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Submaximal Accentuated Eccentric Jump Training Improves Punching Performance and Countermovement Jump Force–Time Variables in Amateur Boxers

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Abstract

Objective: This study aimed to identify the effects of a submaximal jump training program using accentuated eccentric loading (AEL) on punching performance and countermovement jump (CMJ) force–time characteristics in amateur boxers. **Methods:** Twenty-nine amateur boxers (age: 24.9 ± 5.4 years; height of 175.9 ± 5.2 cm; body mass: 76.2 ± 10.5 kg) were randomly assigned to three groups: AEL group (n = 9), CMJ group (n = 10), and control group (n = 10). The AEL group performed countermovement jumps using handheld dumbbells equivalent to 10–20% of body mass, followed by unloaded concentric phases. All participants were evaluated pre- and post-intervention on punching peak force and countermovement jump performance. **Results:** Significant differences were found in favor of the AEL group for the peak force of the jab punch (pre: 1050 ± 203; post: 1158 ± 189 N), straight punch (pre: 1685 ± 393; post: 1861 ± 429 N), right cross punch (pre: 2005 ± 362; post: 2150 ± 417 N), and left cross punch (pre: 1836 ± 312; post: 1977 ± 393 N), along with greater gains in jump height, propulsive impulse, and absolute and relative peak power than the CMJ and control groups. **Conclusions:** A submaximal accentuated eccentric jump training program enhances punching peak force and lower-limb power output in amateur boxers, offering a practical strategy for improving power-oriented performance during preparatory training phases.

Keywords: combat sports; boxing; accentuated eccentric loading; plyometric training

1. Introduction

Currently, the interest of researchers regarding eccentric muscle actions and their associated training methods has increased substantially due to their multiple benefits [1–4].

These include an increased capacity to generate force, a selective recruitment of high-threshold motor units (IIx), and a lower metabolic cost per unit of external work versus concentric and isometric actions [4,5]. Accentuated eccentric loading (AEL) is a training method that uses eccentric loads greater than concentric loading in full stretch-shortening cycles, with minimal disruption to natural movement mechanics [4]. The magnitude of the eccentric load prescribed during AEL can be less than the concentric repetition maximum (i.e., submaximal AEL), equal to the concentric repetition maximum (maximal AEL), or greater than the concentric repetition maximum (i.e., supramaximal AEL) [6]. An example of submaximal AEL is countermovement jump (CMJ), which could be effective when prescribed with loads around 10–20% of body mass to improve muscle strength and power characteristics [3]. Conversely, maximal and supramaximal AEL have commonly been implemented using weight releasers during traditional exercises such as the squat or bench press [6], with the primary goal of improving maximal strength [4,6]. However, these approaches present practical limitations for use in sports settings due to the requirement of specific equipment [6].

The use of submaximal AEL has been reported to produce acute improvements in vertical jump height, strength, velocity, and power [7–11], as well as chronic enhancements in kinetic and kinematic variables of the jump [12–14]. However, the current evidence remains partially inconsistent regarding the optimal prescription of submaximal AEL. This uncertainty arises due to heterogeneity in participants' training experience and relative strength levels, variations in exercise selection (e.g., squat vs. jump exercises), differences in load magnitude, diversity in AEL implementation methods (e.g., weight releasers, dumbbells, elastic bands), and inconsistency in the performance outcomes analyzed across studies [3,4,6]. On the other hand, most existing studies have focused on analyzing the short-term effects of submaximal accentuated eccentric loading (AEL) through jumping exercises (i.e., immediately after or within a few days following a single or limited number of sessions) [7–11]. In contrast, there remains limited research investigating longer-term adaptations following multi-week submaximal AEL interventions aimed at improving physical fitness in athletes [12–15]. To date, only two studies [14,15] have examined multi-week submaximal AEL interventions using CMJ protocols. Both studies concluded that additional research is needed to optimize training parameters (e.g., frequency, volume, intensity) and to better understand the time course and magnitude of adaptations when applying AEL compared to traditional loading protocols.

However, to our knowledge, no study has investigated the longer-term adaptations to AEL in combat sports, specifically in amateur boxers. Given the needs of boxers to increase their lower body muscle strength and power to increase the peak force of their punches [16], the inclusion of a submaximal accentuated eccentric loading jump training program could be beneficial for their performance, becoming a new training alternative for coaches and physical trainers. Therefore, this study aimed to identify the effects of a submaximal accentuated eccentric jump training program on punching performance and countermovement jump force–time characteristics in amateur boxers. Based on existing findings [3,13,14,17], we hypothesized that a submaximal accentuated eccentric loading jump training program would improve punch peak force and CMJ kinetic variables to a greater extent compared to the jumping condition without AEL.

2. Materials and Methods

2.1. Study Design

This study employed a single-blind experimental design for the evaluators (Figure 1). Participants were randomly assigned to one of three groups: an Accentuated Eccentric Loading group (AEL), a Countermovement Jump without AEL group (CMJ), and a control group. The intervention lasted five weeks, and all participants underwent four evaluations: (i) body mass (BM); (ii) one repetition-maximum test in back squat (1RM); (iii) CMJ test; (iv) punching peak force. Participants were re-evaluated post-intervention on CMJ test and punching peak force. Baseline assessments were conducted in the afternoon (PM) with 24 h of rest in between, and participants were asked to refrain from vigorous exercise and alcohol or stimulant consumption for 48 h prior to each measurement.

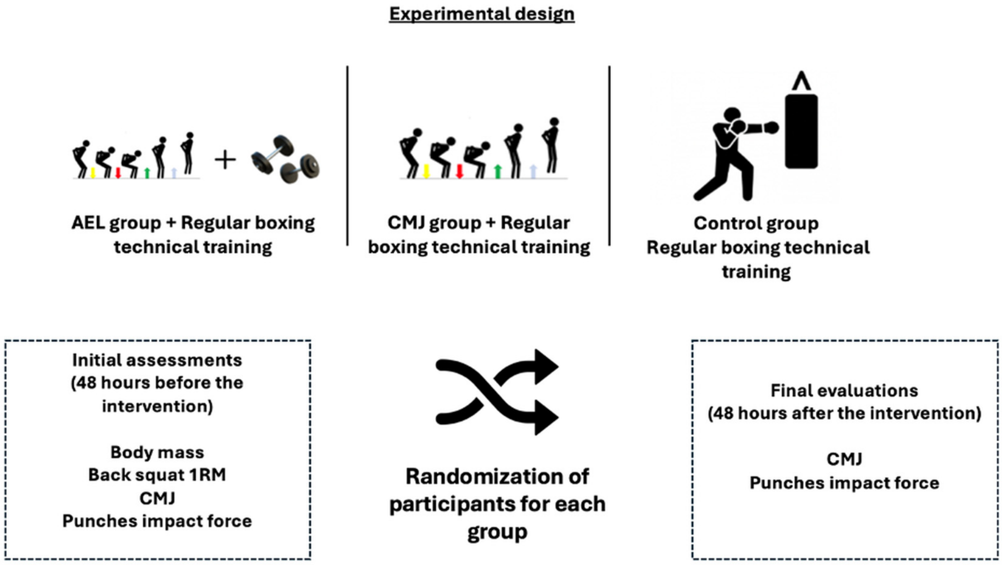

Figure 1. Experimental design of the study. AEL: accentuated eccentric loading. CMJ: countermovement jump. 1RM: one-repetition maximum.

2.2. Participants

A convenience sample of 30 male amateur boxers from a boxing club in Santiago, Chile, participated in this study (mean age: 24.9 ± 5.4 years; height: 175.9 ± 5.2 cm; body mass: 76.2 ± 10.5 kg). Considering the scarcity of randomized controlled trials involving interventions in amateur boxing [18,19] and to ensure a sufficient sample size while accounting for potential dropouts, a total of 30 participants were recruited. Post hoc sensitivity analysis was conducted using G*Power software (Version 3.1.9.6, Franz Faul, Universiät Kiel, Kiel, Germany) for repeated measures ANOVA (3 groups × 2 time points; group × time interaction), with $\alpha = 0.05$, power = 0.80, and a total sample size of 30. The analysis indicated that the present study was adequately powered to detect interaction effects with a minimum effect size of $f \geq 0.30$, which corresponds to a partial eta squared (η^2p) of approximately 0.083 considered a medium effect. All participants were competitive boxers and met the following inclusion criteria: (a) more than 1 year of competition experience; (b) regular boxing training three or more times per week; (c) not undergoing a rapid weight loss process. The study was conducted during the general phase of the season, with no competitions nearby. Boxers had to be free of any injury or neuromuscular disorder. All athletes gave their written consent after being informed about the procedures and associated risks of the intervention. In addition, in case of eventual discomfort or injury in an athlete, the protocol to follow was to refer him to the gym's kinesiologist who, through a diagnosis, evaluated the athlete's continuation in the research; this was only necessary with 1 athlete who had an injury outside of training and was not included in the final evaluations, so the sample consisted of 29 boxers. This research was conducted in compliance with the Helsinki standards for work with human beings and was approved by the Institutional Ethics Committee of the University of Santiago de Chile (number: N° 240/2025). Table 1 presents the demographic data of the participants in each intervention group. No significant differences were found in any of the variables analyzed.

Table 1. Participant demographic and baseline strength characteristics. Values are presented as mean ± standard deviation. AEL: accentuated eccentric loading; CMJ: countermovement jump; CON: control group; 1RM: one-repetition maximum; η^2p: partial eta squared.

Variables	AEL (n = 9)	CMJ (n = 10)	CON (n = 10)	*p*	F Value	η^2p
Age (years)	26.6 ± 4.6	26.8 ± 4.5	27.5 ± 4.8	0.93	$F_{(2,27)}$ 0.21	0.04
Height (cm)	1.75 ± 0.02	1.74 ± 0.06	1.75 ± 0.06	0.53	$F_{(2,27)}$ 1.65	0.04
Body mass (kg)	76.9 ± 8.3	77.2 ± 11.8	73.9 ± 11.7	0.75	$F_{(2,27)}$ 1.62	0.02
Back squat 1RM (kg)	112 ± 1	110 ± 1	110 ± 2	0.95	$F_{(2,27)}$ 0.57	0.003
Relative strength (kg/kg)	1.5 ± 0.2	1.4 ± 0.1	1.5 ± 0.2	0.42	$F_{(2,27)}$ 0.90	0.007

2.3. Procedures

Boxers were randomly assigned to two experimental groups and one control group, with group assignments prepared using an Excel spreadsheet (Microsoft Office Excel 2007). Participants' identities were protected using the CANDIDATE tool, an anonymous identifier generator based on numerical values assigned to each participant. This tool has been shown to successfully assign unique and anonymous IDs [20]. Prior to randomization, participants were stratified by their relative lower-body strength (1RM back squat/body mass) and baseline peak straight punch force to ensure an even distribution of key neuromuscular performance indicators across groups. These IDs were then sequentially allocated to one of the three groups in a 1:1:1 ratio. The allocation was performed by an independent researcher not involved in the intervention or data analysis, ensuring allocation concealment.

The CMJ group with accentuated eccentric load (AEL), the CMJ group without accentuated eccentric load (CMJ) and the control group (CON) were composed of the same number of participants (n = 10). The AEL training group used dumbbells with 10% and 20% of their BM. The countermovement jump (CMJ) with accentuated eccentric loading was performed by executing the eccentric (downward) phase in less than 2 s [2] while holding dumbbells. Upon completion of the eccentric phase, the dumbbells were released by the athlete, and the concentric (upward) phase of the jump was immediately initiated without the external load. The CMJ training group performed countermovement jumps without accentuated eccentric loading. The CON group did not perform any type of jump beyond 10 min of jump rope as a warm-up before technical boxing training. In addition, the control group performed continuous aerobic endurance training at 60% of each individual's maximum heart rate, three times per week for 30 min per session. This protocol was selected to reflect low-intensity, non-resistance-based physical activity, and no additional resistance or plyometric exercises were included. The duration of the training program for all groups was five weeks. In addition, all groups performed their regular boxing training, which was monitored through subjective perception of exertion with the CR-10 scale, which has been shown to be a valid method to quantify training during a wide variety of exercise types and allows quantitative assessment of training periodization [21]. All participants had full assistance during the intervention. Figure 2 details the training program for the AEL and CMJ groups.

Training program
(three times a week)
Weeks 1 and 2 : 3 sets of 5 repetitions with a 3-minute recovery time between sets
Weeks 3 and 4: 4 sets of 5 repetitions with a 3-minute recovery time between sets
Week 5 : 3 sets of 5 repetitions with a 3-minute recovery time between sets

Intensity for AEL training group (Weeks 1 and 2): 10% of BW
Intensity for AEL training group (Weeks 3 and 4): 20% of BW
Intensity for AEL training group (Week 5): 20% of BW
Intensity for CMJ training group : only BM without extra load added

Regular technical boxing training for all groups

Figure 2. Training program for AEL and CMJ groups. AEL: accentuated eccentric loading. CMJ: countermovement jump. BW: body weight.

2.3.1. Regular Boxing Training

The two experimental groups and the CON participated in the same regular boxing training sessions, which took place five times a week for five weeks. Each training session lasted 90 min and consisted of technical and tactical exercises. The session started with a 15 min general warm-up, starting with a jump rope exercise, followed by three rounds of freely executed technical movements, performing punches in the air and visualizing combat situations. The main part of the training lasted 60 min, where combinations of technical punches on the punching bag and impact focuses were performed, followed by tactical work of moderate to high intensity to prepare the athletes for specific combat situations, with a subjective perception of effort (0–10 arbitrary units) of 8–9 [21]. The last 15 min included free flexibility exercises. On Fridays of each week, the boxers participated in a simulated fight lasting three to four rounds.

2.3.2. Training Protocol

The training program for the AEL and CMJ groups had a frequency of three times per week for five weeks. For the CMJ group, the training consisted of performing 3–4 sets of 5 repetitions of the CMJ without additional load (BM only) with 2 min of recovery between sets. For the AEL group, training consisted of performing 3–4 sets of 5 repetitions of CMJ with extra weight via dumbbells representing 10–20% of their BM with 2 min of recovery between sets. As mentioned above, the execution of the CMJ with accentuated eccentric load consisted of performing the descent (eccentric phase) in <2 s [2], holding dumbbells equivalent to 10–20% of their BM, which were released onto mats located on the sides of each leg at the end of the eccentric phase, initiating the concentric phase of the jump without the dumbbells. The reason athletes executed the AEL CMJ in <2 s is because in previous research [2,22], completing eccentric times of < two seconds increased maximal performance, velocity, and power of a subsequent concentric repetition compared to tempos of > four seconds. Specifically, rapid eccentric actions (e.g., eccentric overload or AEL) with velocities or durations less than < two seconds can improve maximal power output, horizontal deceleration, and stretch-shortening cycle skills that are important for performance in many sports [22]. Tempos > four seconds in duration have been shown to increase time under tension (TUT) by accumulating higher concentrations of blood lactate, growth hormone, and testosterone, while reduced tempos allow for a greater training volume to be completed, reducing these effects [2]. Given the few studies with chronic AEL interventions, the program was based on current recommendations and on progressive overload on a weekly basis. In the first and second week, both groups performed three sets with five repetitions in each set; in the third and fourth week, they performed four sets with five repetitions in each set; and in the fifth week, they performed three sets with five repetitions in each set. Attendance to all training sessions was monitored and recorded by the research team. All participants demonstrated full compliance with the intervention protocols, achieving 100% attendance across the five-week training period.

2.4. Assessments

2.4.1. Body Mass

BM was recorded using the CAPSTONE software version 1.13.4 (PASCO®, Roseville, CA, USA) through of force platform PS-2142 (PASCO® Scientific, Roseville, CA, USA) with a sampling rate of 1000 Hz [23]. Subjects were instructed to place their hands on their hips and look straight ahead for two seconds. The data recorded during this time were averaged to obtain body weight (newton) divided by gravity (-9.806 m/s^2) [24] to obtain BM (kg). These data were used to prescribe the training load in the AEL group.

2.4.2. Back Squat One-Repetition Maximum (1RM)

In order to determine participants' relative lower body strength, which may influence their adaptations to AEL training [25], back squat 1RM was assessed using a standardized protocol with individual warm-up loads [26]. During all attempts, participants were required to descend to a depth at which a 90° knee angle was achieved within a weightlifting cage with safety supports. This angle was previously measured prior to the warm-up sets using a goniometer, along with the addition of an elastic band set at a height where it made contact with the glutes as the subjects descended in the eccentric phase; this was also reinforced by verbal commands. All participants had four attempts to obtain their 1RM. Performance of this test was reported as absolute and relative strength (1RM/PC). This assessment was conducted only once prior to the start of the intervention.

2.4.3. Countermovement Jump (CMJ)

Each athlete performed three CMJ recorded using the CAPSTONE software version 1.13.4 (PASCO®, Roseville, CA, USA) on two force platforms PS-2142 (PASCO® Scientific, Roseville, CA, USA) with a sampling rate of 1000 Hz [23], and one minute rest between attempts, under the supervision of physical activity sciences professional. The subjects placed their hands on their hips throughout the jump. Before the evaluation, a warm-up was performed, divided into three blocks: a general block, which consisted of performing joint mobility exercises, as well as dynamic stretches and ballistic stretches with emphasis on the lower limbs. This was followed by a specific block where low-impact jumps were performed on a coordination ladder, performing two sets of five repetitions with a one-minute rest between sets, and the final block, where they performed the CMJ jump three times. The entire warm-up lasted approximately 10 min. The week prior to the assessments, a familiarization session with the jumping technique was carried out. Prior to the intervention period, the reliability of the countermovement jump (CMJ) assessment was evaluated using a test–retest design. Each participant performed two CMJ testing sessions separated by 48 h under identical conditions. The intraclass correlation coefficient (ICC, two-way mixed model, absolute agreement, single measure ICC (3,1)) was calculated to assess relative reliability for jump height, propulsive impulse, and peak power. The standard error of measurement (SEM), coefficient of variation (CV), and technical error (TE) were also calculated to determine absolute reliability. The kinetic and kinematic variables analyzed based on existing literature were as follows [2,3,27]: (i) peak power; (ii) propulsive impulse (concentric); and (iii) jump height.

The reliability results of the CMJ assessment presented significant differences for propulsive impulse ($p = 0.03$) in the test–retest comparison. The jump height presented excellent reliability during the test–retest (ICC of 0.91), the propulsive impulse presented excellent reliability during the test–retest (ICC of 0.97), and likewise the peak power also presented excellent reliability during the test–retest (ICC 0.98). The coefficient of variation for the variables analyzed ranged between 12% and 17%. The standard error of the mean was similar for jump height (SEM 0.24) and propulsive impulse (SEM 0.89), being greater for peak power (SEM 16.7). The technical error (TE) was 1.13 cm for jump height, 3.56 Ns for propulsive impulse, and 79.6 w for peak power.

2.4.4. Punching Peak Force

Punching peak force was recorded using CAPSTONE software version 1.13.4 (PASCO®, Roseville, CA, USA) connected to a force plate (Pasco PS-2142, PASCO® Scientific, Roseville, CA, USA) operating at a sampling rate of 1000 Hz. The force plate was mounted vertically on a wall at a distance that allowed boxers to execute straight and curved punches with proper technique. The force–time data were captured during the moment of initial contact, and the peak force value within that impact window was used as the primary kinetic variable. A double padding of 21 kg and 30 kg high-density foam was installed with the same dimensions as the force plate (35 × 35 cm). The boxers performed a three-punch maximum protocol including straight punches and curved punches with both hands to the vertically mounted force plate, interspersing a five-second rest between each type of punch. Prior to the maximal punching protocol, participants performed a standardized three-minute round of boxing with punching techniques visualizing an imaginary opponent, dynamic activation, and mobility exercises, in addition to a three-minute round of the boxing-specific exercise protocol (BSEP) [28]. The above is based on recommendations on the inclusion of specific activities in the warm-up task to ensure ecological validity [29]. Based on the study by Finlay et al. [28], prior to and at each one-minute interval of the warm-up BSEP round, participants performed submaximal efforts of the punch types described above at progressive self-perceived intensities at 50%, 70%, 90%, and 100% of the force plate. In the maximal and submaximal punching efforts, athletes were asked to punch a target (red circle) located in the middle of the protective foam padding, which corresponded to the center of the force plate. Additionally, participants were asked to perform all punches at a self-selected distance to replicate punching technique from training and competition, thereby increasing ecological validity. Finally, boxers were asked to wear their own hand wraps and 16-ounce gloves during each testing session to protect their hands.

Prior to the intervention period, the reliability of punching peak force assessments was evaluated using a test–retest design. Each participant performed two punching assessment sessions separated by 48 h under identical conditions. The intraclass correlation coefficient (ICC, two-way mixed-effects model, absolute agreement, single measure: ICC(3,1)) was calculated to assess relative reliability for peak force across all punch types (jab, straight, right cross, and left cross). The standard error of measurement (SEM), coefficient of variation (CV), and technical error (TE) were also calculated to determine absolute reliability. The reliability results of the punching peak force assessments showed that no significant differences were found in the test–retest comparison. The peak force of all punches showed excellent reliability during the test–retest (jab punch ICC of 0.91; straight punch ICC of 0.92; right cross punch ICC of 0.95; left cross punch ICC of 0.97). The coefficient of variation (CV) for the peak force of the punches ranged between 5% and 20%. The standard error of the mean was similar for the jab (SEM 11.40), the right cross (SEM 14.49), and the left cross (SEM 11.16), being higher for the straight punch (SEM 18.49). TE for peak force was 44.1 N for the jab, 87.4 N for the straight punch, 57.1 N for the right cross, and 46.6 N for the left cross.

The first day's assessments began with the measurement of BM, CMJ, and punching peak force. On the second day, back squat 1RM was assessed, and on the third day, the retest was conducted for the evaluation of the CMJ and the punching peak force. Prior to the start of the intervention, the AEL group performed two familiarization sessions with 48 h of rest between them for the correct execution of the CMJ with AEL.

2.5. Data Processing

The force's signals were acquired from the CMJ test and punching performance test through CAPSTONE software version 1.13.4 (PASCO® Scientific, Roseville, CA). All signals were processed in the same software, CAPSTONE, and filtered with a fourth-order low-pass Butterworth filter with a cut-off frequency of 50 Hz, and the onset was determined using the five standard deviations. In the CMJ test, the variables were calculated as follows: (i) peak power was calculated through derivation from the force–time curve [net force * velocity] [23]; (ii) propulsive impulse was calculated through derivation from the force–time curve [net force * Δtime] [23]; and (iii) jump height was calculated using the impulse method [24]. For the punching performance test, the variable peak force was identical to the algorithm of maximum magnitude in the force–time curve [28].

2.6. Statistical Analysis

The distribution of the variables was examined using the Shapiro–Wilk test. The data are presented as mean and standard deviation. To determine possible differences in baseline between groups, a one-way ANOVA test was run for different groups. After five weeks, a repeated measures factorial ANOVA (2×3) analysis of variance was performed for the time factor (pre-post intervention) by the group factor (AEL, CMJ and CON). When significant differences were detected in the ANOVA, a Bonferroni post hoc test was corrected, and only the interaction effect post hoc test was reported when significant (i.e., post hoc tests isolated from main effects were not reported). Cohen's d was calculated as a measure of effect size (ES); the formula used was $d = (M^1 - M^2)/SD$. Threshold values for Cohen's d statistics correspond to <0.20 [trivial], 0.20 to 0.59 [small], 0.60 to 1.19 [moderate], 1.20 to 1.99 [large], 2.0 to 3.99 [very large], and >4.0 [extremely large] [30]. The effect size was also measured using partial eta squared (η^2p), where 0.01 was considered small, 0.06 medium, and 0.14 large. In addition, the sample was classified into responders (Rs) and non-responders (NR) using the criterion of two technical errors (TE), according to a previously established equation [31]. NR were identified and defined as individuals who failed to demonstrate an increase or decrease (in favor of beneficial changes) in the variables analyzed that was greater than twice the ET of zero. Additionally, Fisher's exact test was used for comparisons between subject groups that were within the calculated ET for each outcome (NR) or more than double the ET (Rs) [32]. The post-intervention statistical analysis for punching force of the AEL group included only nine boxers, as one boxer was excluded for the final test due to an out-of-gym injury to his right hand. The level of statistical significance was set at $p < 0.05$. All statistical analysis was performed using GraphPad PRISM (version 10.0, San Diego, CA, USA).

3. Results

3.1. Punches Performance

Figure 3 presents the effects of a five-week AEL training program on peak punching force in the AEL, CMJ, and CON groups. The analysis revealed no significant main effects of group for any punch type ($p > 0.28$), although the partial eta squared values ranged from $\eta^2p = 0.02$ to 0.09, suggesting small to moderate effects. In contrast, significant main effects of time were observed for all punches ($p \leq 0.007$), with η^2p ranging from 0.25 to 0.49, indicating large effects and substantial overall improvements over time. Significant group × time interaction effects were found for the jab ($F_{2,26}$ = 5.25; p = 0.010; η^2p = 0.29), straight ($F_{2,26}$ = 7.51; p = 0.002; η^2p = 0.37), right cross ($F_{2,26}$ = 10.89; p = 0.004; η^2p = 0.46), and left cross punches ($F_{2,26}$ = 8.22; p = 0.002; η^2p = 0.39). These represent large interaction effects, suggesting that the magnitude of improvement differed meaningfully between groups, favoring the AEL condition. Post hoc comparisons confirmed that the AEL group demonstrated significant post-intervention improvements across all punch types—jab (p = 0.005; 95% CI_{dif}: 52.63 to 163.5 N), straight (p = 0.001; 95% CI_{dif}: 113.6 to 237.9 N), right cross (p < 0.001; 95% CI_{dif}: 92.80 to 197.5 N), and left cross (p < 0.001; 95% CI_{dif}: 82.59 to 199.7 N). In contrast, no significant changes were observed for the CMJ or CON groups (p > 0.06 for all comparisons), and the effect sizes for these groups were consistently small or negligible. Additional details on the initial group comparisons and training effects can be found in the Supplementary Materials (Tables S1–S4).

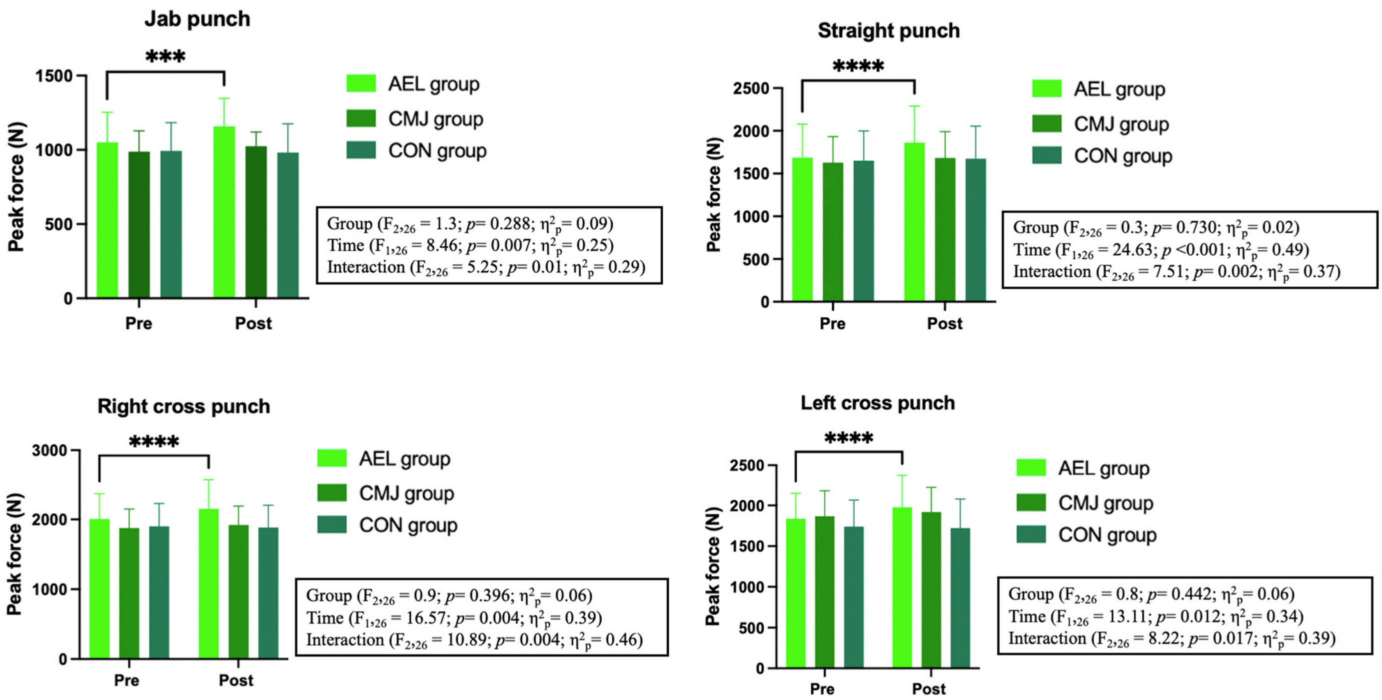

Figure 3. Effects of a five-week AEL training program on punching peak force in the AEL, CMJ, and CON groups. Bars represent mean ± SD for each punch type pre- and post-intervention. Statistical significance refers to time × group interactions. AEL: accentuated eccentric loading; CMJ: countermovement jump; CON: control; N: newton. ***: p = 0.05; ****: p= < 0.001.

Figure 4 presents the distribution of responders (Rs) and non-responders (NRs) to the AEL training program for punching peak force in the AEL, CMJ, and CON groups. For the peak jab punch force, the AEL group showed a small increase (11.1%; d = 0.54) with 66.7% of participants classified as responders (6 out of 9). The CMJ group also exhibited a small effect (4.4%; d = 0.30), with 30% responders (3 out of 10), while the CON group demonstrated a trivial decrease (−1.1%; d = −0.06) and no responders. Regarding the peak straight punch force, the AEL group achieved a small improvement (10.5%; d = 0.43) with 44.4% responders (4 out of 9). In contrast, the CMJ (3.5%; d = 0.18) and CON groups (0.9%; d = 0.06) showed trivial changes, with only one responder in the CMJ group and none in the control. For the right cross punch, the AEL group reported a small effect size (7%; d = 0.38) and 66.7% responders. The CMJ group showed a trivial change (2.6%; d = 0.18) with no responders, and the CON group experienced a trivial decrease (−0.9%; d = −0.06), also with no responders. Finally, for the left cross punch, the AEL group showed a small improvement (7.1%; d = 0.40) and the highest responder rate of all punches (77.8%; 7 out of 9). The CMJ group showed a trivial increase (2.8%; d = 0.16) with one responder, whereas the CON group had a trivial decrease (−1.4%; d = −0.05) and no responders. These findings suggest that the AEL protocol induced consistent and practically meaningful improvements in punching peak force across all punch types, with particularly high responder rates observed in the jab, right cross, and left cross punches. In contrast, the CMJ and control conditions elicited minimal individual adaptations.

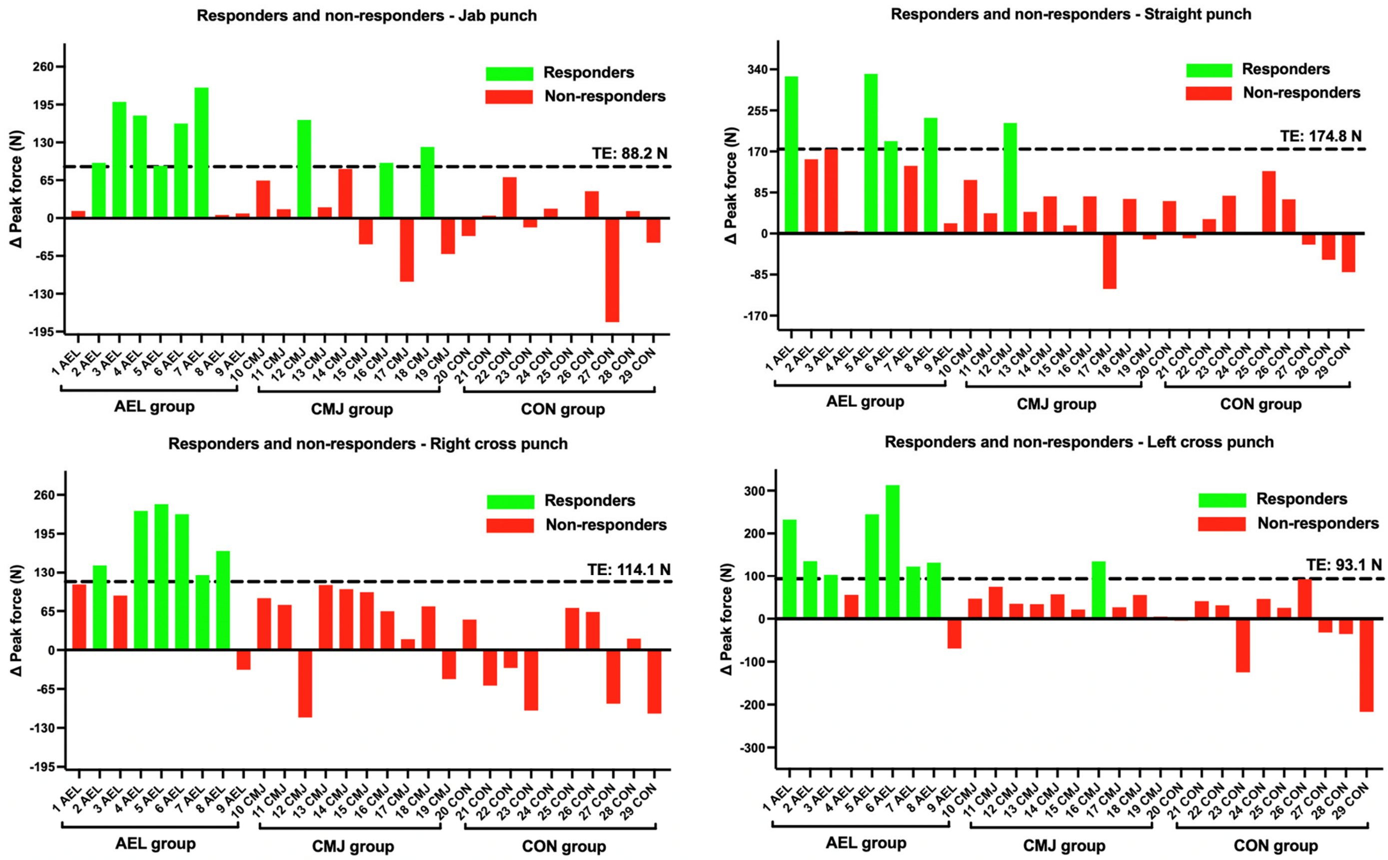

Figure 4. Individual changes in punching peak force for responders and non-responders across AEL, CMJ, and CON groups. Bars represent Δ (delta) values from pre- to post-intervention for each punch type. Dashed lines indicate the technical error (TE) threshold for meaningful change. AEL: accentuated eccentric loading; CMJ: countermovement jump; CON: control; N: newton. Participant IDs 1–9 correspond to the AEL group, 10–19 to the CMJ group, and 20–29 to the CON group.

Comparisons between subject groups showed that there were within 2 times the calculated TE on each outcome (NRs) or greater than two times the TE (Rs) reported significant differences (p = 0.03) between the AEL group versus the CON group for the jab punch. No significant differences were found between the AEL group versus the CMJ group (p = 0.17) and between the CMJ group versus the CON group (p = 0.21). For the straight punch, significant differences were found between the AEL group versus the CON group (p = 0.03), while for the AEL group versus the CMJ group (p = 0.14) and the CMJ group versus the CON group ($p > 0.99$), no significant differences were found. For the right cross punch, significant differences were found between the AEL group versus the CMJ group (p = 0.03) and between the AEL group versus the CON group (p = 0.03), no significant differences were found between the CMJ group versus the CON group ($p > 0.99$). Finally, for the left cross punch, significant differences were reported between the AEL group versus the CMJ group (p = 0.05) and between the AEL group versus the CON group (p = 0.07), while the CMJ group versus the CON group did not report significant differences ($p > 0.99$).

The analysis revealed no significant main effects of group for any of the relative peak punching force variables ($p > 0.19$), although the partial eta squared values ranged from $\eta^2p = 0.01$ to 0.03, indicating small effects. In contrast, significant main effects of time were observed for all punch types ($p \leq 0.004$), with η^2p values ranging from 0.27 to 0.50, which reflect large effects and substantial improvements over time across all participants. Significant group × time interaction effects were found for the jab ($F_{2,26} = 5.35$; $p = 0.011$; $\eta^2p = 0.29$), straight ($F_{2,26} = 7.73$; $p = 0.002$; $\eta^2p = 0.37$), right cross ($F_{2,26} = 10.83$; $p < 0.001$; $\eta^2p = 0.45$), and left cross punches ($F_{2,26} = 7.59$; $p = 0.003$; $\eta^2p = 0.37$), all of which represent large interaction effects. These findings suggest that the relative improvements in punching peak force overtime were meaningfully different between groups, favoring the AEL intervention. Post hoc comparisons confirmed that the AEL group experienced significant increases in relative punching peak force for the jab ($p = 0.003$; 95% CI_{dif}: 0.6953 to 2.082 W/kg), straight ($p < 0.001$; 95% CI_{dif}: 1.598 to 3.291 W/kg), right cross ($p = 0.001$; 95% CI_{dif}: 1.199 to 2.579 W/kg), and left cross punches ($p < 0.001$; 95% CI_{dif}: 1.096 to 2.793 W/kg). No significant changes were observed for the CMJ or CON groups ($p > 0.05$ for all comparisons), and effect sizes in these groups remained negligible.

3.2. Countermovement Jump Performance

Figure 5 presents the effects of a five-week AEL training program on countermovement jump height, propulsive impulse, peak power, and relative peak power in the AEL, CMJ, and CON groups. For jump height, significant effects of group ($F_{2,27} = 4.31$; $p = 0.02$; $\eta^2p = 0.24$) and time ($F_{1,27} = 13.42$; $p < 0.01$; $\eta^2p = 0.33$) were found, both representing large effects. Additionally, a large group × time interaction was observed ($F_{2,27} = 74.20$; $p < 0.01$; $\eta^2p = 0.85$), indicating that the magnitude of change varied meaningfully across groups. Post-intervention comparisons revealed significantly greater jump height in the AEL group compared to CON ($p < 0.001$; d = 1.50, large effect) and in the CMJ group compared to CON ($p = 0.003$; d = 1.00, moderate effect). Both AEL ($p < 0.001$; 95% CI_{dif}: 4.081 to 6.059 cm) and CMJ ($p = 0.017$; 95% CI_{dif}: 0.231 to 2.209 cm) groups improved significantly, whereas the CON group decreased in jump height ($p < 0.001$; 95% CI_{dif}: −4.219 to −2.241 cm). For peak power, a significant group effect was found ($F_{2,27} = 4.83$; $p = 0.01$; $\eta^2p = 0.26$, large), while no significant main effect of time was observed ($F_{1,27} = 2.57$; $p = 0.12$; $\eta^2p = 0.09$, medium). However, a large group × time interaction was present ($F_{2,27} = 76.71$; $p < 0.001$; $\eta^2p = 0.85$). Post-intervention comparisons showed significant differences between AEL and CON ($p = 0.002$; d = 0.59, small effect) and between CMJ and CON ($p = 0.006$; d = 0.43, small effect). The AEL group improved significantly ($p < 0.001$; 95% CI_{dif}: 180.1 to 279.7 W), while no significant change was observed in the CMJ group ($p = 0.195$; 95% CI_{dif}: −17.60 to 81.96 W). The CON group showed a significant decrease ($p < 0.001$; 95% CI_{dif}: −244.5 to −145.0 W). Regarding relative peak power, no significant group effect was found ($F_{2,27} = 2.91$; $p = 0.07$; $\eta^2p = 0.18$, large), nor a time effect ($F_{1,27} = 1.66$; $p = 0.208$; $\eta^2p = 0.06$, medium), but a large interaction was present ($F_{2,27} = 62.62$; $p < 0.001$; $\eta^2p = 0.82$). Significant post-intervention differences were observed between AEL and CON ($p = 0.01$; d = 0.73, moderate effect), and CMJ and CON ($p = 0.03$; d = 0.36, small effect). The AEL group showed significant improvements ($p < 0.001$; 95% CI_{dif}: 2.317 to 3.823 W/kg), while the CMJ group showed no significant change ($p = 0.202$; 95% CI_{dif}: −0.273 to 1.233 W/kg). The CON group declined significantly ($p < 0.001$; 95% CI_{dif}: −3.483 to −1.977 W/kg). Finally, for propulsive impulse, a significant group effect ($F_{2,27} = 3.56$; $p = 0.04$; $\eta^2p = 0.21$), time effect ($F_{1,27} = 8.65$; $p = 0.006$; $\eta^2p = 0.24$), and group × time interaction ($F_{2,27} = 41.47$; $p < 0.001$; $\eta^2p = 0.75$) were observed—all large effects. Post hoc comparisons showed significant differences between AEL and CON ($p = 0.002$; d = 0.71, moderate effect). The AEL group improved significantly ($p < 0.001$; 95% CI_{dif}: 12.47 to 20.15 N·s), the CMJ group showed no change ($p = 0.754$; 95%

CI_{dif}: −3.249 to 4.429 N·s), and the CON group declined significantly (p = 0.005; 95% CI_{dif}: −11.21 to −3.528 N·s).

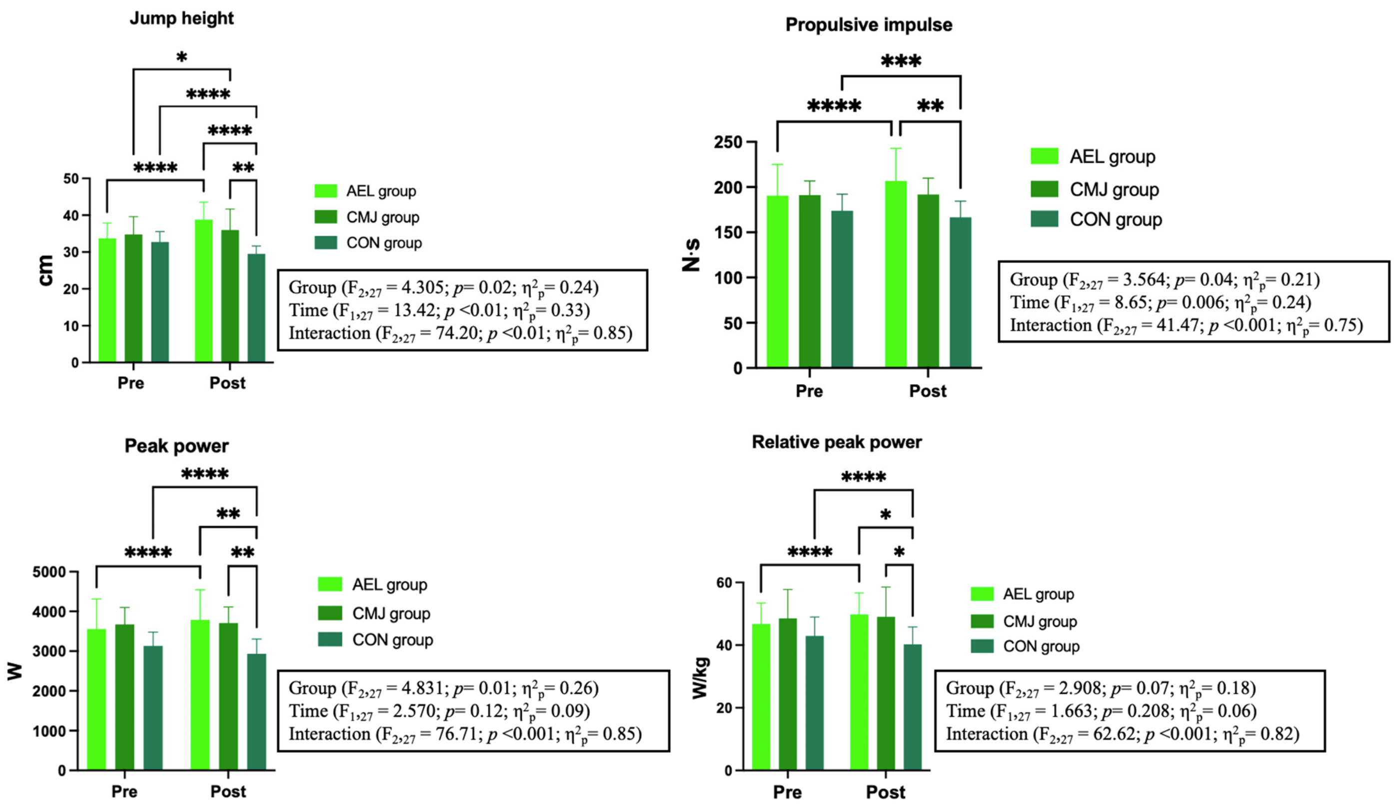

Figure 5. Effects of a five-week AEL training program on countermovement jump height, propulsive impulse, peak power, and relative peak power in the AEL, CMJ, and CON groups. Bars represent mean ± standard deviation. AEL: accentuated eccentric loading; CMJ: countermovement jump; CON: control; N: newton; W: watt; kg: kilogram. *: p = 0.01; **: p = 0.03; ***: p = 0.04 ****: p = <0.001.

Figure 6 presents the Rs and NRs boxers to the AEL training program for jump height, propulsive impulse, peak power, and relative peak power of the CMJ in the AEL, CMJ, and CON groups. For jump height, the AEL group exhibited a large improvement (15.1%; d = 1.00) with a responder rate of 90% (9 out of 9). The CMJ group showed a small increase (3.3%; d = 0.24) with three responders (30%), while the CON group demonstrated a large decrease (−9.7%; d = −1.10) and no responders. Regarding propulsive impulse, the AEL group achieved a small but meaningful increase (8.7%; d = 0.50) with 90% responders. The CMJ group presented a trivial change (0.3%; d = 0.04) and a 20% responder rate (2 out of 10), whereas the CON group showed a small decrease (−4.3%; d = −0.41) and no responders. For peak power, the AEL group improved by 6.7% (d = 0.31, small effect) with all participants classified as responders (90%). The CMJ group exhibited a trivial increase (1.0%; d = 0.08) and no responders, while the CON group showed a small decrease (−6.4%; d = −0.53) with zero responders. Finally, in relative peak power, the AEL group demonstrated a moderate improvement (6.7%; d = 0.64) with an 80% responder rate (8 out of 9). The CMJ group showed a trivial increase (1.0%; d = 0.05) with only one responder, whereas the CON group experienced a small decrease (−6.4%; d = −0.47) and no responders. These findings highlight the superior responsiveness of the AEL group across all CMJ performance variables, while the CMJ and CON groups showed minimal or no meaningful individual adaptations.

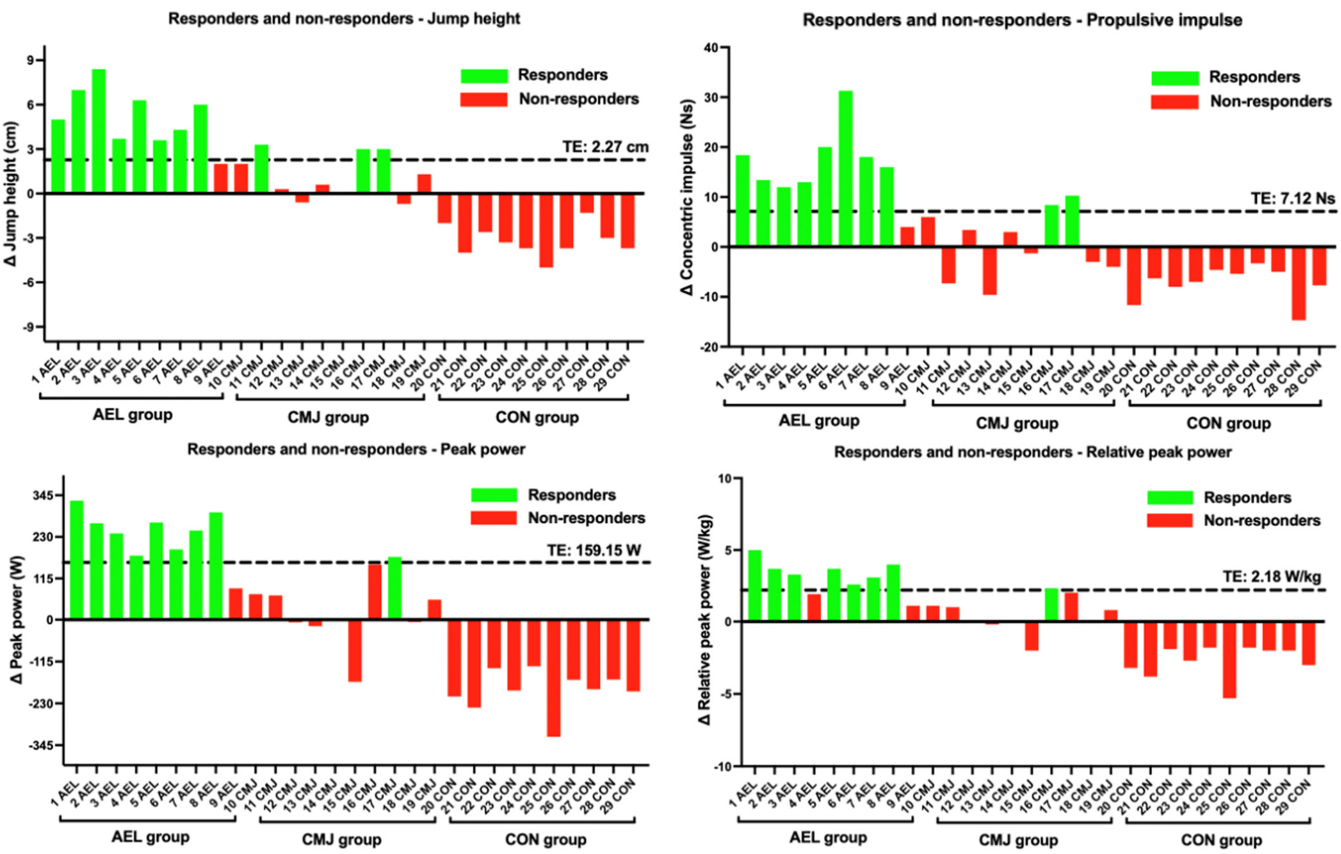

Figure 6. Individual changes in countermovement jump height, propulsive impulse, peak power, and relative peak power for responders and non-responders across AEL, CMJ, and CON groups. Bars represent Δ (delta) values from pre- to post-intervention. Dashed lines indicate the technical error (TE) thresholds used to classify meaningful individual responses. Participant IDs 1–9 correspond to the AEL group, 10–19 to the CMJ group, and 20–29 to the CON group. AEL: accentuated eccentric loading; CMJ: countermovement jump; CON: control; W: watt; kg: kilogram.

Comparisons between Rs and NRs subject groups indicated significant differences ($p = 0.01$) between the AEL and the CMJ group and between the AEL and the CON group ($p = 0.001$) for jump height, while no significant differences were reported between the CMJ and the CON group ($p = 0.21$). For propulsive impulse, significant differences were found between the AEL and the CMJ group ($p = 0.05$) and for the AEL vs. the CON group ($p = 0.001$), while for the CMJ vs. the CON group ($p = 0.47$), no significant differences were found. For peak power, significant differences were found between the AEL group and the CMJ group ($p = 0.001$) and between the AEL group and the CON group ($p = 0.01$), while no significant differences were found between the CMJ group and the CON group ($p > 0.99$). Finally, for relative peak power, significant differences were found between the AEL group and the CMJ group ($p = 0.005$) and between the AEL group and the CON group ($p = 0.07$), while no significant differences were found between the CMJ group and the CON group ($p > 0.99$).

4. Discussion

The aim of this study was to identify the effects of a submaximal accentuated eccentric jump training program on punching performance and CMJ force–time characteristics in amateur boxers. The main findings of this study were the significant group × time interaction effects observed for both punching peak force and CMJ performance variables, indicating that the AEL group improved to a greater extent compared to the CMJ and CON groups. Therefore, the hypothesis raised at the beginning of the research was confirmed. These results are consistent with existing literature reporting improvements in punch strength and power following strength training interventions in amateur boxers [19]. For example, Kim et al. [33] indicated increases in straight punch and curved punch force with the dominant hand in amateur boxers after 16 weeks of training using traditional strength exercises with loads of 50% to 70% of 1RM, elastic bands of different resistances, and medicine ball exercises. Similarly, Bu [34] reported increases in straight punch power after 12 weeks of training in amateur female boxers through traditional speed-focused strength exercises with intensities of 5 kg to 25 kg. Similarly, Čepulenas et al. [35] observed improvements in straight punch and rear-hand low punch strength along with increases in side punches and lead-hand low punches in amateur boxers after 4 weeks of training using upper and lower body resistance exercises at intensities of 20–90% of 1RM in combination with plyometric exercises. Based on the current literature, this is the first study to investigate the effects of a submaximal accentuated eccentric loading jump training on punching peak force in amateur boxers.

Punches require a transmission of force through the boxer's entire kinetic chain, starting with the force applied against the ground by the lower body and then transferring the energy generated through the core to the upper extremities to hit the opponent in the head or trunk [16]. The improvements in the peak force of the punches in the AEL group confirm the importance of the muscle power of the lower body in punches, given that the AEL training program only involved the execution of jumps with 10–20% of the boxers' BM. This is relevant, as current research has suggested that lower body muscle power is strongly associated with punching peak force in elite amateur boxers [16,36]. Furthermore, amateur boxers who punch harder have been reported to possess higher levels of lower body muscle power compared to boxers who punch with lower impact forces [36]. Early research reporting the importance of leg contribution to punching force highlighted that the lower extremities and trunk contributed 76–78% of the force generated during a punch in experienced boxers [16]. In this regard, boxers in the AEL group may have benefited from the accentuated eccentric loading jump training program by improving force application through triple extension of the ankle, knee, and hip joints, generating greater peak force during punches [25].

4.1. Jab Punch Performance

The jab punch is characterized by being a quick punch, generally used to open the opponent's defense, initiate punch combinations, and control the opponent's distance [37]. Research has reported that it has the shortest execution time compared of all types of punches [28], and this has been mainly attributed to its shorter trajectory towards the opponent [38]. Also, it has been reported as the punch with the lowest force compared to the rest of the punches [28,39]. This is consistent with the findings of this study, where the peak force of the jab punch averaged 1019 ± 187 N and 1035 ± 174 N for the test—retest, being the lowest value of the punches evaluated, possibly due to the lower contribution of the trunk during the execution of the punch and the lower generation of ground reaction forces (GRF) [28,40]. Group analysis reported significant improvements for the peak force of the jab punch (Δ 11.1%) in the AEL group, and this could be attributed to the increased propulsive impulse and peak power of the boxers' rear leg during the execution of the punch. Stanley et al. [40] have reported that the rear leg during the jab punch produces on average 71% of the GRF, making it essential to propel the hand rapidly along the anteroposterior axis against the opponent. Likewise, it is likely that the torque and GRF generated by the rear leg improved the transmission of force through the kinetic chain by means of a rapid extension of the ankle, knee and hip joints, increasing the force of the punch towards the target with less dependence on the upper body's stretch-shortening cycle (SSC) [40]. The analysis of Rs and NRs reported that three boxers in the AEL group did not exceed the technical error threshold for jab force, although they did not worsen either (Δ 0–1%). This could reflect that AEL jumps are not an optimal stimulus for all boxers and their individual characteristics such as maximum lower body muscle strength values need to be considered prior to prescribing them, given that it has been suggested that lower neuromuscular performance may inhibit improvements in muscle activity due to the difficulty of reaching high levels of force during eccentric actions [3]. On the other hand, the CMJ group had three boxers that surpassed the technical error threshold by improving jab force. This suggests that CMJ performance may be a beneficial stimulus for some boxers to increase applied lower body muscle strength and consequently improve peak jab force. However, individualization in exercise selection and training load is necessary to optimize jab performance in boxers.

4.2. Straight Punch Performance

The straight punch is defined as a rear-hand punch delivered with the arm furthest from the opponent [38]. It is considered a "power" punch that can cause great damage to the opponent [41]. It has been reported that the straight punch can generate greater acceleration of the fist and forearm compared to the jab punch mainly due to the additional rotation of the trunk during its execution [37]. The literature has also reported a higher GRF in the straight punch (1709.28 ± 486.62 N) compared to the jab punch (1176.55 ± 248.69 N) in amateur boxers. Likewise, a higher peak force has been reported in the straight punch (2328.547 N) compared to the jab punch (1534.514 N) [28]. Similar to the results of this study, where the peak force of the straight punch was also greater, averaging 1664 ± 346 N and 1702 ± 323 for the test–retest vs. 1019 ± 187 N and 1035 ± 174 N for the peak force of the jab punch. The group analysis reported significant post-intervention improvements for peak straight punch force (Δ 10.5%) in the AEL group. Cheraghi et al. [42] and Lenetsky et al. [43] have mentioned that during the straight punch, the impulse developed in both the vertical and horizontal directions from the rear leg towards the lead leg (produced through plantar flexion of the ankle joint and extension of the knee joint) is crucial for upper limb velocity by improving proximal to distal sequencing during the punch. Therefore, the execution of AEL jumps by increasing the propulsive impulse of the lower body may have led to the improvements in peak straight punch force. Furthermore, it has been suggested that the boxers' ability to maintain a rigid lead leg (by producing vertical anteroposterior braking forces), the generation of lower extremity extensor moments, and the ability to control the degree of knee flexion in the lead leg may enhance force transmission from the lower extremities to the arm/hand segments during the execution of the straight punch [41–43]. In this regard, it has been suggested that to improve straight punch performance, exercises that increase the ability of the lead leg to absorb force and resist excessive knee flexion and exercises that increase the ability of the rear leg to powerfully extend the hip, knee, and ankle joints are needed [43]. Therefore, the implementation of AEL jumps through acute eccentric loading may help absorb forces at an intermediate degree of knee flexion to subsequently generate force against the ground by extending the lower extremities during the flight phase. Based on the findings of this study, this may be positive for increasing peak straight punch force. The analysis of Rs and NRs indicated that five boxers in the AEL group did not exceed the technical error threshold for straight punch force, and although the delta of these boxers was positive (Δ 0–11%), it was not enough to overcome the technical error. As mentioned above, lower relative lower body muscle strength can affect adaptations to AEL training, so athletes with less experience in strength training may see their improvements through AEL diminished by requiring slower-tempo strategies during the application of eccentric loads affecting the speed of the eccentric phase and muscle elongation, decreasing the recruitment of motor units and fast-twitch explosive fibers [3,44]. Regarding the CMJ group, there was only one responding boxer (Δ 15%), which suggests that a greater stimulus is necessary, through an increase in the volume or intensity of the jumps to improve the peak force of the straight punch in amateur boxers.

4.3. Right Cross Punch Performance

The right cross is typically considered the strongest punch in boxing [41], due to its execution, which involves a slight countermovement and rapid rotation of the trunk and rear hip, enabling an effective transfer of force from the lower body to the fist [38]. In elite amateur boxers, peak force values of 2620 ± 596 N have been reported—higher than those of the left cross (2488 ± 565 N) [28]. In our study, the right cross also showed the highest force among all punches evaluated, averaging 1929 ± 317 N and 1936 ± 313 N for test and retest, respectively. These differences in force magnitudes across studies may be explained by methodological variations, such as measurement devices (force platforms vs. load cells), glove type, padding density, athlete level, and individual strength capacities [39]. After the intervention, the AEL group showed a significant improvement in right cross peak force (Δ 7%). This punch shares key biomechanical traits with the straight punch, notably the force generation from the rear leg and its transfer through trunk rotation to the upper extremity [41,43,45]. The enhanced lower limb impulse and power potentially improved GRF transmission, supporting the observed gains. Moreover, the slight countermovement involved in this punch may have benefitted from the AEL stimulus during the jump phase. Regarding individual responses, three boxers in the AEL group did not exceed the technical error threshold (Δ −2 to 7%). It has been proposed that protective inhibitory mechanisms—such as those mediated by the Golgi tendon organ—may limit force production during eccentric actions to prevent injury [46]. Although the presence of such mechanisms under submaximal AEL conditions remains unclear, non-responders may require a longer adaptation period to fully benefit from AEL-based training.

4.4. Left Cross Punch Performance

The left cross punch, like the right cross, relies heavily on the transfer of force from the lower extremities to the upper body [45]. Both punches can serve as power strikes or as setup punches within combinations [43]. Although the right cross generally produces greater impact forces—likely due to enhanced trunk rotation and center of mass displacement during execution [40,47]—the left cross still plays a key role in offensive strategies. In this study, the AEL group showed a significant post-intervention improvement in left cross peak force (Δ 7%). During this punch, the lead leg primarily generates vertical momentum, while the rear leg contributes to stabilization and momentum transfer to the striking arm [38,43]. Vertical AEL jumps may have improved this force production, particularly by enhancing vertical impulse in the lead leg. Moreover, the increased CMJ peak power in the AEL group could explain the observed gains in punch force. Regarding individual responses, two boxers from the AEL group did not exceed the technical error threshold (Δ −6 and 3%). As noted earlier, eccentric training may activate protective neuromuscular mechanisms—especially in athletes with limited strength training background—which could reduce muscle activity during the eccentric phase. Nevertheless, these inhibitory responses may diminish over time with greater exposure to AEL protocols [48,49].

4.5. Countermovement Jump Performance

Theoretically, it has been proposed that a high or faster eccentric load may allow for the selective recruitment of high-threshold motor units, leading to increased force production in the subsequent concentric muscle action [50]. In this regard, the application of AEL during jumping with minimal disruption to the natural mechanics of the movement may increase the rate of eccentric force production and the momentum of the SSC, thus improving power production [3]. The group analysis indicated significant post-intervention improvements for jump height (Δ 15%) in the AEL group and in the CMJ group (Δ 3%). However, the analysis of Rs and NRs indicated that nine boxers for the AEL group exceeded the technical error threshold for jump height, while for the CMJ group, only three boxers did so. This is consistent with abundant research that has shown increases in jump height using AEL via jumping. For example, Bridgeman et al. [12] reported increases in jump height via a four-week AEL drop jump intervention in rugby players, although the volume was not reported; the players used a 20 kg AEL load via dumbbells. This is similar to results reported in a second investigation by Bridgeman et al. [13], where they reported increases in jump height in trained athletes through a three-week intervention with AEL drop jumps using a 20 kg load via dumbbells. The higher number of Rs in the AEL group compared to the CMJ group could be physiologically attributed to a greater activation of the motor cortex that compensates for the spinal inhibition that occurs during eccentric actions [51]. In this sense, the additional weight used during the eccentric phase and released at the beginning of the concentric phase may have generated a greater accumulation of elastic energy in the lower body, potentiating the concentric phase of each jump [52]. Therefore, the effectiveness of AEL through jumps could be dictated by the magnitude of the differences between eccentric and concentric loads, which may explain the lower number of Rs in the CMJ group [6].

Regarding CMJ propulsive impulse, the group analysis indicated significant improvements post-intervention (Δ 8.7%) for the AEL group, similar to those reported in an acute intervention by Aboodarda et al. [8] using CMJ with AEL via elastic bands with 20% and 30% of body mass, where they found increases in net lower body impulse (Δ 16.65%) in the 30% AEL condition compared to the CMJ condition using only their BM. As mentioned above, during the execution of a AEL jump, the additional weight can increase the load of the hip and knee muscles by enhancing the pre-stretch of the muscle tissue, generating a greater force production in the propulsive phase of the jump [53]. Consequently, the improvements in propulsive impulse in the AEL group could be justified by the greater elastic energy stored in the parallel elastic component, the series elastic component and titin, the stimulated muscle spindle reflexes, type Ia afferent nerves, and the greater recruitment of high-threshold motor units [54]. The analysis of Rs and NRs indicated that nine boxers for the AEL group exceeded the technical error threshold for concentric drive, while only two boxers for the CMJ group did so. Based on these findings, it is likely that a larger stimulus is needed during the CMJ condition to improve concentric drive, since CMJ without additional load was only beneficial for 30% of the boxers in the CMJ group.

Regarding peak power and relative peak power of the CMJ, the group analysis indicated significant improvements post intervention (Δ 6.7%) for the AEL group. This is similar to that reported by Sheppard et al. [14] in elite volleyball players, observing increases in lower body power after five weeks of training performing CMJ with AEL loads of 40 kg for males and 20 kg for females via dumbbells compared to the group that only performed the CMJ with their own BM. This is in line with research such as that of Aboodarda et al. [8], who found increases in lower body power output in trained subjects performing CMJ with AEL via 30% of BM compared to the CMJ condition that used only their BM. Similarly, Sheppard et al. [17] also reported increases in lower body peak power in elite male volleyball players using a countermovement blocking jump with a 20 kg AEL load compared to the blocking jump without AEL. Evidence has suggested that eccentric training may be effective in increasing power output through changes in muscle architecture that may reflect a shift toward a more explosive phenotype and a stiffer muscle-tendon unit, improving the ability to produce force rapidly [4]. It is important to mention that accentuating the eccentric load does not improve concentric muscle production "per se" [53]. The load used must be considered as manageable for the tissues by the nervous system; otherwise, muscle elasticity increases and the muscle-tendon system will act more as a shock absorber absorbing forces than as a spring [55]. Therefore, the effects on the maximum power of the lower body may be different depending on the magnitude of AEL [56]. The analysis of Rs and NRs indicated that nine boxers from the AEL group exceeded the technical error threshold for peak power. Similarly, eight boxers from the AEL group exceeded the technical error threshold for relative peak power, while for the CMJ group, only one boxer exceeded the technical error threshold for peak power and relative peak power. This is similar to the findings reported for the propulsive impulse of the CMJ. Consequently, it is likely that the increase in propulsive impulse directly contributes to the improvements found in peak power of the CMJ [4]. On the other hand, the execution of CMJ with BM alone may be an insufficient stimulus to improve lower body muscle power in amateur boxers.

It is important to note that although improvements in punching and jumping performance were observed, the present study did not directly assess neuromuscular variables such as rate of force development, electromyographic activity, or muscle architecture. Therefore, any explanations regarding underlying mechanisms—such as enhanced motor unit recruitment, increased stiffness, or SSC efficiency—should be considered speculative. These hypotheses are grounded in previous findings from similar interventions, but further research is needed to confirm the specific neuromechanical adaptations induced by submaximal AEL in amateur boxers.

The present study expands the evidence on submaximal AEL by demonstrating that a low-load protocol (10–20% of body mass), applied using dumbbells, is effective even in amateur boxers with no prior AEL experience for improving lower-limb muscle power and punching force. Future studies should consider including direct neuromuscular and biomechanical assessments, such as electromyography or motion capture, to more accurately identify the mechanisms responsible for these adaptations. Additionally, different volumes and intensities of AEL loading should be explored to determine the optimal stimulus for maximizing physical performance in athletes.

4.6. Relative Strength in Adaptations to Submaximal AEL Training

The literature has suggested that to obtain the benefits of submaximal AEL through jumping, it is important for athletes to possess considerable levels of muscle strength [3,4,6]. Majeedkutty et al. [15] investigated the effects of four weeks of AEL training three times per week through CMJ compared to a control group that only performed CMJ without AEL. The sample consisted of university students aged 18–23 years who were mostly untrained, presenting mean values of muscle strength in the 5RM squat test of 43.6 $\pm$ 14.9 kg for the AEL group and 47.7 $\pm$ 8.4 kg for the control group. Despite the low levels of lower body muscle strength of the participants, the findings of this investigation indicated a significant improvement in horizontal jump distance and lower body muscle strength (5RM squat test) for the AEL group compared to the non-AEL group. It is important to mention that this study has a major limitation, as it did not report the intensity of AEL used during CMJ. However, the authors suggested that AEL through CMJ may be a good option to improve performance in untrained young adults.

The results of our study suggest different effects than those reported by Majeedkutty et al. [15] in the AEL group. Specifically, the analysis of Rs and NRs indicated that boxer number 9 of the AEL group failed to exceed the technical error threshold for any of the variables analyzed during this study. When analyzing the relative strength values obtained in the pre-intervention back squat 1RM test, it was found that boxer number 9 had the lowest relative strength value (0.98 kg/kg) compared to the rest of the boxers in the AEL group, who had a minimum value of 1.27 kg/kg and a maximum value of 1.60 kg/kg. This finding contradicts what was mentioned by Majeedkutty et al. [15], since the boxer with lower relative strength could not benefit from the effects reported in the AEL training. As mentioned above, lower muscle strength leads to lower neuromuscular performance, which may inhibit the benefits of AEL given the difficulty of generating high levels of force during eccentric actions [3]. Submaximal AEL requires fast velocities of muscle elongation during the eccentric phase to generate greater recruitment of fast-twitch motor units [3,44]. However, untrained individuals may require a slower pace of execution to control the eccentric load during jumps, so their benefits through AEL may be lower [3]. Finally, as mentioned in previous sections, during eccentric actions, protective inhibitory mechanisms may occur as a result of the activation of the Golgi tendon organ to protect the muscle-tendon unit from damage, which could explain our findings on the non-responding boxer of the AEL group [46].

4.7. Strengths and Limitations of the Study

This study has the following limitations: (i) despite conducting familiarization sessions, the boxers had not been previously exposed to AEL training through jumps, which could have generated greater gains in the variables analyzed given the new stimulus for the boxers; (ii) the potential influence of uncontrolled physical conditioning activities performed outside the supervised intervention sessions. Although participants were instructed to refrain from additional strength training, it is possible that variations in general conditioning routines may have influenced the observed adaptations; (iii) the sample size per group was relatively small, which may limit the statistical power to detect between-group differences and generalize the findings; (iv) no electromyographic or neuromuscular function measures were included, precluding direct conclusions about underlying activation patterns or neural adaptations; (v) it did not include physiological variables related to muscle damage that could provide a better understanding of the effects of AEL through jumps and; (vi) no quantitative method using ground reaction force (GRF) was employed to precisely identify the timing of dumbbell release during AEL jumps or to complement the kinetic analysis of the lower limbs during punching actions. On the other hand, this study has the following strengths: (i) being the first study to investigate the effects of AEL through jumps with the inclusion of two experimental groups and a control group, which increases the quality in the comparison of the effects of the variables analyzed; (ii) the inclusion of right cross and left cross punches as outcome measures, which are rarely analyzed in the literature, where research has predominantly focused on straight punches; (iii) the inclusion of Rs and NRs analysis, which allowed the analysis of the individual responses of boxers in each group; (iv) the reduction of the research gap on AEL through jumping, presenting evidence on the effects of AEL with 10–20% of BM; (v) the comprehensive assessment of both kinetic variables from the countermovement jump (e.g., peak power, relative peak power, propulsive impulse) and punching performance, providing a broader understanding of lower-limb power adaptations and their potential transfer to sport-specific performance in boxing.

4.8. Practical Applications

Based on the findings of the present study, coaches can incorporate a submaximal CMJ AEL training program to improve punching peak force and lower-body muscle power, starting with a lower volume and intensity (week 1, three sets of five repetitions at 10% of BM with dumbbells, three times per week) before progressing to a higher volume and intensity (weeks 3 and 4, four sets of five repetitions at 20% of BM with dumbbells, three times per week). However, coaches are encouraged to consider lower-body relative strength levels, as relative strength values less than 1.0 may be ineffective in improving punching peak force and lower-body muscle power via CMJ AEL jumps.

5. Conclusions

The findings of this study suggest that submaximal AEL implemented through CMJ jumps with a progressive increase from 10% to 20% of BM may be more effective than traditional CMJ in improving punching peak force and CMJ performance in amateur boxers. While the results are promising, they should be interpreted with caution given the limited sample size and the absence of direct neuromuscular or biomechanical measurements. Nevertheless, the observed effects indicate that AEL protocols could represent a feasible strategy for enhancing lower-body power and striking performance in amateur boxers. Coaches and practitioners may consider implementing submaximal AEL jump training in athletes with sufficient relative strength levels, as part of broader conditioning programs, while closely monitoring individual responses. Future studies should aim to confirm these findings in larger cohorts and under more controlled biomechanical and physiological assessment protocols.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app15147873/s1, Table S1: Results of the one-way ANOVA used to assess initial punching performance across groups. Table S2: Results of the one-way ANOVA for the initial assessment of jump performance across groups. Table S3: Results of the one-way ANOVA for the initial assessment of relative punch performance across groups. Table S4: Effects of the training intervention on peak punch force in the AEL, CMJ, and CON groups.

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