, endocrine, thermoregulatory disorders, or musculoskeletal conditions that could compromise testing. This study was approved by the University's institutional review board (IRB# 220106A) and complied with the Declaration of Helsinki. Written informed consent was obtained prior to the start of the study.

Procedures

Subjects reported to the laboratory for a total of five sessions and detailed breakdown of full protocol can be found in Figure 1. Upon entering the laboratory, subjects filled out informed consent documentation, provided basic demographic information (height, weight, age, and training age), and were given time to ask questions regarding the protocol. The first session was to determine the back squat one repetition maximum (1RM) and to familiarize the subjects with the weight releasers used for the AEL procedures. Seven days following this session, subjects completed baseline testing of LCMJ with fixed barbell and trap bar loads of 20, 30, 40, 50kg. The following three experimental sessions occurred, in random order, on separate days with a minimum of five days of rest between sessions. Then, subjects completed the same fixed barbell and trap bar LCMJ with AEL via weight releasers at additional loads of 10, 20, or 30 kg, respectively. For each testing session barbell CMJ were performed before trap bar CMJ.

One Repetition Maximum and Familiarization

Prior to completing the 1RM protocol, each subject completed a standardized warm up of 20 jumping jacks, 10 body weight squats, 5 body weight lunges on each leg, and one set of 10 repetitions of a back squat with an empty barbell. Next, each subject completed 5 repetitions at 50%, 3 repetitions at 70%, 2 repetitions at 80%, and then one repetition at 90% of their initial self-reported 1RM. Subjects were then given 3-5 maximal attempts at the back-squat until a true max was obtained. Subjects were given two minutes of passive rest at all attempts up to 90% and then 3-5 minutes of passive rest was given between maximum trials.[12] All repetitions occurred in a power rack with spotters. Trained testers determined depth with the hip crease descending below the knee for consideration of a full back squat repetition. The 1RM protocol was only tested for the back squat to

Table 1. Subject demographic data.

Subject	N	Age (years)	Mass (kg)	Height (cm)	1RM (kg)	Relative 1RM (kg/kg)	Training Age (years)
Male	16	23.6 ± 2.2	81.4 ± 10.6	176.9 ± 7.2	145.4 ± 26.2	1.7 ± 0.2	7.1 ± 2.6
Female	5	23.5 ± 0.8	65.8 ± 6.3	162.5 ± 5.9	87.5 ± 4.9	1.3 ± 0.1	3.5 ± 3.2
Total	21	23.5 ± 1.8	77.8 ± 11.5	173.2 ± 9.1	133.4 ± 35.2	1.7 ± 0.3	6.4 ± 3.2

Note: All values mean ± standard deviation; 1RM= one repetition maximum Back Squat; Relative 1RM= Back Squat 1RM to body mass ratio; N=sample size; kg=kilogram; cm=centimeter

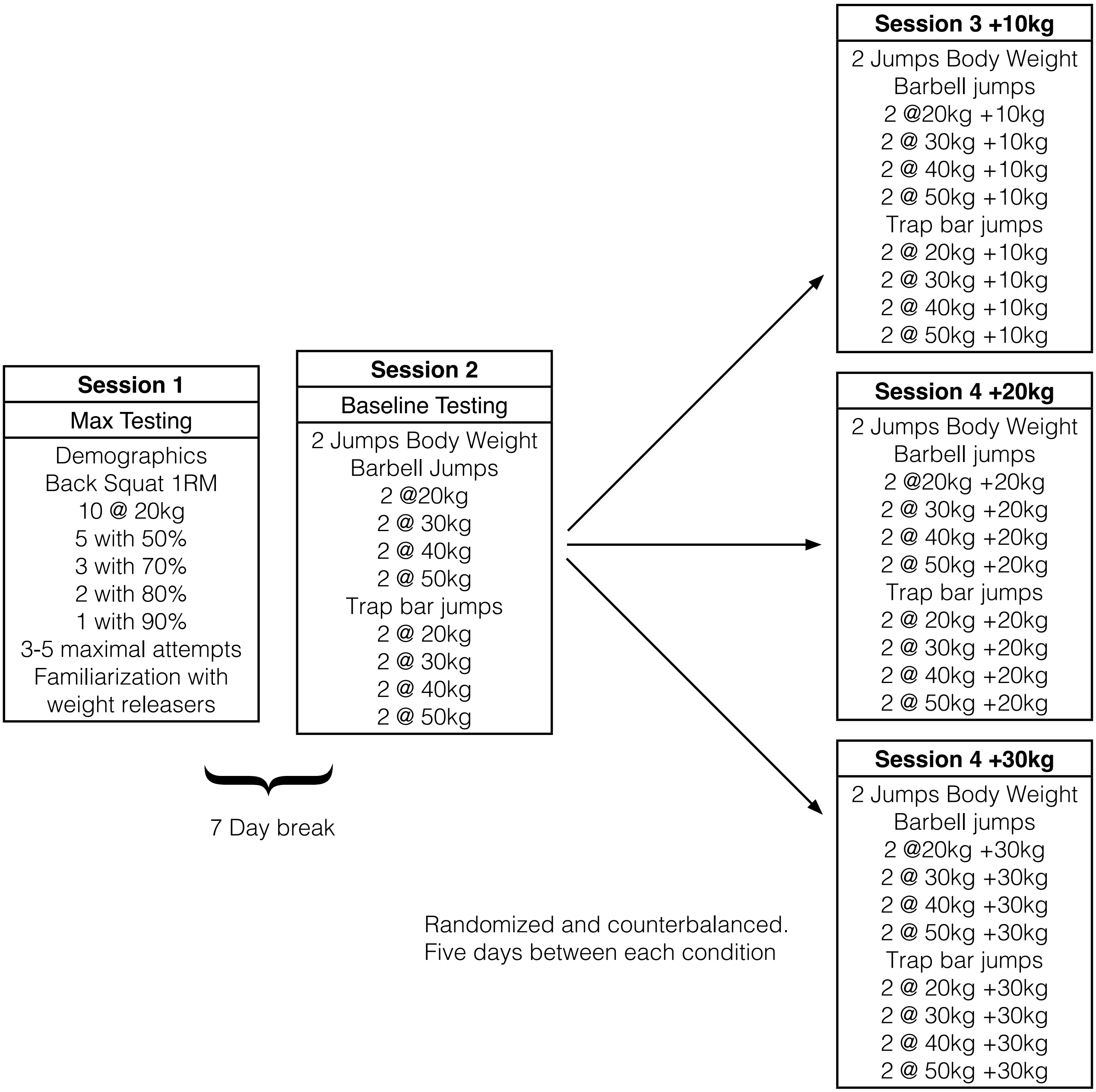

Figure 1. Study protocols for Session 1 (one repetition maximum back squat testing and weight releaser familiarization), Session 2 (baseline testing for control condition with fixed bar loads), Session 3-5 (accentuated eccentric loading, AEL, conditions with 10, 20 and 30 kg in random order).

describe the current cohort's lower body strength levels for future investigations.

Following these procedures, the subjects were familiarized with how to jump with the weight releasers used for AEL conditions. Up to five practice attempts were given for the LCMJ with both the barbell and the trap bar. Following the familiarization session, the order of experimental conditions to be performed by the subjects were randomized to reduce training effects. The load was 20 kg for each bar (barbell, Pendlay Nexgen, USA; trap bar, Hulk Fit, USA) used throughout the duration of this study.

Baseline Testing Session

Seven days after the 1RM testing was conducted, subjects reported back to the laboratory to conduct the baseline session. Subjects completed the same general warm up prior to testing. After the general warm up, a specific warm up consisting of two bodyweight vertical jumps, one at 50% of subjects perceived max effort and one at 75% of the subjects perceived max effort, was instructed. After a rest period of two minutes, two body weight countermovement jumps were performed on the force plates, with one minute of passive rest between jumps. For those countermovement jumps, subjects held a PVC pipe on their shoulders in the back-squat position. Subjects were instructed to "jump as high as possible." Two minutes after the last baseline test, the experimental protocol occurred. Subjects completed 2 vertical jumps starting at 20kg, 30kg, 40kg, and 50kg for both the barbell and trap bar LCMJ. A 45 second rest was provided between the first and second LCMJ of the same weight and a 2-minute rest was provided between weight changes for both barbell and trap bar LCMJ. An average of the two LCMJ was used for analysis.

Experimental Loading Sessions

The next three sessions were separated by five days each and followed the same baseline LCMJ procedures, but with the addition of AEL via weight releasers to add more weight on the eccentric portion while preserving the same weight on the concentric portion. Elevated platforms were utilized if the weight releasers were not long enough to properly hit the floor and fall off the barbell at the bottom of the countermovement decent. Platforms were adjusted during barbell jump trials for each subject based on their squat depth at the bottom of their countermovement jump, to allow the weight releasers to release at a countermovement squat depth rather than a deep squat depth. The riser alone was four inches, with additional platforms used to add an extra two inches as needed. The weight releases were also adjusted individually for the trap bar to ensure the weight releasers disengaged at each subject's countermovement squat depth. The subjects randomly completed three additional load sessions with either +10kg, +20kg, or +30kg on the weight releasers. Subjects were instructed to step back, allow the weight releasers to become motionless, then begin the jumping action. The additional weight was added to the fixed load in ascending order. The weight releasers used were custom welded hooks weighing 5kg from (Monsterhooks, USA). The average of two LCMJ was used for analysis.

Data Analyses

All jumps were performed on dual force plates (ForceDecks, Vald Performance, Brisbane, Queensland, Australia) with vertical ground reaction forces (vGRF) collected at a sampling rate of 1,000 Hz. The vGRF were exported as .csv files from ForceDecks and analyzed using custom analyses in analytical software (MATLAB version 7.12, MathWorks, R2011a, Natick, MA, USA).[26] All key landmarks (e.g., start of movement detection, propulsive phase, takeoff, landing) were visually inspected during analysis and trials were discarded if the data appeared too noisy leading to obvious landmark identification errors. This process resulted in the removal of 60 trials from the total 1,344 trials (4%) and 1 of the 2 trials were then used for analysis for that timepoint. The vGRF data were not filtered according to prior research.[27]

The integration process began at the initiation of movement as 0 $m \cdot s^{-1}$. Due to AEL loading in the initial weighing phase of the jumps, system weight (including body, bar, and AEL weight when necessary)) were derived from ~1 second of quiet standing after completing each jump. The initiation of the CMJ was identified utilizing a 5 Standard Deviation (SD) decrease in system weight and then backtracking to within 1 SD of initial system weight (combination of bodyweight , bar weight, and AEL weight depending on condition).[26,28] The braking phase was subsequently identified as the negative center of mass (COM) velocity from peak eccentric vGRF until 0 $m \cdot s^{-1}$ (coinciding with a return in vGRF to system weight of the weighing phase). The unweighing phase was from the initiation of movement to the start of braking phase.

Since AEL includes a change in system weight after removal of the weight releasers, a new system weight (bodyweight + bar weight) was calculated from a quite standing period upon completion of each jump. The quite standing period was taken from the final second of each jump trial after the landing phase where subjects were instructed to return to an upright position as quickly as possible and remain as still as possible until the trial was saved. The integration process was then recalculated using the new system weight for the remainder of the jump starting at the end of the braking phase. Starting from the end of the braking phase, the propulsive phase was identified as positive COM velocity from the point where COM velocity was > 0 $m \cdot s^{-1}$ until take-off. Take-off was identified when vGRF fell below 30 N.[26] The flight phase was identified as point of take-off until point of landing identified as point where vGRF returned to above 30 N. Performance metrics included in analysis consisted of jump height ((9.81 * (FlightTime^2) / 8)*100) and modified reactive strength index (mRSI, [Jump Height / 100 / Contraction Time]).[26,28] Flight time was calculated as (duration of flight phase) and contraction time (duration from initiation of the CMJ to the point of take-off). Additional metrics were also calculated from the braking and propulsive phases described earlier such as impulse (total area under the force-time curve using the trapezoidal method of net force (vGRF − System Weight)), average force (mean vGRF), peak force (peak vGRF) and duration during each phase respectively.

Statistical Analysis

Statistical procedures were performed in R version 4.3.1 (R Foundation, Vienna, Austria, https://www.R-project.org) with an alpha level of $p < 0.05$. Data are reported as mean and SD. All metrics were considered normally distributed according to Shapiro-Wilks test. Within-subject reliability for each force-time metric was assessed via coefficient of variation ((SD / Mean) *100) and considered poor when < 10%.[29] The mean CV across participants and conditions were reported with 95% confidence intervals. To understand the influence of AEL on barbell and trap bar loaded countermovement jumps with multiple loading strategies, mixed effect linear modeling approaches were used via the 'nlme' package. The fixed conditions of AEL and fixed loading magnitudes (level 1) were nested within subjects (level 2, random effect). Explanatory variables (conditions) included AEL conditions (No-AEL, AEL with 10kg, AEL with 20kg, and AEL with 30kg) and fixed loading magnitudes (20kg, 30kg, 40kg, 50kg). Two separate analyses were run for barbell and trap bar fixed loading conditions. If a significant effect was identified, post-hoc analyses were conducted using the "emmeans" function with Tukey method p-value adjustments. The magnitudes of these differences were evaluated by calculating Cohen's D effect sizes using the `eff_size` function with sigma equal to the square root of the total model standard deviation. The effect size and 95% confidence intervals are reported and interpreted as: very small < 0.20, small = 0.20 to 0.49, medium = 0.50 to 0.79, large >= 0.80.[30]

RESULTS

According to coefficient of variation measures, the reliability of metrics was considered acceptable for the control conditions without AEL of any magnitude, except for the unweighing duration for the trap bar LCMJ. In addition to the barbell, AEL resulted in poor reliability for countermovement depth, braking velocity, and braking power, while adequate reliability was demonstrated for all other force-time metrics (Figure 2). The AEL during trap bar LCMJ resulted in poor reliability for propulsive power, countermovement depth, braking velocity, braking power, braking duration, and braking impulse (Figure 2). Due to poor reliability, countermovement depth, velocity, and power were not included in further analysis.

There were no statistically significant AEL by bar load interactions for either barbell or trap bar LCMJ across all force-time metrics. However, there were significant main AEL effects during the barbell LCMJ for all metrics of interest except propulsive peak force (Table 2). During the trap bar LCMJ there were significant main AEL effects for jump height, propulsive impulse, propulsive peak force, propulsive duration, braking impulse, braking average force, and braking impulse (Table 2).

Post Hoc comparisons from AEL main effects during the barbell condition are displayed in Table 3 with means and standard deviations collapsed across AEL conditions, while respective effect sizes are presented in Table 4. Additional visuals of select force-time metrics from barbell LCMJ across each AEL condition and barbell load are displayed in Figure 3. During the barbell LCMJ, post hoc analyses revealed significantly reduced jump height by AEL with 30kg compared to No-AEL. The longer propulsive phase durations may have led to increased propulsive phase impulse but lower mRSI during AEL conditions. The overall braking impulse and braking forces were greater during AEL loadings, 30 kg demonstrating the highest braking forces compared to No-AEL, and AEL with 10kg and 20kg. Braking duration during AEL was not significantly different than no AEL condition.

Post Hoc comparisons from AEL main effects during the trap bar condition are displayed in Table 5 with means and standard deviations collapsed across AEL conditions, while respective effect sizes are displayed in Table 6. Additional visuals of select force-time metrics from trap bar LCMJ across each AEL condition and trap bar load are displayed in Figure 4. During the trap bar condition, post hoc analyses revealed significantly reduced jump height and shorter propulsive and braking durations and as a result mRSI was unaffected, by AEL with 10kg, 20kg, 30kg compared to No-AEL. Propulsive impulse and average force were not affected by AEL, but AEL with 10kg and 30kg had greater propulsive peak force compared to No-AEL. Braking impulse was reduced by AEL likely as a result of shorter braking durations, as average braking forces were greater during all AEL conditions compared with No-AEL.

Figure 2. Reliability of force-time metrics of the barbell and trap bar loaded countermovement jump using accentuated eccentric loading (AEL) with 10kg, 20kg, or 30kg, as well as the control condition (NoAEL).

Table 2. Effects of AEL and Bar Loads on CMJ metrics with Barbell & Trap Bar.

	Barbell		Trap Bar	
Metrics	**AEL Load Main Effect**	**AEL by Bar Load Interaction**	**AEL Load Main Effect**	**AEL by Bar Load Interaction**
Jump Height	0.018*	0.325	<0.001†	0.901
mRSI	<0.001†	0.577	0.212	0.850
Propulsive Impulse	<0.001†	0.914	0.037*	0.994
Propulsive Avg. Force	0.0368	0.936	0.078	0.912
Propulsive Peak Force	0.351	0.209	<0.001†	0.209
Propulsive Duration	<0.001†	0.880	0.020*	0.990
Braking Impulse	0.008*	0.829	0.005†	0.981
Braking Avg. Force	<0.001†	0.654	<0.001†	0.865
Braking Peak Force	<0.001†	0.279	0.133	0.926
Braking Duration	0.0368	0.150	<0.001†	0.947

**p < 0.05 = statistically significant difference; †p<0.001=statistically significant difference*

Table 3. Post hoc analyses for AEL main effects during Barbell LCMJ.

Metrics	**No-AEL**	**AEL 10kg**	**AEL 20kg**	**AEL 30kg**
Jump Height (cm)	22.8 ± 6.1	22.6 ± 6.3	22.3 ± 6.2	21.8 ± 6.6*
mRSI (m/s)	0.23 ± 0.08	0.21 ± 0.07*	0.21 ± 0.07*	0.21 ± 0.08*
Propulsive Impulse (N·s)	615.3 ± 111.6	645.4 ± 125.2*	666.4 ± 147.5*	706.1 ± 182.7*†‡
Propulsive Avg. Force (N)	1734 ± 245	1718 ± 259	1709 ± 251*	1711 ± 250
Propulsive Peak Force (N)	2079 ± 296	2082 ± 306	2069 ± 316	2087 ± 313
Propulsive Duration (s)	0.36 ± 0.06	0.38 ± 0.08*	0.40 ± 0.10*	0.42 ± 0.12*†
Braking Impulse (N·s)	603.2 ± 156.3	646.2 ± 167.6*	641.6 ± 172.2*	641.7 ± 224.8*
Braking Avg. Force (W)	1236 ± 176	1259 ± 176*	1266 ± 188*	1292 ± 184*†‡
Braking Peak Force (N)	1953 ± 293	1911 ± 301	1839 ± 307*†	1799.77 ± 294*†
Braking Duration (s)	0.48 ± 0.08	0.51 ± 0.09	0.50 ± 0.09	0.48 ± 0.13

Values are displayed as Mean ± SD collapsed over the levels of Barbell Load
**, statistically significant difference at p < 0.05 compared to no AEL*
†, statistically significant difference at p < 0.05 compared to 10kg
‡, statistically significant difference at p < 0.05 compared to 20 kg

Table 4. Effect Sizes of AEL Loads compared to No-AEL (0kg) on LCMJ metrics across all Barbell Loads.

Metrics	(0kg - 10kg)	(0kg - 20kg)	(0kg - 30kg)	(10kg - 20kg)	(10kg - 30kg)	(20kg - 30kg)
Jump Height	0.03 (-0.08, 0.14)	0.09 (-0.02, 0.2)	0.17 (0.06, 0.28)	0.06 (-0.05, 0.17)	0.14 (0.03, 0.25)	0.08 (-0.03, 0.19)
mRSI	0.28 (0.12, 0.45)	0.36 (0.19, 0.53)	0.38 (0.22, 0.55)	0.08 (-0.09, 0.24)	0.10 (-0.06, 0.26)	0.02 (-0.14, 0.19)
Propulsive Impulse	-0.24 (-0.43, -0.05)	-0.43 (-0.63, -0.24)	-0.77 (-0.97, -0.57)	-0.19 (-0.38, 0.00)	-0.52 (-0.72, -0.33)	-0.33 (-0.53, -0.14)
Propulsive Avg. Force	0.08 (0.00, 0.15)	0.10 (0.02, 0.18)	0.09 (0.02, 0.17)	0.02 (-0.05, 0.10)	0.02 (-0.06, 0.09)	-0.01 (-0.08, 0.07)
Propulsive Peak Force	0.00 (-0.06, 0.06)	0.03 (-0.03, 0.09)	-0.03 (-0.09, 0.03)	0.03 (-0.03, 0.09)	-0.03 (-0.09, 0.04)	-0.06 (-0.12, 0.01)
Propulsive Duration	0.26 (-0.46, -0.07)	-0.47 (-0.67, -0.26)	-0.72 (-0.93, -0.51)	-0.20 (-0.40, 0.00)	-0.46 (-0.66, -0.26)	-0.26 (-0.46, -0.06)
Braking Impulse	-0.33 (-0.55, -0.10)	-0.30 (-0.53, -0.08)	-0.30 (-0.52, -0.08)	0.02 (-0.20, 0.24)	0.02 (-0.20, 0.24)	0.00 (-0.22, 0.22)
Braking Avg. Force	-0.14 (-0.23, -0.04)	-0.2 (-0.29, -0.10)	-0.39 (-0.49, -0.29)	-0.06 (-0.15, 0.04)	-0.25 (-0.35, -0.16)	-0.20 (-0.29, -0.1)
Braking Peak Force	0.16 (0.03, 0.29)	0.40 (0.27, 0.54)	0.54 (0.40, 0.68)	0.24 (0.11, 0.38)	0.38 (0.24, 0.51)	0.13 (0, 0.27)
Braking Duration	-0.26 (-0.48, -0.04)	-0.2 (-0.42, 0.02)	-0.01 (-0.23, 0.21)	0.06 (-0.16, 0.28)	0.25 (0.03, 0.47)	0.19 (-0.03, 0.41)

AEL, accentuated eccentric loading; LCMJ, loaded countermovement jump; mRSI, modified reactive strength index
Effect size interpretations: very small < 0.20, small = 0.20 to 0.49, medium = 0.50 to 0.79, large >= 0.80

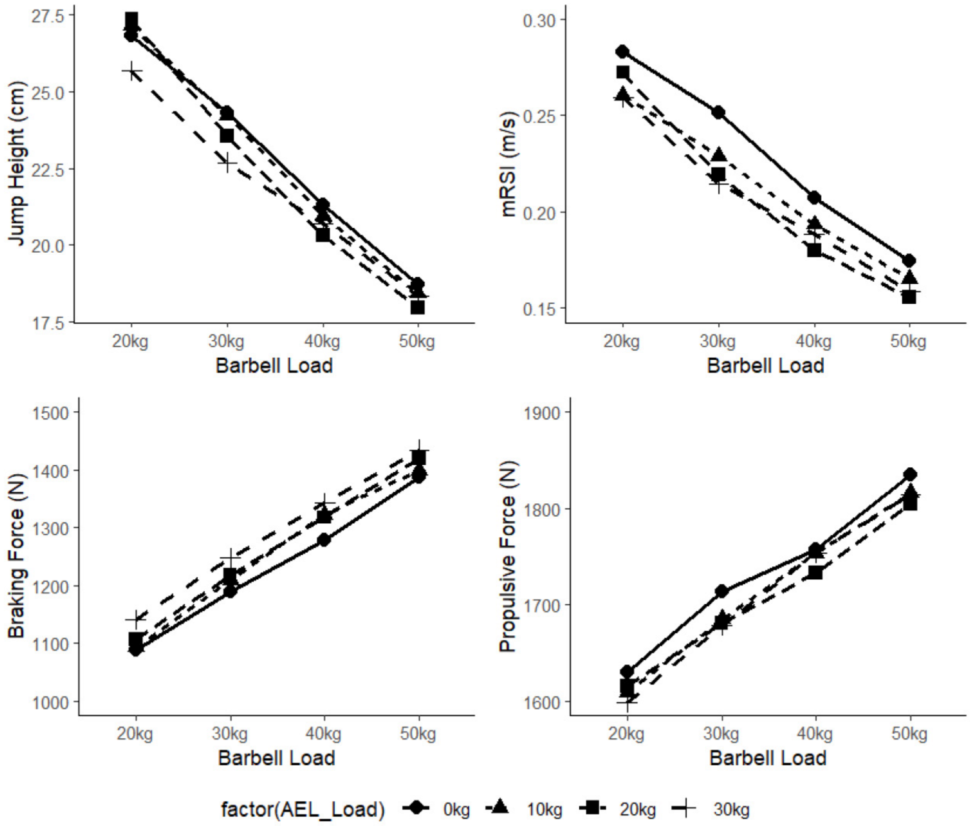

Figure 3. Barbell Loaded countermovement jump height, modified reactive strength index (mRSI) braking phase impulse and propulsive phase impulse across varying barbell loads in addition to accentuated eccentric loading (AEL) with varying magnitudes compared to no AEL. Fixed barbell loads are on the x-axis, while the AEL schemes are displayed via alternative line colors according to the figure legend.

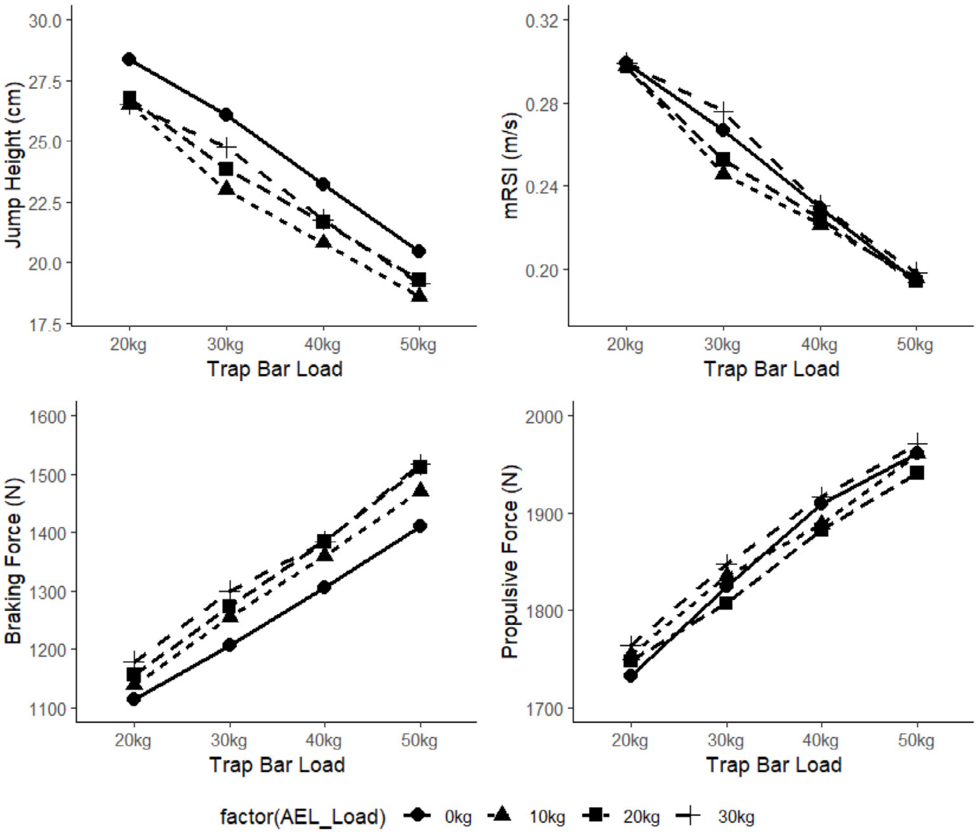

Figure 4. Trap Bar Loaded countermovement jump height, modified reactive strength index (mRSI) braking phase impulse and propulsive phase impulse across varying barbell loads in addition to accentuated eccentric loading (AEL) with varying magnitudes compared to no AEL.

Table 5. Post hoc analyses for AEL main effects during Trap Bar LCMJ.

Metrics	No AEL 0kg	AEL 10kg	AEL 20kg	AEL 30kg
Jump Height (cm)	24.5 ± 6.2	22.2 ± 6.5*	22.9 ± 6.1*	23 ± 6.3*
mRSI (m/s)	0.25 ± 0.09	0.24 ± 0.08	0.24 ± 0.09	0.25 ± 0.09
Propulsive Impulse (N·s)	595.3 ± 104.6	561.1 ± 134.3	554.1 ± 154.2	564.4 ± 135.6
Propulsive Avg. Force (N)	1857 ± 286	1860 ± 301	1845 ± 303	1875 ± 304
Propulsive Peak Force (N)	2242 ± 377	2291 ± 386*	2267 ± 385	2306 ± 388*‡
Propulsive Duration (s)	0.32 ± 0.06	0.30 ± 0.07*	0.30 ± 0.07	0.30 ± 0.07*
Braking Impulse (N·s)	643.5 ± 173.5	607.9 ± 136.4*	629.1 ± 195.1*	579.4 ± 161.8*
Braking Avg. Force (W)	1260 ± 178	1305 ± 201*	1331 ± 209*	1346 ± 226*†
Braking Peak Force (N)	1964 ± 324	2001 ± 364	2005 ± 360	2006 ± 389
Braking Duration (s)	0.51 ± 0.1	0.46 ± 0.07*	0.47 ± 0.12*	0.43 ± 0.1*†‡

Values are displayed as Mean ± SD collapsed over the levels of Barbell Load
**, statistically significant difference at $p < 0.05$ compared to no AEL*
†, statistically significant difference at $p < 0.05$ compared to 10kg
‡, statistically significant difference at $p < 0.05$ compared to 20 kg

Table 6. Effect Sizes of AEL Loads compared to No-AEL (0kg) on LCMJ metrics across all Trap Bar Loads.

Metrics	(0kg - 10kg)	(0kg - 20kg)	(0kg - 30kg)	(10kg - 20kg)	(10kg - 30kg)	(20kg - 30kg)
Jump Height	0.40 (0.27, 0.53)	0.29 (0.16, 0.42)	0.26 (0.13, 0.38)	-0.11 (-0.24, 0.02)	-0.14 (-0.27, -0.02)	-0.04 (-0.16, 0.09)
mRSI	0.09 (-0.05, 0.23)	0.07 (-0.07, 0.22)	-0.04 (-0.19, 0.10)	-0.02 (-0.16, 0.13)	-0.14 (-0.28, 0.01)	-0.12 (-0.26, 0.03)
Propulsive Impulse	0.27 (0.06, 0.47)	0.24 (0.03, 0.45)	0.24 (0.03, 0.45)	-0.03 (-0.24, 0.18)	-0.03 (-0.23, 0.18)	0.00 (-0.21, 0.21)
Propulsive Avg. Force	-0.01 (-0.08, 0.06)	0.03 (-0.04, 0.10)	-0.06 (-0.13, 0.01)	0.04 (-0.03, 0.11)	-0.05 (-0.12, 0.02)	-0.09 (-0.16, -0.02)
Propulsive Peak Force	-0.01 (-0.08, 0.06)	-0.06 (-0.12, 0.00)	-0.17 (-0.23, -0.11)	0.07 (0.01, 0.13)	-0.04 (-0.10, 0.02)	-0.11 (-0.16, -0.05)
Propulsive Duration	0.30 (0.08, 0.52)	0.23 (0.01, 0.46)	0.30 (0.08, 0.52)	-0.07 (-0.29, 0.16)	0.00 (-0.22, 0.21)	0.06 (-0.16, 0.28)
Braking Impulse	0.25 (0.00, 0.50)	0.17 (-0.08, 0.43)	0.45 (0.20, 0.70)	-0.08 (-0.33, 0.18)	0.2 (-0.05, 0.45)	0.28 (0.02, 0.53)
Braking Avg. Force	-0.29 (-0.42, -0.15)	-0.42 (-0.57, -0.28)	-0.53 (-0.68, -0.38)	-0.14 (-0.28, 0.00)	-0.24 (-0.38, -0.11)	-0.11 (-0.25, 0.03)
Braking Peak Force	-0.11 (-0.22, 0.01)	-0.11 (-0.23, 0.01)	-0.12 (-0.24, -0.01)	0.00 (-0.12, 0.11)	-0.01 (-0.13, 0.10)	-0.01 (-0.13, 0.10)
Braking Duration	0.44 (0.18, 0.71)	0.43 (0.16, 0.69)	0.78 (0.52, 1.05)	-0.02 (-0.28, 0.25)	0.34 (0.08, 0.60)	0.35 (0.09, 0.62)

AEL, accentuated eccentric loading; LCMJ, loaded countermovement jump; mRSI, modified reactive strength index
Effect size interpretations: very small < 0.20, small = 0.20 to 0.49, medium = 0.50 to 0.79, large >= 0.80

DISCUSSION

The objectives of this study were to examine various AEL schemes during LCMJ by a barbell and trap bar. The main findings of this study were that across fixed loads the inclusion of AEL had negligible reductions to jump height when using a barbell and small reductions to jump height when using the trap bar. Yet, mRSI with AEL had small decrements during the barbell LCMJ and no changes during the trap bar LCMJ compared to No-AEL. These findings were likely due to the moderately longer propulsive durations during AEL barbell LCMJ compared to the moderately shorter braking and propulsive durations due to AEL trap bar LCMJ. The longer durations also explain the increased propulsive impulse during the barbell LCMJ, which was also demonstrated in the braking phase with higher braking impulse and forces but unchanged braking durations during AEL in the barbell LCMJ. Meanwhile, braking durations being reduced during trap bar LCMJ with AEL may have led to lower braking impulse despite greater average braking forces. The propulsive duration was also lower due to AEL during the trap bar LCMJ, but propulsive average force and impulse were not affected. Ultimately, the additional mass added during AEL resulted in greater but altered braking and propulsive phase durations which may have reduced jump height and mRSI. Although not analyzed in the current study due to poor reliability, the countermovement depth may have also been altered due to AEL which could directly impact countermovement jump performances (e.g., jump height or mRSI).[31,32] Furthermore, the depth displacement and loading on the body of AEL during the barbell was likely different to that of the trap bar LCMJ. Keeping in mind that prior literature has found greater power output during loaded squat jump and vertical jumps when using the trap bar compared to barbell,[33,34] in line with results of the current study (albeit not directly analyzed).

It should be noted that while no AEL load conditions improved LCMJ height, the findings also suggest no negative effect on jump height of AEL barbell LCMJ until the heaviest external loads of 30kg. During the braking phase, there was a greater impulse resulting from greater forces and unchanged durations for the barbell LCMJ. Propulsive impulse was increased not by additional force but by increased propulsive durations which was reflected in decreased mRSI values and maintenance of the jump height. Ideally, the increase in propulsive impulse would come from an increase in forces in shorter durations to elicit higher jump heights but was not the case in the current results. This indicates that the weight in the study may have been too heavy for these subjects, which may have impacted their jumping strategy and mechanics. Alterations in phase durations or countermovement depth could be the main explanations for the jump height outcomes.[31,32] Previous studies used AEL loads equivalent to 20-30% of the subject's body mass, which were removed before the concentric phase, and found increases in jump height, force, power, and velocity.[16,21] Our study implemented AEL via weight releasers that remove the extra loads at the bottom of the movement, which ranged from 13-39% of the subjects body mass. The AEL was in addition to fixed loads on the barbell or trap bar which remained for the entire LCMJ and ranged from 26-66% of the subject's body mass. The total load (AEL + bar mass) during the eccentric phase from the lightest (AEL = 10 kg, bar = 20 kg) to the heaviest (AEL = 30 kg, bar = 50 kg) AEL condition ranged from 39-105% of the subject's body mass, on average. This combination of fixed loads appears to have exceeded the subject's strength levels or impacted movement mechanics (i.e., increased propulsive duration) which contributed to the lack of improvement in jump height. It is unknown if lighter fixed bar loads of <20% of body mass may have been more appropriate and resulted in different outcomes when implementing AEL during LCMJ. When implementing AEL during the back squat exercise, lighter concentric loads may permit further benefit from AEL compared to heavier fixed bar conditions but this may also be a result of the larger magnitude difference between the AEL load and fixed bar loads.[11,12] Moreover, the outcomes in the current study are the first to allude to using AEL while training mid-range performances of the force-velocity curve by attempting to improve responses of LCMJ instead of high-velocity low-force bodyweight jumping tasks or low-velocity high-force squatting tasks.[11,18]

Unlike the barbell LCMJ, trap bar jump height was reduced (small effect sizes) in all conditions compared to the control condition without AEL. Contrasting with the barbell jumps the trap bar jumps demonstrated similar mRSI values across all conditions driven by statistically significant decreases propulsive and braking phase durations. Braking forces were increased during all AEL conditions compared to not using AEL (see Table 5 and Figure 5). It is likely that the decrease in braking impulse were underpinned by the shorter braking durations during AEL conditions. Propulsive phase metrics remained relatively unchanged with the exception of propulsive peak force being greater and propulsive durations being shorter at the 10 and 30 kg AEL conditions. Much like the barbell LCMJ it appears that the loading encountered in this study was too great in magnitude to express any acute enhancement in LCMJ performance. However, it is possible that the ranges of motion were different between barbell and trap bar loaded jumps due to weight releaser depths when using AEL. It is possible the smaller displacement in the trap bar jump may have altered movement mechanics, via changed jump strategy and shortened durations, subsequently influencing force-time metrics and jump height. The No-AEL trap bar LCMJ also appeared higher than the barbell LCMJ, in agreement with prior research,[33,34] which may partially explain the greater decreases in jump height during AEL conditions with the trap bar LCMJ. Although the shorter countermovement depths may be an explanation for differences in LCMJ performances under AEL, this was not directly analyzed during this study due to reliability concerns. Future research should consider assessing these movements with motion capture systems to understand the effects of similar loading strategies on jumping movement mechanics, as alterations in the movement mechanics may ultimately influence the efficacy of AEL.[11]

The present findings of this study do not support utilization of AEL to acutely improve performances of barbell and trap bar LCMJ. This is in opposition to prior research that showed benefits of AEL for acutely enhancing jump performance.[16,21,23] Our study is in alignment with a previous study examining depth jumps and AEL via elastic bands, which demonstrated no improvement in jumping height with added band weight but alterations in jump phase characteristics.[22] However, the depth jump and LCMJ exhibit higher intensity plyometric training that may be more susceptible to altered mechanics due to AEL implementation without extensive familiarization periods. It is also important to consider the use of band tension during depth jumps as the tension will be greatly reduced as the individual drops from the box through the landing phase.[11,24] Further, previous AEL research conducted with fixed dumbbell loads and elastic resistance bands incorporated full release of the weights/bands upon the concentric portion of the jump, and allowed the subjects to swing their arms upward after release.[16,21–23] In contrast, by utilizing a barbell and trap bar in our study, weight was never fully released by the subjects as they had to jump with the bars which eliminated arm swing. These conditions may have limited natural jumping mechanics which is a one aspect of proper inclusion of AEL into a training protocol.[18] Nonetheless, this was the first study to examine LCMJ with the inclusion of AEL which may provide the ability to load the middle of the force-velocity curve and improve braking velocity and force absorption under loaded conditions.

This study is not without limitations. Subjects in this study on average possessed a relative strength level approximately 1.7 times their body weight. Previous work in this area have shown differential outcomes based on individual characteristics such as lowering technique and that stronger athletes handle AEL more efficiently than weaker athletes.[13] At the current strength levels, this type of loading may have altered movement mechanics and inhibited AEL benefit to jumping performance. This study employed fixed barbell and weight releaser loads for all subjects which may have exceeded their strength capacities in relation to their 1RM. Future studies should attempt to quantify which loads would be most appropriate based on individual strength levels, body weight, and jumping abilities. It is also important to note that the trap bar LCMJ always followed barbell LCMJ which may explain some of the apparent difficulties in executing this movement in the current study (in addition to the different amount of AEL being incorporated to trap bar LCMJ due to varied depth displacement). However, the trap bar LCMJ during No-AEL was higher than barbell LCMJ during No-AEL, which may suggest little effect of fatigue during the current protocol prescribed rest. Finally, subjects were instructed to maintain normal jumping mechanics, but variability may have occurred as the weights increased. Future studies should incorporate motion analysis to understand changes in movement strategies that occur with this type of loading. Of note, the reliability of braking phase metrics and countermovement depth when implementing AEL during LCMJ was not acceptable. This may further indicate the difficulty of utilizing AEL during LCMJ of this magnitude. However, these results may also allude to the complexity of solely analyzing vGRF to obtain velocity and position data during AEL jumping tasks which further warrants the need for additional kinematic analysis of future research.

PRACTICAL APPLICATIONS

Strength coaches and practitioners may implement AEL with barbell and trap bar jumping into their athletes' training programming if the desired outcome is to increase athletes' total eccentric volume of workload while not sacrificing their jump height or mRSI during LCMJ. However, the greater braking impulses occurred during AEL with barbell LCMJ appeared to result from greater braking average forces with unchanged braking durations, while the trap bar LCMJ exhibited lower braking impulses and durations despite greater average forces. This type of programming would be potentially beneficial at the mid to end of an athlete's off-season where increasing athletes' tolerance to and volume of eccentric workload is most desirable to prepare for the deceleration requirements during the pre-season and in-season. Since this protocol utilized predetermined loads on the bars and weight releasers instead of loads determined through percentages of each participant's individual 1RM, this may eliminate the need for time consuming 1RM testing, greater load variability, and complex calculations based on individuals' % of 1RM, thus the protocol can be implemented smoothly and efficiently by any level organization or team. Further research is recommended to discover the optimal delivery of AEL for different performance measures and outcomes, especially in specific sport populations, as well as to discover the long-term effects of AEL training. Lastly, improvements to propulsive phase metrics, jump height, and mRSI outcomes were not exhibited in any AEL condition. Thus, if the training intent is maximizing those variables of interest, the current AEL protocols may not be appropriate.

REFERENCES

1. Cronin JB, Hansen KT. Strength and power predictors of sports speed. J Strength Cond Res. 2005;19(2):349-357.
2. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med. 2016;46(10):1419-1449. doi:10.1007/s40279-016-0486-0
3. Lorenz DS, Reiman MP, Lehecka BJ, Naylor A. What performance characteristics determine elite versus nonelite athletes in the same sport? Sports Health. 2013;5(6):542-547.
4. McBurnie AJ, Harper DJ, Jones PA, Dos' Santos T. Deceleration training in team sports: Another potential 'vaccine'for sports-related injury? Sports Med. Published online 2022:1-12.
5. Harper D, McBurnie A, Santos T, et al. Biomechanical and neuromuscular performance requirements of horizontal deceleration: A review with implications for random intermittent multi-directional sports. Sports Med. Published online May 29, 2022. doi:10.1007/s40279-022-01693-0
6. Chaabene H, Prieske O, Negra Y, Granacher U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. Sports Med. 2018;48(8):1773-1779. doi:10.1007/s40279-018-0907-3

7. Godwin MS, Fearnett T, Newman MA. The potentiating response to accentuated eccentric loading in professional football players. Sports. 2021;9(12):160. doi:10.3390/sports9120160
8. Gross M, Seiler J, Grédy B, Lüthy F. Kinematic and kinetic characteristics of repetitive countermovement jumps with accentuated eccentric loading. Sports. 2022;10(5):74. doi:10.3390/sports10050074
9. Handford MJ, Rivera FM, Maroto-Izquierdo S, Hughes JD. Plyo-accentuated eccentric loading methods to enhance lower limb muscle power. Strength Cond J. 2021;43(5):54-64. doi:10.1519/SSC.0000000000000635
10. Hughes JD, Massiah RG, Clarke RD. The potentiating effect of an accentuated eccentric load on countermovement jump performance. J Strength Cond Res. 2016;30(12):3450-3455. doi:10.1519/JSC.0000000000001455
11. Merrigan J, Borth J, Taber C, Suchomel T, Jones M. Application of accentuated eccentric loading to elicit acute and chronic velocity and power improvements: A narrative review: Int J Strength Cond. 2022;2(1). doi:10.47206/ijsc.v2i1.80
12. Merrigan JJ, Tufano JJ, Falzone M, Jones MT. Effectiveness of accentuated eccentric loading: Contingent on concentric load. Int J Sports Physiol Perform. 2021;16(1):66-72. doi:10.1123/ijspp.2019-0769
13. Merrigan JJ, Tufano JJ, Jones MT. Potentiating effects of accentuated eccentric loading are dependent upon relative strength. J Strength Cond Res. 2021;35(5):1208. doi:10.1519/JSC.0000000000004010
14. Merrigan JJ, Jones MT. Acute inflammatory, cortisol, and soreness responses to supramaximal accentuated eccentric loading. J Strength Cond Res. 2021;35:S107. doi:10.1519/JSC.0000000000003764
15. Moore CA, Weiss LW, Schilling BK, Fry AC, Li Y. Acute effects of augmented eccentric loading on jump squat performance. J Strength Cond Res Champaign. 2007;21(2):372-377.
16. Sheppard J, Newton R, McGuigan M. The effect of accentuated eccentric load on jump kinetics in high-performance volleyball players. Int J Sports Sci Coach. 2007;2(3):267-273. doi:10.1260/174795407782233209
17. Wagle J, Taber C, Carroll K, et al. Repetition-to-repetition differences using cluster and accentuated eccentric loading in the back squat. Sports. 2018;6(3):59. doi:10.3390/sports6030059
18. Wagle JP, Taber CB, Cunanan AJ, et al. Accentuated eccentric loading for training and performance: A review. Sports Med. 2017;47(12):2473-2495. doi:10.1007/s40279-017-0755-6
19. Douglas J, Pearson S, Ross A, McGuigan M. Effects of accentuated eccentric loading on muscle properties, strength, power, and speed in resistance-trained rugby players. J Strength Cond Res. 2018;32(10):2750-2761. doi:10.1519/JSC.0000000000002772
20. Sarto F, Franchi MV, Rigon PA, et al. Muscle activation during leg-press exercise with or without eccentric overload. Eur J Appl Physiol. Published online 2020.
21. Aboodarda SJ, Yusof A, Osman NAA, Thompson MW, Mokhtar AH. Enhanced performance with elastic resistance during the eccentric phase of a countermovement jump. Int J Sports Physiol Perform. 2013;8(2):181-187. doi:10.1123/ijspp.8.2.181
22. Aboodarda SJ, Byrne JM, Samson M, Wilson BD, Mokhtar AH, Behm DG. Does performing drop jumps with additional eccentric loading improve jump performance? J Strength Cond Res. 2014;28(8):2314-2323. doi:10.1519/JSC.0000000000000498
23. Sheppard J, Hobson S, Barker M, et al. The effect of training with accentuated eccentric load counter-movement jumps on strength and power characteristics of high-performance volleyball players. Int J Sports Sci Coach. 2008;3(3):355-363. doi:10.1260/174795408786238498
24. Frost DM, Cronin J, Newton RU. A biomechanical evaluation of resistance: fundamental concepts for training and sports performance. Sports Med. 2010;40:303-326.
25. Ullrich B, Pelzer T, Pfeiffer M. Neuromuscular effects to 6 weeks of loaded countermovement jumping with traditional and daily undulating periodization. J Strength Cond Res. 2018;32(3):660. doi:10.1519/JSC.0000000000002290
26. Merrigan JJ, Stone JD, Galster SM, Hagen JA. Analyzing force-time curves: Comparison of commercially available automated software and custom MATLAB analyses. J Strength Cond Res. 2022;36(9):2387-2402. doi:10.1519/JSC.0000000000004275
27. Harry JR, Blinch J, Barker LA, Krzyszkowski J, Chowning L. Low-pass filter effects on metrics of countermovement vertical jump performance. J Strength Cond Res. Published online November 15, 2021. doi:10.1519/JSC.0000000000003611
28. Merrigan JJ, Stone JD, Thompson AG, Hornsby WG, Hagen JA. Monitoring neuromuscular performance in military personnel. Int J Environ Res Public Health. 2020;17(23):9147.
29. Merrigan JJ, Stone JD, Hornsby WG, Hagen JA. Identifying reliable and relatable force–time metrics in athletes—considerations for the isometric mid-thigh pull and countermovement jump. Sports. 2021;9(1):4. doi:10.3390/sports9010004
30. Cohen J. Statistical Power Analysis for the Behavioral Sciences (2nd Edition). Routledge; 1988. Accessed March 17, 2019. http://www.amazon.ca/exec/obidos/redirect?tag=citeulike09-20&path=ASIN/0805802835
31. Pérez-Castilla A, Weakley J, García-Pinillos F, Rojas FJ, García-Ramos A. Influence of countermovement depth on the countermovement jump-derived reactive strength index modified. Eur J Sport Sci. 2021;21(12):1606-1616. doi:10.1080/17461391.2020.1845815
32. Merrigan JJ, Stone JD, Wagle JP, et al. Using random forest regression to determine influential force-time metrics for countermovement jump height: A technical report. J Strength Cond Res. 2022;36(1):277.

doi:10.1519/JSC.0000000000004154

33. Turner TS, Tobin DP, Delahunt E. Peak power in the hexagonal barbell jump squat and its relationship to jump performance and acceleration in elite rugby union players. J Strength Cond Res. 2015;29(5):1234. doi:10.1519/JSC.0000000000000770
34. Swinton PA, Stewart AD, Lloyd R, Agouris I, Keogh JWL. Effect of load positioning on the kinematics and kinetics of weighted vertical jumps. J Strength Cond Res. 2012;26(4):906-913. doi:10.1519/JSC.0b013e31822e589e