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Research article

Accentuated Eccentric Loading in Countermovement Jumps Vs. Drop Jumps: Effects on Jump Performance and Strength in A Randomized Controlled Trial

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Abstract

This study examined the effects of Accentuated Eccentric Loading Countermovement Jump (AEL CMJ) training on jump performance, lower body strength, sprint performance, and change of direction ability, compared to drop jump (DJ) training. This study used a randomized controlled trial (RCT) with a parallel design. Forty men physical education students (Mean ± SD: age 22.60 ± 3.24 years, body mass 75.21 ± 8.12 kg, height 1.79 ± 0.07 m) were randomly assigned to AEL (n = 14), DJ (n = 13), or a control group (CON, n = 13). The AEL and DJ groups trained three times per week for 8 weeks, while the CON group maintained their usual routines. All groups with similar levels of physical activity outside the training. Pre-, mid- (4 weeks), and post-intervention (8 weeks) assessments measured jump performance (CMJ and squat jump (SJ)), 1RM squat strength, 30 m sprint time, and change of direction (T-test). A mixed-effects model evaluated group and time effects. Significant group × time interactions were observed for CMJ height (P = 0.006), with both AEL and DJ training improving CMJ (AEL: +11.8%, ES = 0.77; DJ: +7.7%, ES = 0.47), SJ height (AEL: +5.7%, ES = 0.37; DJ: +11.3%, ES = 0.66), and 1RM squat (AEL: +7.0%, ES = 0.44; DJ: +8.4%, ES = 0.46) at 8 weeks. Neither training method significantly improved sprint or change of direction performance. Additionally, no significant gains were seen in any indicator at 4 weeks. These results indicate that AEL CMJ and DJ training both effectively enhance vertical jump and strength, positioning AEL CMJ as an effective alternative or complement to DJ training.

Key words: Plyometric, stretch-shortening cycle, power, reactive strength, T-test, squat.

Introduction

Lower body explosive power is a critical ability in many sports, particularly those involving frequent jumping, changes of direction (COD), and sprinting (Pereira et al., 2018). Plyometric training is an effective method to improve lower body power, which is achieved by optimizing the stretch-shortening cycle (SSC) (McClenton et al., 2008). The SSC involves a high-intensity eccentric contraction immediately followed by a rapid concentric contraction (Hasan, 2023), and is prominently involved in vertical jump movements.

The drop jump (DJ) and countermovement jump (CMJ) are two of the most commonly used vertical jump assessments. The DJ involves stepping off a raised platform and immediately jumping upon landing (Gillen et al., 2021), while the CMJ consists of a downward movement followed by an explosive upward acceleration from standing. Previous research has demonstrated that the DJ can acutely generate greater jump height (+ 6.4 to 13.2%), power output (+ 0.8%), and force (+ 2.3 to 31.7%) compared to CMJ (McCaulley et al., 2007; Makaruk et al., 2012). This improvement is attributed to the increased eccentric loading phase in DJ, which enhances the storage and utilization of potential kinetic energy, as well as greater motor unit recruitment and activation (Bobbert et al., 1986; Kenny et al., 2012). Given these advantages, DJ training has been shown to effectively enhance lower body power, vertical jump height, lower body strength, sprint performance and COD ability (Vera-Assaoka et al., 2020; Ando et al., 2021; Brini et al., 2022). The studies by Young et al. (1999) and Newton et al. (2001) reported that among 26 men undergoing 6 weeks of DJ training, 3 cases of lower body injuries were related to the DJ training, while no injuries were reported in the 9 man who maintained their usual routines. This suggests that DJ training carries a risk of lower body injury.

Accentuated eccentric loading (AEL) is another technique that increases the eccentric load during the CMJ and has received increasing levels of attention in recent years. Several studies have shown that AEL during a CMJ, involving holding weights or attaching an elastic band to a harness worn at the hip level and removing the load before the concentric phase, can acutely enhances lower body power (+ 9.4 to 3.10%, ES = 0.39 to 0.81) more effectively than a bodyweight CMJ alone (Sheppard et al., 2007; Aboodarda et al., 2013; Godwin et al., 2021). This is likely due to immediate increases in motor neuron activation and greater elastic energy storage during the eccentric phase (Sheppard et al., 2007; Aboodarda et al., 2013). Moreover, chronic AEL CMJ training has consistently been demonstrated to outperform traditional CMJ training in improving both lower body power (+20% *vs.* +1%) and vertical jump height (+11% *vs.* -2%) over time (Sheppard et al., 2008). However, to the best of our knowledge, no studies have confirmed whether AEL applied to a CMJ can improve other independent measures of physical performance, such as: lower body strength, sprinting, and COD performance;

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which somewhat limits its broader application for practitioners. Furthermore, no studies have directly compared the effects of a DJ and AEL applied to the CMJ in this way.

Therefore, the present study aimed to: (a) investigate whether AEL CMJ training can improve lower body strength, sprinting, and COD performance; and (b) compare the effects of AEL CMJ training and DJ training on the aforementioned independent measures of athletic performance. We hypothesized that: (a) AEL CMJ training would enhance lower body strength, sprinting, and COD performance; and (b) AEL CMJ training and DJ training would produce similar effects on improving lower body power, vertical jump height, lower body strength, sprinting, and COD performance.

Methods

Experimental approach to the problem

Participants were randomly stratified based on their physical activity levels into one of three groups: an AEL group, a DJ group, or a control (CON) group, with a ratio of 1:1:1. The AEL and DJ groups participated in an 8-week training program, utilizing the AEL CMJ or DJ with an optimal power load or height, respectively. The control group did not undergo any additional training. A single-blind design was used, with participants unaware of their group assignments. Participants engaged in weekly activities, including athletics class, fitness training class, and self-selected sports class such as basketball, football, and badminton. Both training programs consisted of three sessions per week, with participants performing the same total number of repetitions. Participants were required to complete at least 80% of the scheduled workouts. Assessments of lower body power (CMJ and Squat Jump), lower body strength (1RM squat), acceleration (30m sprint), and COD performance (T-test) were conducted at baseline (pre-test), after 4 weeks training (mid-test), and after 8 weeks training (post-test) (Figure 1).

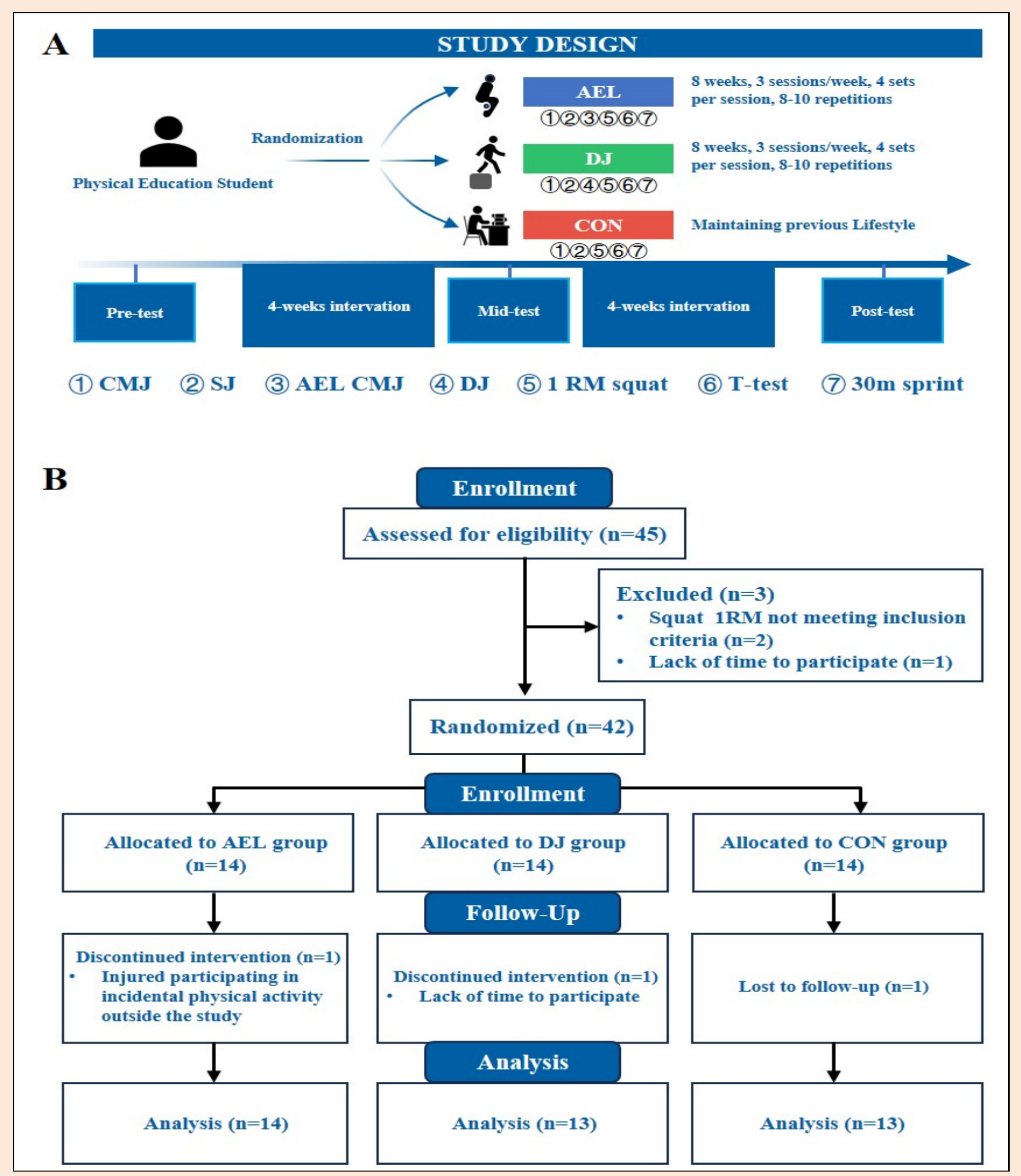

Figure 1. Study design and testing timeline for the AEL, DJ, and CON Groups. AEL = accentuated eccentric loading; CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; 1 RM = 1 repetition maximal; CON = control group.

Subjects

Participants were men physical education students who had been training for a minimum of 2 times per week for at least the previous 2 years, including three university-level track and field athletes (sprints and long jump) and three wrestlers. A sample size of 36 was determined a priori using G*Power (version 3.1.9.2) based on a repeated-measures analysis of variance using a within-between interaction design (alpha = 0.05, power = 0.80, effect size = 0.25). Forty-two participants were recruited for the study through university class groups and WeChat friend circles, of which a final of 40 students (lack of time: n = 1; injury: n = 1) were retained for analysis. Participants were randomly assigned to one of three groups: AEL group (n = 14, age = 22.6 ± 4.9 years, body mass = 76.2 ± 7.2 kg, height = 1.78 ± 0.07 m, body fat percentage = 18.1 ± 4.2), DJ group (n = 13, age = 22.6 ± 2.5 years, body mass = 77.3 ± 8.0 kg, height = 1.80 ± 0.06 m, body fat percentage = 16.1 ± 3.1) and control group (n = 13, age = 22.6 ± 1.3 years, body mass = 72.1 ± 8.9 kg, height = 1.78 ± 0.08 m, body fat percentage = 16.2 ± 4.3). Study inclusion also required that each subject be able to squat at least 1.5 times their body mass and with no history of neurological and orthopedic disorders or injuries. The study was approved by the Shanghai University of Sport Ethics Committee (102772023RT102), and the experiment was conducted in accordance with the Helsinki Declaration. All participants provided written informed consent prior to participation.

Procedures

Before the 8-week training program, all participants completed two familiarization sessions designed to ensure proper understanding and execution of the testing procedures. In the first familiarization session, measurements of height, body mass, and body composition were conducted, followed by the random assignment of participants into their respective groups. Emphasis was placed on ensuring correct movement patterns for the upcoming tests and training, which was also reinforced during the warm-up period preceding each test.

The testing protocol was divided into two sessions to minimize fatigue and ensure accurate performance measurements, with more than 48h between the two sessions. In the first session, participants completed the CMJ, SJ, and 1RM squat testing in a temperature- and humidity-controlled room (24-28°C, 43-55% humidity, 1013-1030 mbar), with a 3-minute rest before SJ and a 30-minute rest before the 1RM test. Ten minutes after the SJ test, the AEL group performed AEL CMJ-specific testing, while the DJ group performed DJ-specific testing. In the second session, the T-test and 30m sprint were administered in an indoor track and field facility, with a 10-minute rest before the 30m sprint. To ensure consistency, the same examiners administered all assessments at pre-test, mid-test and post-test. Testing sessions were conducted in a consistent order and at the same time of day between 1:00 PM and 5:00 PM, to control for potential circadian influences. Participants were instructed to avoid any exhaustive physical activity for at least 48 hours prior to each testing session. A standardized verbal encouragement was given during each assessment to ensure maximal effort.

Countermovement Jump and Squat Jump Tests

The CMJ and SJ tests were performed using two force plates (9260AA, Kistler, Switzerland) with sampling frequency of 1 000 Hz on a hard rubberized floor. For the CMJ, participants started from an upright standing position with their hands on their hips. Upon the tester's command, participants performed a rapid downward countermovement by flexing their legs into a semi-squat position (approximately 90° knee flexion). Immediately following this, coupling the eccentric and concentric phases, participants explosively extended their legs to perform a vertical jump. Participants were instructed to jump as high as possible. For the SJ, participants began from a semi-squat position (approximately 90° knee flexion and trunk/hips in a flexed position), maintaining this position for approximately 2 seconds before jumping vertically as quickly and explosively as possible, aiming to achieve the highest possible jump in the shortest possible time upon the tester’s command. Both the CMJ and SJ were performed for 3 trials, with the best trial used for analysis. The jump height and peak power were calculated using methods previously described by Jiménez-Reyes et al. (2017), while other jump metrics in Table 1 were calculated using methods previously described by Bright et al. (2024).

Table 1. Reliability of the measurements from intraclass coefficients (ICC) and their 95% confidence intervals (CI), as well as the coefficients of variation (%CV) for the AEL, DJ, and CON groups.

Condition	AEL group (n = 42)		DJ group (n = 39)		CON group (n = 39)	
	ICC (95% CI)	CV % (95% CI)	ICC (95% CI)	ICC (95% CI)	CV % (95% CI)	ICC (95% CI)
CMJ height (m)	.97 (.71, .99)	14.2 (11.1, 17.2)	.98 (.96, .99)	14.5 (11.4, 17.6)	.97 (.94, .98)	13.1 (10.3, 15.9)
CMJ power (W)	.97 (.92, .99)	15.2 (11.9, 18.4)	.94 (.87, .97)	10.7 (8.3, 13.1)	.99 (.97, .99)	16.9 (13.1, 20.6)
CMJ displacement (cm)	.87 (.77, .93)	12.4 (7.6, 17.2)	.97 (.94, .98)	18.0 (11.1, 24.9)	.88 (.78, .94)	10.7 (6.6, 14.8)
CMJ Braking Time (s)	.86 (.76, .92)	22.2 (17.5, 27.0)	.88 (.79, .94)	25.9 (20.4, 31.5)	.85 (.73, .92)	26.6 (20.9, 32.3)
CMJ Propulsion Time (s)	.94 (.89, .97)	11.8 (9.2, 14.3)	.94 (.88, .97)	11.4 (8.9, 13.9)	.88 (.79, .94)	11.3 (8.8, 13.8)
CMJ Braking mean force (N)	.74 (.56, .85)	20.4 (16.0, 24.8)	.88 (.79, .94)	18.1 (14.2, 22.1)	.92 (.85, .96)	24.4 (19.1, 29.8)
CMJ Propulsion mean force (N)	.99 (.97, .99)	13.5 (10.6, 16.4)	.96 (.89, .98)	8.4 (6.5, 10.2)	.96 (.92, .98)	16.8 (13.1, 20.5)
SJ height (m)	.96 (.92, .98)	13.7 (10.8, 1.7)	.99 (.97, .99)	16.1 (12.5, 19.7)	.96 (.92, .98)	15.0 (11.63, 18.3)
SJ power (W)	.97 (.91, .99)	14.6 (11.5, 17.7)	.96 (.89, .98)	11.4 (8.9 14.0)	.98 (.97, .99)	18.2 (14.2, 22.3)
SJ Propulsion Time (s)	.80 (.66, .89)	22.8 (17.8, 27.8)	.95 (.90, .97)	25.6 (19.9, 31.2)	.80 (.66, .89)	15.9 (12.9, 19.5)
SJ Propulsion mean force (N)	.96 (.92, .98)	15.7 (12.3, 19.1)	.91 (.83, .95)	13.3 (10.4, 16.3)	.94 (.89, .97)	14.4 (11.2, 17.5)
1 RM squat (kg)	/	16.1 (12.6, 19.6)	/	16.8 (13.3, 20.3)	/	16.8 (13.3, 20.3)
30 m sprint (s)	.92 (.85, .96)	3.07 (2.4, 3.7)	.90 (.34, .97)	3.83 (3.0, 4.7)	.91 (.48, .97)	4.38 (3.41, 5.4)
T test (s)	.91 (.53, .97)	4.45 (3.5, 5.4)	.91 (.44, .97)	5.92 (4.6, 7.2)	.93 (.57, .98)	4.68 (3.64, 5.7)

AEL = accentuated eccentric loading; CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; CON = control; 1 RM = 1 repetition maximal.

30-m Sprint Test and T-Test

The 30-m sprint test was conducted on an indoor plastic track using two Beam electronic timing gates (SmartSpeed, Fusion Sport, Australia), with the starting line placed 20 cm before the first timing gate. Data were collected in real-time using an iPad. The photoelectric cells were positioned approximately 75 cm above the ground to detect trunk movement, minimizing interference from limb motion. Participants were instructed to sprint at maximum speed through the finish line, ensuring full sprint effort, starting from a stance with one foot in front of the other. Each participant completed three trials with a 3-minute rest between trials, and the fastest 30-m time was used for analysis.

For the T-test, the protocol was conducted according to the study by Vera-Assaoka et al. (2020). The starting point positioned 20 cm behind a pair of electronic timing gates. Participants began the test by sprinting 9.14 m forward to touch a cone, followed by a lateral shuffle of 4.57 m to the left to touch another cone. They then shuffled 9.14 m to the right to touch a third cone, before completing another 4.57 m leftward shuffle to touch the final cone. The test concluded with participants running backward for 9.14 m toward the starting line. Any missed cone touches or crossing of feet during the lateral shuffle resulted in a repeat trial. The fastest time from the two trials was selected for analysis.

1 RM Squat Test

Participants received training through the university's specialized fitness courses and were proficient in performing squat correctly. The 1RM squat test was conducted as follows: (a) 5 - 10 warm-up repetitions at 40 - 60% of perceived 1RM, (b) a 1-min rest with light stretching followed by 3 - 5 repetitions at 60 - 80% of perceived 1RM, and (c) 3 - 5 attempts to reach 1RM with 5-min rests between attempts. The highest successfully completed lift was recorded as the 1RM. All squats were executed to a depth where the thighs were approximately parallel to the floor.

AEL CMJ and DJ Test

Participants changed into standardized footwear and shorts, and four 14 mm reflective markers were affixed to the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) on both sides before the test. The kinematic data were recorded using a 10-camera optoelectronic system (V5, Vicon, UK). For the AEL CMJ test, participants performed a series of tests with loads from 10%, 20%, 30% and 40% body mass. Participants held a dumbbell in each hand while standing on two force plates. Subsequently, the participants were instructed to execute a countermovement to achieve approx. 90° flexion at the knee joint and perform a maximal jump. Dumbbells were dropped before the concentric phase began, and hands were returned to the hips. For the DJ test, participants performed a series of tests with box from 20 to 50 cm. Participants were required to stand upright on top of box with their hands on their hips throughout the jump and perform a maximal jump. Instructions were to step out from the box ensuring no vertical elevation or sinking and contact twin force plates. On contact with the force plates, participants were instructed to immediately perform a rapid maximum vertical jump. Each condition of AEL CMJ or DJ comprised 2 trials, with the better trial selected for final analysis. A 2-min rest interval between consecutive trials. The kinematic data were smoothed using a low-pass Butterworth filter with a cut-off frequency of 10 Hz, while kinetic data were smoothed at a cut-off frequency of 50 Hz using C-Motion Visual 3D 3.0 software. The global coordinate system was defined with the z-axis representing the vertical direction, and only data along this axis was used for further analysis. Pelvic velocity was used to represent center of mass (COM) velocity. Ground reaction force (GRF) was used to calculate force, and power was computed as the product of velocity and GRF (Power = Velocity × GRF). The concentric phase was defined from the lowest point of the pelvis along the Z-axis until the GRF dropped below 20N.

Table 2. Changes in Physical activity (MET-min/week) over time among different groups.

	Pre-test	Mid-test	Post-test
AEL group	2991.57 ± 1411.18	3259.29 ± 1195.01	3342.86 ± 1298.93
DJ group	3003.69 ± 1332.40	3334.31 ± 1388.13	3235.19 ± 1096.23
CON group	2972.62 ± 1175.08	3012.94 ± 1427.19	2877.12 ± 1375.77

AEL = Accentuated Eccentric Loading (Countermovement jump); DJ = drop jump; CON = control.

Training program

The training program lasted eight weeks, consisting of three sessions per week. Each session was supervised by the same coach to monitor technique, training volume, and program implementation. Participants were required to complete three sessions per week at a consistent time of day, with at least 48 hours between sessions. All training sessions were conducted on an indoor track and field. Each jump training session was preceded by the same standardized warm-up used during the measurement sessions. Participants warmed up by jogging on an indoor track for 10 min at an intensity rated approximately 4 - 5 on the RPE (Rating of Perceived Exertion) CR10 scale. This was followed by 10 min of dynamic full-body stretching, including the World's Greatest Stretch, Sumo Squat to Hamstring Stretch, Handwalk, and Inverted Hamstring Stretch, with two sets performed on each side. The AEL and DJ groups performed 32 jumps per session during the first four weeks and 40 jumps per session during the final four weeks. Each session was divided into 4 sets, with 8 repetitions per set during the first four weeks and 10 repetitions per set during the last four weeks. A 2-minute rest interval was provided between sets, and the rest interval between individual jumps within each set ranged from 3 to 5 seconds (Table 2). The CON group maintained their habitual lifestyle and only took part in the testing sessions. The jumping technique for the AEL and DJ groups was identical to that used in the AEL CMJ or DJ tests, with loads selected to maximize power output based on the AEL CMJ or DJ test results. Participants were instructed to perform each jump with maximal effort. Participants were instructed to maintain their regular diet and physical activity levels throughout the 8-week intervention period. To monitor this, participants completed 7-day physical activity recall (7-day PAR) interviews at three time points: pre, mid- (4 weeks), and post-intervention (8 weeks). The interviews were conducted by a trained researcher to ensure consistency and accuracy in data collection (Sallis et al., 1985).

Statistical analysis

All data are presented as means ± standard deviations. The normality of the data was confirmed using the Shapiro-Wilk test (P > 0.05). The reliability of the test variables were evaluated with a two-way random intraclass correlation coefficient (ICC) with 95% confidence intervals (CI), based on the best two test results for each type of test, and the coefficient of variation (CV) with 95% CI (Table 1).

A mixed-effects model was used to assess the effects of group (AEL, DJ, CON) and time (pretraining, after 4 weeks, after 8 weeks) on the dependent variables (CMJ, SJ, 30m sprint, T-test, squat 1RM and physical activity). F-values and p-values for the main effects and interaction effects were obtained using Type III analysis of variance (ANOVA) based on the fitted mixed-effects model. Post hoc pairwise comparisons were conducted using model-derived estimated marginal means (EMMs) with Tukey-adjusted P-values to control for multiple comparisons. Statistical significance was set at $P < 0.05$. Within-group effect sizes were calculated using Hedges *g*, interpreted as small (g = 0.2), moderate (g = 0.5), or large (g = 0.8). All analyses were performed using SPSS and R software (R Core Team, 2023) with the lme4, lmerTest, and emmeans packages.

Results

As shown in Table 3, there were no significant main effect for time ($F_{(2, 80)} = 0.74$, P = 0.48, $\eta^2 = 0.02$), group ($F_{(2, 40)} = 0.23$, P = 0.80, $\eta^2 = 0.01$) and time × group ($F_{(4, 80)} = 0.30$, P = 0.88, $\eta^2 = 0.02$) in physical activity.

As shown in Figure 2, the optimal power load for AEL CMJ was 10% BM at both pre-test and mid-test. For DJ, the optimal power height was 30 cm at pre-test and 20 cm at mid-test.

Table 3. Training program for AEL and DJ group.

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
AEL group	Sessions	3	3	3	3	3	3	3	3
	Sets	4	4	4	4	4	4	4	4
	Repetitions	8	8	8	8	10	10	10	10
	Intensity	OPL	OPL	OPL	OPL	OPL	OPL	OPL	OPL
DJ group	Sessions	3	3	3	3	3	3	3	3
	Sets	3	3	3	3	3	3	3	3
	Repetitions	8	8	8	8	10	10	10	10
	Intensity	OPL	OPL	OPL	OPL	OPL	OPL	OPL	OPL

AEL = Accentuated Eccentric Loading (Countermovement jump); DJ = drop jump; OPL = optimal power load; A 2-minute rest interval was provided between sets, and the rest interval between individual jumps within each set ranged from 3 to 5 seconds.

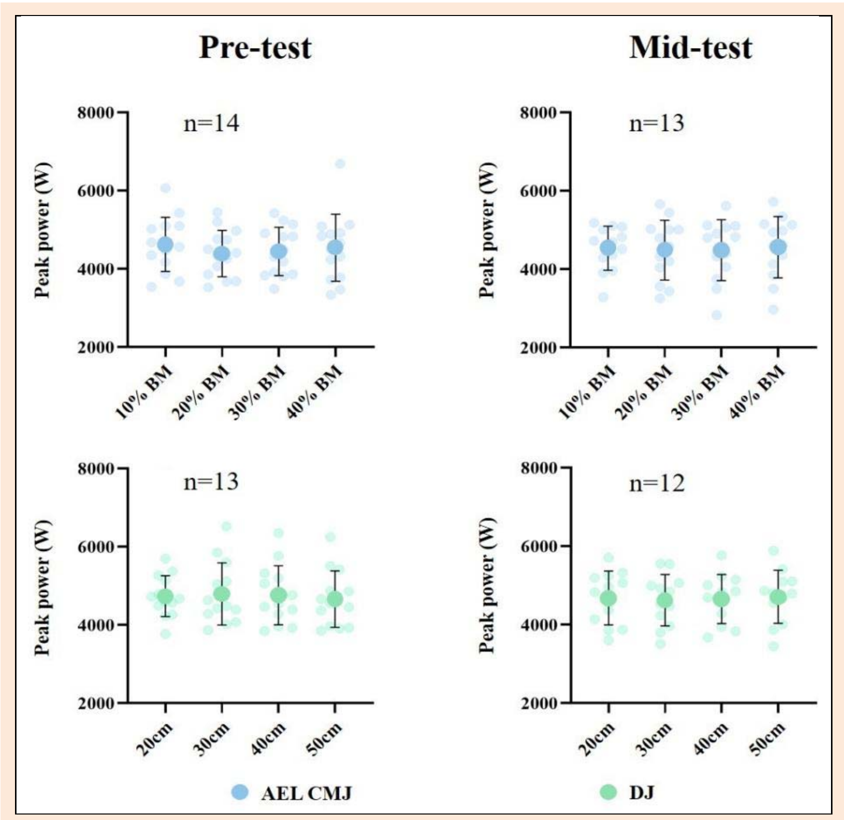

Figure 2. The peak power of CMJ, AEL CMJ and DJ test at various condition pre-test and mid-test.
AEL = accentuated eccentric loading (top panels); DJ = drop jump (bottom panels); BM = body mass.

The reliability results for CMJ, SJ, 1RM squat, 30 m sprint, and T-test across different groups and time points are presented in Table 3. ICC values ranged from 0.76 to 0.99, indicating excellent reliability across all conditions. CV values varied between 3.07% and 26.57%, reflecting variability across some indicators.

Regard jump performance, a significant time effect was observed for CMJ height ($F_{(2, 80)} = 18.38$, $P < 0.01$, $\eta^2 = 0.32$), CMJ power ($F_{(2, 80)} = 6.11$, $P < 0.01$, $\eta^2 = 0.13$), CMJ displacement ($F_{(2, 80)} = 33.71$, $P < 0.01$, $\eta^2 = 0.45$), CMJ breaking time ($F_{(2, 80)} = 6.71$, $P < 0.01$, $\eta^2 = 0.14$), CMJ propulsion time ($F_{(2, 80)} = 21.38$, $P < 0.01$, $\eta^2 = 0.35$), CMJ propulsion force ($F_{(2, 80)} = 7.05$, $P < 0.01$, $\eta^2 = 0.15$), SJ height ($F_{(2, 80)} = 15.19$, $P < 0.01$, $\eta^2 = 0.28$) and SJ power ($F_{(2, 80)} = 9.99$, $P < 0.01$, $\eta^2 = 0.20$). As shown in Table 3, both AEL and DJ groups exhibited significant improvements in CMJ height, CMJ power, CMJ displacement, CMJ propulsion time, CMJ breaking force, SJ height and SJ power after 8 weeks of training ($P < 0.05$). The percentage increases ranged from -15.4% to +11.8%, with small to large effect sizes ranging from -1.15 to 0.82 (Table 4). The CMJ breaking time also showed significant improvements in DJ group after 8 weeks ($P < 0.01$). In the CON group, the CMJ displacement and CMJ propulsion force significantly decreased after 8 weeks ($P < 0.01$ and $P < 0.05$), while CMJ propulsion time significantly improved ($P < 0.05$). CMJ displacement and CMJ propulsion time was significant changed in AEL group after 4 weeks ($P < 0.05$, -8% and +9.2%, g = -0.56 and 0.70). Further improvements were found in CMJ displacement, CMJ breaking time and CMJ propulsion time in AEL group after 4 weeks ($P < 0.05$, -8.7% to +16.3%, g = -0.46 to 0.63).

Regard lower body strength, a significant time effect was observed for 1 RM back squat ($F_{(2, 80)} = 13.76$, $P < 0.01$, $\eta^2 = 0.26$). Both AEL and DJ groups demonstrated significant improvements after 8 weeks of training ($P < 0.01$), with percentage increases of 7.0% and 8.4%, and small effect sizes (0.42 and 0.46) (Table 4). No significant improvements were observed after 4 weeks in either AEL or DJ group. For CON group, no significant improvement was observed after both 4 and 8 weeks training.

Regard acceleration and COD performance, no significant time effects were observed for 30 m sprint and T-test across AEL, DJ and CON groups. None of the groups exhibited significant improvements in 30 m sprint and T-test after 4 and 8 weeks of training (Table 5). Additionally, no significant between-group differences were found for any of the measures.

Discussion

The study explored the effects of AEL CMJ training on jump performance, lower body strength, sprinting, and COD ability and compared it with DJ training. The primary findings indicate that both 8-weeks of AEL CMJ training and DJ training produced significant improvements in jump performance and lower body strength, with no notable difference in efficacy between the two methods. However, neither intervention led to substantial improvements in sprint or COD performance, suggesting limited potential of these training modalities in enhancing these specific athletic qualities.

Table 4. Changes in CMJ, SJ, 30 m sprint, T-test, and 1RM squat over time among different groups.

	AEL group			DJ group			CON group		
	Pre-test	**Mid-test**	**Post-test**	**Pre-test**	**Mid-test**	**Post-test**	**Pre-test**	**Mid-test**	**Post-test**
CMJ Height (cm)	43.16 ± 6.24	44.84 ± 6.04	48.33 ± 6.66**	46.48 ± 6.54	48.51 ± 6.36	50.06 ± 8.12**	47.74 ± 7.34	48.61 ± 6.13	48.37 ± 6.617
CMJ Peak Power (W)	4512.48 ± 694.17	4641.72 ± 697.71	4705.70 ± 683.98**	4579.42 ± 518.63	4662.98 ± 553.54	4779.87 ± 505.14**	4462.57 ± 838.63	4488.37 ± 734.24	4421.85 ± 733.35
CMJ Displacement (cm)	-37.76 ± 5.52	-40.77 ± 4.89*	-43.63 ± 4.25**	-40.38 ± 7.95	-43.91 ± 7.02**	-46.59 ± 8.49**	-41.64 ± 5.27	-42.37 ± 4.99	-45.15 ± 5.91**
CMJ Braking Time (s)	0.20 ± 0.05	0.21 ± 0.04	0.19 ± 0.04	0.19 ± 0.04	0.22 ± 0.05*	0.23 ± 0.07**	0.18 ± 0.04	0.19 ± 0.06	0.21 ± 0.06
CMJ Propulsion Time (s)	0.28 ± 0.03	0.31 ± 0.04**	0.31 ± 0.03**	0.29 ± 0.03	0.31 ± 0.03*	0.31 ± 0.03**	0.29 ± 0.03	0.30 ± 0.03	0.31 ± 0.04*
CMJ Braking mean force (N)	1236.68 ± 306.39	1264.70 ± 223.52	1372.05 ± 252.45*	1329.91 ± 211.74	1279.35 ± 255.49	1279.35 ± 255.49	1349.37 ± 317.87	1319.09 ± 340.94	1279.40 ± 327.98
CMJ Propulsion mean force (N)	1525.62 ± 203.27	1479.08 ± 206.57	1499.57 ± 199.11	1560.39 ± 135.24	1522.03 ± 134.26	1520.08 ± 122.53	1459.09 ± 267.41	1432.03 ± 228.25	1398.87 ± 239.55*
SJ Height (cm)	41.18 ± 6.35	41.60 ± 5.12	43.54 ± 5.88*	43.35 ± 7.09	44.95 ± 6.57	48.26 ± 7.94**	43.83 ± 7.63	44.81 ± 6.38	45.32 ± 6.40
SJ Peak Power (W)	4445.24 ± 630.87	4480.36 ± 597.08	4607.02 ± 757.51*	4572.73 ± 541.59	4691.81 ± 586.32	4816.67 ± 531.52**	4451.75 ± 886.23	4324.57 ± 769.62	4483.01 ± 786.29
SJ Propulsion Time (s)	0.32 ± 0.06	0.36 ± 0.09	0.33 ± 0.08	0.33 ± 0.09	0.34 ± 0.09	0.34 ± 0.09	0.33 ± 0.07	0.32 ± 0.04	0.31 ± 0.04
SJ Propulsion mean force (N)	1426.19 ± 223.43	1370.68 ± 207.24	1429.09 ± 243.78	1479.16 ± 216.84	1451.32 ± 207.68	1475.19 ± 175.89	1352.24 ± 196.64	1360.79 ± 181.71	1383.44 ± 222.82
1 RM squat (kg)	122.86 ± 19.88	127.86 ± 22.68	131.43 ± 19.56**	124.23 ± 24.99	129.23 ± 22.16	134.62 ± 18.08**	126.92 ± 23.14	124.23 ± 21.78	131.54 ± 20.35
30 m sprint (s)	4.36 ± 0.12	4.29 ± 0.14	4.29 ± 0.13	4.28 ± 0.15	4.28 ± 0.19	4.26 ± 0.18	4.32 ± 0.22	4.32 ± 0.17	4.33 ± 0.20
T-test (s)	10.14 ± 0.56	9.93 ± 0.48	9.91 ± 0.38	10.02 ± 0.64	9.84 ± 0.64	9.83 ± 0.52	10.16 ± 0.60	10.08 ± 0.33	9.96 ± 0.48

AEL = Accentuated Eccentric Loading; DJ = drop jump; SJ = squat jump; CON = control; *significant from mid-test or post-test to pre-test ($P < 0.05$); **significant from mid-test or post-test to pre-test ($P < 0.01$).

Table 5. Comparison of Jump, Strength, Sprint, and COD Test Results Before (Pre), After 4 weeks (Mid), and After 8 weeks (Post) Tests Across AEL, DJ, and CON Groups (Mean ± SD, 95% Confidence Interval, Δ% and Effect Size)

		AEL		DJ		CON	
		%	Hedges *g*	%	Hedges *g*	%	Hedges *g*
CMJ height (cm)	pre - mid	+ 3.7%	0.26 (-0.49, 1.00) small	+ 4.4%	0.31 (-0.47, 1.08) small	+ 1.8%	0.12 (-0.65, 0.89) trivial
	pre - post	+ 11.8%	0.77 (0.00, 1.54) moderate	+ 7.7%	0.47 (-0.31, 1.25) small	+ 1.3%	0.09 (-0.68, 0.86) trivial
CMJ power (W)	pre - mid	+ 2.9%	0.18 (-0.56, 0.92) trivial	+ 1.8%	0.07 (-0.70, 0.84) trivial	+ 0.6%	0.03 (-0.74, 0.80) trivial
	pre - post	+ 4.3%	0.27 (-0.47, 1.02) small	+ 4.4%	0.31 (-0.46, 1.09) small	- 0.9%	-0.05 (-0.82, 0.72) trivial
CMJ displacement (cm)	pre - mid	- 8.0%	-0.56 (-1.32, 0.19) moderate	- 8.7%	-0.46 (-1.23, 0.32) small	- 1.7%	-0.46 (-1.23, 0.32) small
	pre - post	- 15.6%	-1.15 (-1.95, 0.35) large	- 15.4%	-0.73 (-1.53, 0.06) moderate	- 8.4%	-0.73 (-1.53, 0.06) moderate
CMJ Braking Time (s)	pre - mid	+ 7.4%	0.29 (-0.45, 1.04) small	+ 16.3%	0.63 (-0.16, 1.42) moderate	+ 8.2%	0.29 (-0.48, 1.07) small
	pre - post	- 1.3%	-0.05 (-0.79, 0.69) trivial	+ 20.8%	0.67 (-1.23, 1.46) moderate	+ 15.9%	0.57 (-0.21, 1.35) small
CMJ Propulsion Time (s)	pre - mid	+ 9.2%	0.70 (-0.07, 1.46) moderate	+ 6.8%	0.57 (-0.21, 1.35) moderate	+ 2.5%	0.22 (-0.56, 0.99) small
	pre - post	+ 7.8%	0.69 (-0.07, 1.45) moderate	+ 9.8%	0.82 (-0.02, 1.62) large	+ 6.4%	0.55 (-0.24, 1.33) small
CMJ Braking mean force (N)	pre - mid	+ 2.3%	0.10 (-0.64, 0.84) trivial	- 3.8%	-0.21 (-0.98, 0.56) small	-2.2%	-0.09 (-0.96, 0.68) trivial
	pre - post	+ 11.0%	0.47 (-0.68, 1.22) small	- 2.9%	-0.16 (-0.93, 61) trivial	-5.2%	-0.21 (-0.98, 0.56) small
CMJ Propulsion mean force (N)	pre - mid	-3.2%	-0.23 (-0.97, 0.51) small	-2.5%	-0.28 (-1.05, 0.50) small	-1.9%	-0.11 (-0.88, 0.66) trivial
	pre - post	-1.9%	-0.14 (-0.88,0.61) trivial	- 2.6%	-0.30 (-1.08, 0.47) small	- 4.1%	-0.23 (-1.00, 0.54) small
SJ height (m)	pre - mid	+ 1.0%	0.07 (-0.70, 0.84) trivial	+ 3.7%	0.23 (-0.54, 1.00) small	+ 2.2%	0.14 (-0.63, 0.91) trivial
	pre - post	+ 5.7%	0.37 (-0.40, 1.15) small	+ 11.3%	0.63 (-0.16, 1.42) moderate	+ 3.4%	0.21 (-0.57, 0.98) trivial
SJ power (W)	pre - mid	+ 0.8%	0.07 (-0.67, 0.81) trivial	+ 2.6%	0.20 (-0.57, 0.98) small	- 2.9%	-0.15 ((-0.92, 0.62) trivial
	pre - post	+ 3.6%	0.23 (-0.52, 0.97) small	+ 5.3%	0.44 (-0.34, 1.22) small	+ 0.7%	0.04 (-0.73, 0.805) trivial
SJ Propulsion Time (s)	pre - mid	- 3.9%	-0.25 (-1.00, 0.49) small	- 1.9%	-0.13 (-0.90, 0.64) trivial	+ 0.6%	0.04 (-0.73, 0.81) trivial
	pre - post	+ 0.2%	0.01 (-0.73, 0.75) trivial	- 0.3%	-0.02 (-0.79, 0.75) trivial	+ 2.3%	0.14 (-0.63, 0.91) trivial
SJ Propulsion mean force (N)	pre - mid	+ 11.6%	0.48 (-0.27, 1.23) small	+ 4.5%	0.16 (-0.61, 0.93) trivial	- 4.6%	-0.27 (-1.04, 0.51) small
	pre - post	+ 4.2%	0.18 (-0.56, 0.93) trivial	+ 4.2%	0.15 (-0.62, 0.92) trivial	- 5.9%	-0.35 (-1.32, 0.43) small
1 RM squat (kg)	pre - mid	+ 4.1%	0.23 (-0.52, 0.97) small	+ 4.0%	0.21 (-0.57, 0.98) small	- 2.1%	-0.12 (-0.89, 0.65) trivial
	pre - post	+ 7.0%	0.42 (-0.33, 1.17) small	+ 8.4%	0.46 (-0.32, 1.24) small	+ 3.6%	0.21 (-0.56, 0.98) small
30 m sprint (s)	pre - mid	- 1.4%	-0.45 (-1.23, 0.33) small	- 0.1%	-0.01 (-0.78, 0.75) trivial	+ 0.1%	0.02 (-0.77, 0.79) trivial
	pre - post	- 1.4%	-0.56 (-1.34, 0.23) moderate	- 0.6%	-0.16 (-0.93, 0.61) trivial	+ 0.3%	0.07 (-0.70, 0.84) trivial
T test (s)	pre - mid	- 2.1%	-0.45 (-1.20, 0.31) small	- 1.7%	-0.26 (-1.04, 0.51) small	- 0.9%	-0.18 (-0.95, 0.60) trivial
	pre - post	- 2.3%	-0.53 (-1.29, 0.22) moderate	- 1.9%	-0.31 (-1.09, 0.46) small	- 1.8%	-0.36 (-1.13, 0.42) small

CMJ = countermovement jump; SJ = squat jump; AEL = accentuated eccentric loading countermovement jump group; DJ = drop jump group; 1 RM = 1 repetition maximal; CON = control group.

Jump performance

Previous research has confirmed that both AEL CMJ training and DJ training can enhance both lower body power and vertical jump height (Sheppard et al., 2008; Marshall and Moran, 2013). Consistent with these findings, the results of the present study demonstrate that after 8-week training, the AEL group achieved increases of 4.3% and 3.6% in CMJ and SJ power, respectively, alongside improvements of 11.8% and 5.7% in CMJ and SJ height. Similarly, the DJ training group experienced increases of 4.4% and 5.3% in CMJ and SJ power, respectively, and enhancements of 7.7% and 11.3% in CMJ and SJ height. In contrast, the CON group showed a 0.9% decrease and a 0.7% increase in CMJ and SJ power, respectively, along with a 1.3% and 3.4% increase in CMJ and SJ height, respectively. The mechanisms behind AEL are hypothesized to involve two main factors: enhanced storage and return of elastic strain energy through external loading, and increased motor neuron activation, leading to stronger efferent impulses to the extrafusal muscle fibers (Sheppard et al., 2007; Bright et al., 2024). Similarly, the mechanisms of the DJ are based on two key aspects: the descent phase enhances the ability to store and release elastic strain energy, and muscle excitation levels are increased by eliciting a functional stretch reflex or monosynaptic reflex, thereby facilitating a more forceful concentric contraction (Stone, 1993; McClenton et al., 2008).

Although AEL CMJ training and DJ training increase eccentric loading by incorporating external load to the downward phase of the jump and experiencing greater eccentric loading from dropping off an elevated platform, both training methods exhibit similar improvements in lower body power and jump height. The use of individualized optimal power loads and heights in both training methods may have influenced the level of similarity in change for jump metrics in both training methods irrespective of the differing eccentric stimulus provided to the groups, supporting the existing research that suggests optimal power loading provides the most effective for power improvements across various movements (Soriano et al., 2015). The improvements in lower body power and jump height may be attributable to both neurogenic and myogenic factors. Both AEL and DJ are forms of plyometric training, which can significantly increase maximal voluntary contraction (MVC) and improve inter-muscular coordination (Markovic and Mikulic, 2010). A previous study has indicated that both DJ and CMJ training can improve the muscle contractile component (Gehri et al., 1998), enhancing the muscle's ability to generate force. Therefore, AEL CMJ may also benefit from this mechanism. Furthermore, both groups exhibited significant increases in lower body strength after the 8-week training period. Given the relationship of: Power = Force × Velocity, the increases in strength contributes to the observed enhancements in lower body power and jump height.

Lower body strength

In this study, both the AEL and DJ groups demonstrated significant improvements in lower body strength after 8-weeks training, with 1RM squat increased 7.0% and 8.4%, with effect size of 0.42 and 0.46, respectively. While the control group showed no significant changes. These findings align with previous research indicating that plyometric training effectively enhances lower body strength. Kaabi et al. (2022) reported a 13.5% increase in 1RM squat among men junior table tennis players following 8-weeks of plyometric training, where the baseline strength of participants was lower than the current study (87.20 ± 4.71 *vs.* 124.63 ± 22.17 kg), which may explain their larger improvement. The increase in lower body strength can be attributed to two factors. Firstly, similar to the enhancements in lower body power, the improvement of motor unit behavior can increase muscle strength. Secondly, muscle hypertrophy may also play a role. Both AEL CMJ training and DJ training involve accentuated eccentric loading, which can cause damage to muscle fibers contractile and cytoskeletal components (Friden and Lieber, 1992). This damage triggers an immune response that releases cytokines and other growth factors, promoting muscle growth and repair, which results in muscle hypertrophy (Schoenfeld, 2010). However, it is important to note that muscle hypertrophy was not directly measured in this study, and thus, this remains a proposed mechanism based on existing evidence rather than a confirmed outcome of the training protocols used here.

Sprint performance

None of the groups exhibited significant improvement in sprint performance after 8 weeks of training. However, both DJ and AEL groups showed a trend towards reduced sprint times (ES = -0.16 and -0.56, respectively). The findings of a meta-analysis by Villarreal et al. examining the effects of plyometric training on sprint performance are consistent with those of the present study. Their results showed that although plyometric training significantly reduced sprint times ($P < 0.01$), single-mode vertical jump training (i.e., DJ or SJ) did not significantly reduce sprint times, with effect sizes of 0.27 and 0.16, respectively (de Villarreal et al., 2012). The lack of horizontal plyometric training may be a contributing factor to the lack of significant improvements. In the present study, the training involved repeated single-type, discrete vertical plyometric jumps, whereas the 30 m sprint is both a continuous movement and independent motor skill. Additionally, both AEL CMJ and DJ training required participants to focus on achieving maximum jump height rather than completing the movement as quickly as possible. This approach is beneficial for enhancing lower body propulsive ability but may have a limited effect on tendon adaptations. In contrast, sprinting is a "fast" SSC activity that places greater demands on tendon function (Stafilidis and Arampatzis, 2007). This difference may explain the observed discrepancies between acceleration sprinting and vertical jump performance. Furthermore, although the 30 m sprint is a commonly used method to measure acceleration performance, some studies suggest that plyometric training is more effective at improving short-distance sprints (i.e., 5 m and 10 m) (Loturco et al., 2015). These findings further highlight that improving sprint performance requires not only vertical plyometric training but also specific movement-pattern training tailored to the sprint task.

Change of Direction Performance

Similar to the results for the sprint performance, none of the three groups showed significant improvements in COD performance after 8 weeks of training ($P = 0.10 - 0.23$). This finding contrasts with a meta-analysis by Asadi et al., (2016). which examined the effects of plyometric training on COD ability In that study, plyometric training significantly improved COD ability, with an effect size (0.96) significantly higher than control group (-0.02). Studies using the T-test as the assessment method also reported a high effect size (0.99). This may be due to the relatively low repetitions of jumps per session in this study, with only 32 repetitions per session, while other studies have employed 48 - 72 repetitions per session. The training volume used in this study may not have been sufficient to achieve improvements in COD ability. Therefore, enhancing COD ability may require a minimum of 48 repetitions per session.

The results of this study did not show any significant improvements in lower body power or related performance measures after 4 weeks of training. Similar findings were reported by Luebbers et al. (2003) who also observed that 4 weeks of plyometric training did not lead to significant gains in vertical jump power. However, other studies have demonstrated that plyometric training for 4 weeks can significantly enhance lower body strength and related performance (Keller et al., 2014; Poomsalood and Pakulanon, 2015). These discrepancies may be because 4 weeks of training represents a threshold period for inducing improvements in lower body power, with variations in training protocols and individual differences influencing the overall outcomes. Additionally, the training volume during the first 4 weeks was lower than 5 - 8 weeks, which could further explain why the 8-week intervention was more effective. It is worth noting that participants maintained their usual exercise habits throughout the study. The impact of these habitual activities on the study outcomes remains unclear.

The findings of this study suggest that both AEL and DJ training are effective in enhancing vertical jump performance and lower body strength after 8 weeks of intervention. Practitioners and coaches aiming to improve vertical jump performance and lower body strength in athletes can implement either AEL or DJ training as part of their plyometric training programs, as both methods yield comparable improvements. However, AEL training may serve as a safer alternative for athletes in the early stages of lower limb injury recovery, as the eccentric load in AEL CMJ tends to be lower than that in DJ, potentially reducing the risk of injury during the recovery phase. Although the current study did not specifically measure eccentric torque, existing evidence suggests that AEL CMJ training could place less stress on the lower limbs, making it a suitable option for athletes needing controlled eccentric loads during rehabilitation. Future research could explore whether combining AEL CMJ and DJ training offers greater benefits than using each method individually.

Several limitations are worth mentioning. First, although this study employed a randomized controlled design, baseline differences in participant characteristics (e.g., baseline strength or jump ability) may have diminished the observed training effects between groups. Second, this study did not include long-term follow-up testing, limiting insights into retention of adaptations. Additionally, this study is the lack of a monitoring process to track the intensity and load throughout the intervention. This prevents a clear understanding of whether the participants received the intended training stimulus at the appropriate level. Despite these factors, the main conclusions regarding immediate intervention effects remain valid.

Conclusion

Eight-week AEL CMJ training and DJ training improved vertical jump performance and lower body strength in physically active individuals, both training methods with similar effects. However, neither training improved acceleration or COD performance, and no significant gains were observed after the first four weeks. Practitioners and coaches aiming to improve vertical jump performance and lower body strength in athletes can implement either AEL or DJ training as part of their plyometric training programs, as both methods yield comparable improvements. Future research could consider combining AEL and DJ training with other types of SSC exercises to explore complementary methods for optimizing sprint and COD performance.

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Key points

- Eight-week AEL CMJ training and DJ training improved vertical jump performance and lower body strength, both training methods with similar effects.
- Neither 8-week AEL CMJ training and DJ training improved acceleration or COD performance.
- Neither 4-week AEL CMJ training and DJ training improved vertical jump performance, lower body strength, acceleration or COD performance.

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