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STRENGTH AND POWER QUALITIES ARE HIGHLY ASSOCIATED WITH PUNCHING IMPACT IN ELITE AMATEUR BOXERS

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Running title: *Punching impact in elite amateur boxers*

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ABSTRACT

This study investigated the relationship between punching impact and selected strength and power variables in 15 amateur boxers from the Brazilian National Team (9 men and 6 women). Punching impact was assessed in the following conditions: 3 jabs starting from the standardized position (FJ), 3 crosses starting from the standardized position (FC), 3 jabs starting from a self-selected position and (SSJ) and 3 crosses starting from a self-selected position (SSC). For punching tests, a force platform (1.02 m x 0.76 m) covered by a body shield was mounted on the wall at a height of 1 m, perpendicular to the floor. The selected strength and power variables were: vertical jump height (in squat jump [SJ] and countermovement jump [CMJ]), mean propulsive power (MPP) in the jump squat (JS), bench press (BP), and bench throw (BT), maximum isometric force (MIF) in squat and BP, and rate of force development (RFD) in the squat and BP. Sex and position main effects were observed, with higher impact for males compared to females (*P*< 0.05) and the self-selected distance resulting in higher impact in the jab technique compared to the fixed distance (*P*< 0.05). Finally, the correlations between strength/power variables and punching impact indices ranged between 0.67 and 0.85. Due to the strong associations between punching impact and strength/power variables (e.g., lower limb muscle power), this study provides important

information for coaches to specifically design better training strategies to improve punching impact.

Key words: combat sports; punches; muscle power; strength training; plyometrics

INTRODUCTION

In amateur boxing fights, boxers are only allowed to use punching techniques, which must targetthe frontal or lateral parts of their opponents' head or torso (5, 16). The scoring system in amateur boxing is centered on the number of quality punches in the target area, domination during the bout, competitiveness, technical and tactical dominance and infringement of the rules (5). The duration and number of rounds varies in amateur boxing depending on the competitive level and agreement of the coaches and athletes (5): novice boxers compete in three 2-min rounds, intermediate boxers compete in four 2-min rounds, and open-class boxers compete in three 3-min or four 2-min rounds. In all cases, rounds are interspersed by 1-min. A recent investigation (9) concerning the activity profile of elite male amateur boxing reported that boxers maintain an activity rate of around 1.4 actions per second. In a simulated boxing match using the temporal structure as the reference, the total estimated energy expenditure was around 680 kJ, with the following relative contributions: aerobic - 77%; anaerobic alactic – 19%; anaerobic lactic – 4% (10).However, an athlete can win the fight at any time if he/she knocks the opponent out with a punch, thus reducing the total duration of the fight and the corresponding energy expenditure. Since knockout is a constant goal during a match, boxers must have well-developed muscle power and strength (5, 27, 28, 44) in order to increase punch impact and, as a consequence, knockout power.

A number of descriptive studies have already reported that punching impact force is one of the main performance indicators in amateur boxing (19, 27, 37). Smith et al. (38) showed that the maximal punching impact measured using a boxing-specific dynamometer was more elevated in elite boxers than in intermediate level boxers, and higher in the intermediate level than in novice boxers. Indeed, Pierce et al. (27) observed that the boxers who achieved higher cumulative force (number of punches performed multiplied by the impact produced in each stroke during a fight) and greater number of punches won by unanimous decision regardless of the weight category. Based on these findings, punching impact measurements can be used to select boxers, distinguish levels of performance and for training control purposes.

As in other combat sports, boxers regularly undergo technical, tactical, strength and conditioning sessions to improve their specific skills and physical condition (5). As for other combat sports such as karate (20), it is possible to infer that both upper- and lower-body muscle power might influence the kinematic and kinetic characteristics of jabs and crosses, the most common techniques applied in boxing (9, 11). In addition, the distance from the target seems to affect the magnitude of the impact. One study with kung fu and another with karate athletes investigated the effects of varying the distance to the target on punch impact and acceleration, respectively (20, 25). Neto et al. (25) reported that the palm strike kung-fu technique resulted in higher impact when its execution was preceded by stepping towards the target when compared to its execution without this preceding action. Loturco et al. (20) analyzed the combination of distance (fixed or self-selected) and goal (speed or impact) on karate punching kinematics and observed that a combination of impact-oriented instruction and self-selected distance resulted in higher acceleration rates. In boxing, athletes need to punch at different distances from the target in both training and competition; thus, investigating the effect of distance variation (self-selected vs. predetermined) on impact is important to establish the best training strategy for enhancing boxers' technical and tactical skills.

Additionally, identification of the strength-power qualities more associatedwith punching impact in the most executedstrokes(i.e., jabs and crosses) is essential for developing better neuromuscular training methods and, as a consequence, for improving the boxers' competitiveness. Therefore, the objectives of this study were to describe the impact force in male and female amateur boxers in jabs and crosses and to verify the relationshipsbetween punching impact forces andmechanical variables collected in traditional strength-power exercises, which are commonly executed by boxersduring strength and conditioning training sessions. Based on a previous research (20) that reported high correlations between punching acceleration and selected strength-power variables, and considering the crucial role of the G-forces (i.e., acceleration due to gravity) on the impact measurements, we hypothesized that the stronger/more powerful athletes would perform better in both punching techniques.

METHODS

Experimental Approach to the Problem

The study design was characterized as cross-sectional and correlational. Athletes were tested on 3 consecutive days, as follows: *Day 1)* jump squat and bench throw mean propulsive power at optimum load tests and vertical jump (squat and countermovement) tests; *Day 2)* impact tests using jabs and cross movements and maximal isometric strength; *Day 3)* bench press mean propulsive power at optimum load test. All athletes were highly familiar with the testing protocols, due to their extensive training routine in our Sports Performance Training Center. Before performing the tests, the athletes completed a 20-min standardized warm-up, including

15-min of general (i.e., 10-min running at a moderate pace followed by 5-min of lower-limb active stretching) and 5-min of specific exercises (specific to each test).

Subjects

Fifteen elite amateur boxers from the Brazilian National Team (9 men and 6 women; age: 25.9 ± 4.7 years; height: 1.72 ± 0.1 m and body mass: 64.56 ± 12.1kg) volunteered to participate in the study.

Among the male boxers, there was 1 flyweight (49-52 kg), 1 bantamweight (52-56 kg), 1 lightweight (56-60 kg), 1 welterweight (64-69 kg), 2 middleweight (69-75 kg), 2 light heavyweight (75-81) and 1 heavyweight (81-91 kg). Among the female boxers, there was 1 featherweight (54-57 kg), 1 light weight (57-60 kg), 1 light welterweight (60-64 kg), 1 welterweight (64-69 kg), 1 middleweight (69-75 kg) and 1 light heavyweight (75-81 kg). The investigated sample comprised 1 Olympic medalist, 1 World Championship medalist and 8 Pan-American Games medalists. All of the participants were South-American Games medalists, attesting their high level of competitiveness. All athletes were tested at the beginning of the preseason, immediately prior to the competitive period. Theprocedures were approved by an Institutional Review Board for use of human subjects. After being fully informed of the risks and benefits associated with the study, all athletes signed a written informed consent form.

Maximal Isometric Force and Impact Measurements

The maximal isometric force (MIF) was determined for upper and lower limbs through bench press (BP) and half-squat exercises, both performed on a Smith-Machine (Hammer Strength Equipment, Rosemont, IL, USA). The knee angle used for each athlete was ≈ 90°(14). For BP, the barbell was positioned across the boxers' chest, at the level of their nipples. The athletes held the barbell at shoulder width, with an initial elbow angle of ≈ 90° (angle between the arm and forearm)(40). The initial position of each exercise was validated by an experienced test administrator, who set the bar on the safety pins at a height corresponding to 90° of knee/elbow flexion, as determined during the pre-testing sessions. For both measurements, after a starting command, the subjects exerted force as rapidly as possible against the mechanically fixed bar, for 5-s. The specific warm-up comprised submaximal attempts using isometric half-squat and bench press exercises. The peak forces were determined using a force platform with custom designed software (AccuPower, AMTI, Graz, Austria), which sampled at a rate of 400 Hz. The platform was fixed to the floor using a specific base. For BP testing, a bench was fixed onto the platform and the force applied against the barbell was transmitted by the bench to the force platform in the vertical plane. The resultant force during both exercises was calculated after subtracting the forces equivalent to the subjects' weight (half-squat) and subject + bench weights (bench press) in order to isolate the effects of muscle contractions against the bar. Rate of force development (RFD) was determined as the average slope of the force-time curve (Δ Force/Δ time), for the first 100 milliseconds, after the onset of the muscle contraction. Strong verbal encouragement was provided during the attempts.

For punching tests, the same 1.02 m x 0.76 m force plate was mounted on the wall at a height of 1 m perpendicular to the floor, allowing the athletes to execute the strokes at a height of between 1.0 and 1.76 m (Figure 1). The platform was fully covered by a body shield (Bad Boy, San Diego, CA, USA) to prevent impact injuries to the boxers, who also used their own competition gloves to perform the impact tests. A pilot study revealed that the "absorption effect" provided by the body shield on the punching impact measurements is < 3% (in comparison to the punches performed without the shield).The specific warm-up comprised submaximal attempts at jabs and crosses hitting the body shield. The boxers performed 12 punches on the target (i.e., central area of the body shield), as follows: 1) 3 jabs starting from the standardized position (FJ); 2) 3 crosses starting from the standardized position (FC); 3) 3 jabs starting from a self-selected position (SSC) and; 4) 3 crosses starting from a self-selected position (SSJ). The pilot study showed that 3 attempts were sufficient to obtain representative force measurements from each boxer. In addition we intended to reduce the risk of injuries related to study participation, which is why we did not expose the participants to a higher number of attempts per punching type. This order was fixed due to the athletes' preference and for ease of test administration (as requested by the technical staff). The standardized position was individually established prior to punching according to the arm length, by measuring the distance from the front foot to the wall, which resulted in a full extension of the dominant arm after throwing both the jab and the cross.

The self-selected position was determined by each boxer to elicit optimal performance. A 15-s and 1-min resting interval was allowed between attempts within each condition and between conditions, respectively. Verbal motivation was provided to the boxer in order to elicit maximal impact in each attempt.

*****INSERT FIGURE 1 HERE*****

Mean Propulsive Power in Jump Squat, Bench Press and Bench Throw

Mean propulsive power (MPP) was assessed in jump squat (JS), BP, and bench throw (BT) exercises, all being performed on a Smith machine (Hammer Strength Equipment, Rosemont, IL, USA). Participants were instructed to execute 3 repetitions at maximal velocity for each load, starting at 40% of their BM in JS and 30% of their BM in the BT andBP. In the JS, participants executed a knee flexion until the thigh was parallel to the ground and, after the command to start, jumped as fast as possible without their shoulder losing contact with the bar. During the BT and BP, athletes were instructed to lower the bar in a controlled manner until the bar lightly touched the chest and, after the command to start, throw it as high and fast as possible for BT and move the bar as fast as possible for BP. A load of 10% of BM for JS and 5% of BM for BP and BT was progressively added in each set until a decrease in MPP was observed (demanding, on average, from 2 to 5 attempts for all exercises). A 5-minute interval was provided between sets. To determine MPP, a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) was attached to the Smith machine bar. The bar position data were sampled at 1,000 Hz using a computer. Finite differentiation technique was used to calculate bar velocity and acceleration. MPP rather than peak power in JS, BP and BT was used since Sanchez-Medina et al. (34)demonstrated that mean mechanical values during the propulsive phase better reflect the differences in the neuromuscular potential between 2 given individuals. This approach avoids underestimation of true strength potential as the higher the mean velocity (and lower the relative load), the greater the relative contribution of the braking phase to the entire concentric time. We considered the maximum MPP value obtained in each exercise for data analysis purposes.

Squat Jump and Countermovement Jump Heights

Both the squat jump (SJ) and countermovement jump (CMJ) were performed with the hands on the hips.In the SJ, a static position with a 90^{o}-knee flexion angle was maintained for 2 seconds before a jump attempt without any preparatory movement. In the CMJ, subjects were instructed to perform a downward movement followed by a complete extension of the lower limb joints and freely determine the amplitude of the countermovement to avoid changes in jumping coordination pattern. The jumps were performed on a contact platform (Smart Jump; Fusion Sport, Coopers Plains, Australia), five attempts being given for each jump, interspersed by 15-second intervals. The obtained flight time (t) was used to estimate the height of the rise of the body's center of gravity (h) during the vertical jump (i.e., $h = gt^2 /8$, where $g = 9.81\ m.s^{-2}$). A given jump was only considered valid for analysis if the take-off and landing positions were visually similar. The best attempt was used for data analysis purposes.

Statistical Analysis

Data are presented as mean ± standard deviation (SD). The Shapiro-Wilk test was used to check the normality of the data. The Levene's Test for homogeneity of variance was used. When the homogeneity of variance was confirmed, parametric tests were used. Otherwise, non-parametric tests were applied. The independent Student t test was used for the comparison of test performances between men and women. A two-way (sex and punching position) analysis of variance with repeated measures in the second factor was used to compare the punching impact between positionsand sexes. When a significant difference was observed the Bonferroni post hoc test was applied. For the analysis of variance with repeated measures the compound symmetry was tested via Mauchly's test and the Greenhouse-Geisser correction was applied when necessary. The effect sizes (ES) were calculated as the mean differences between themale and femalevalues divided by the mean ofthe standard deviation of both genders (7). The magnitudes of the ES were interpreted using the thresholds proposed by Rhea (32) for highly trained subjects, as follows: <0.25, 0.25-0.50, 0.50-1, and >1 for trivial, small, moderate, and large, respectively. For normally distributed data, a Pearson productmoment coefficient of correlation was used to analyze the relationships between punch impacts and strength and power tests. When the normality of data was not confirmed the Spearman test was used to test the correlations between the previously cited variables. As 95% CI correlation coefficients did not differ between genders, only the significant correlation coefficients for all the athletes grouped were reported. The threshold used to qualitatively assess the correlations was based on Hopkins (18), using the following criteria: <0.1, trivial; 0.1 - 0.3, small; 0.3 - 0.5, moderate; 0.5 - 0.7, large; 0.7 - 0.9, very large; >0.9 nearly perfect.Intraclass correlations (ICCs) were used to indicate the relationship within SJ and CMJ for height; within JS, BT and BP for mean propulsive power; and within FJ, FC, SSJ and SSC for punching impact indices. The ICC was 0.96 for the SJ, 0.94 for the CMJ, 0.93 for the BT and BP, 0.94 for the JS, 0.97 for the FJ and FC, 0.95 for the SSJ and 0.96 for the SSC. The statistical significance level for all the analyses was set at $P<0.05$.

Results

The correlations between body mass and punch variables were 0.56, 0.60, 0.58, and 0.59 for FJ, FS, CSJ, and CSS, respectively ($P< 0.05$). Table 1 presents the punching impacts, muscle power measures and isometric force tests.

*****INSERT TABLE 1 HERE*****

Men presented higher performances in the SJ (t = -4.26, df = 13, $P< 0.001$), CMJ (t = -4.62, df = 13, $P< 0.001$), MPP BT (t = -2.58, df = 13, $P = 0.023$), MPP BP (t = -3.57, df = 13, $P = 0.003$), MIF Squat (t = -4.00, df = 13, $P = 0.002$), RFD BP (t = -2.25, df = 13, $P = 0.042$) and RFD Squat (t = -3.01, df = 13, $P = 0.010$) than women. No significant differences between men and women (*P*> 0.05) were found for the MPP JSand MIF BP.

A sex effect was found for jab impact ($F_{1,13}$ = 4.66; P = 0.050), with lower values for females compared to males (*P* = 0.050). A position effect was also observed ($F_{1,13}$ = 6.58; *P* = 0.024), with higher impact in the self-selected distance compared to the fixed distance (*P* = 0.016). However, no interaction effect was found ($F_{1,13}$ = 0.68; *P* = 0.425).

A sex effect was also detected for cross impact ($F_{1,13}$ = 8.51; *P* = 0.012), with lower values for females compared to males (*P* = 0.007). However, no effect of position ($F_{1,13}$ = 1.22; *P* = 0.289) or interaction effect ($F_{1,13}$ = 2.55; *P* = 0.135) was observed. When comparing the ES analysis, the male and female performances presented large differences (Table 1).

The correlations of punching impact with power and isometric force tests are displayed in table 2. The punching impact variables presented large to very large correlations with the power and isometric force tests. Finally, jump heights showed very large to nearly perfect correlations with lower limb muscle power and isometric force tests (Table 3).

*****INSERT TABLE 2 HERE*****

*****INSERT TABLE 3 HERE*****

DISCUSSION

This is the first study to investigate the correlations between a wide range of strength-power measurements and the impact of two types of punching (i.e., jabs and crosses) performed by elite amateur boxers. The main finding reported herein is that these neuromechanical measurements explain from 67 to 85% of the impact forces produced by boxers when executing different punch techniques. Moreover, except for MPP JS and MIF BP, the men presented superior performances to the women in all assessments.

As hypothesized, we expected to find high correlations between strength-power capacities and punching impact forces. Impact has been defined as a force resulting from the collision of two or more bodies over a relatively short time(26). This amount of force generally possesses a relatively higher magnitude than a lower force applied over a proportionally longer time(39). The effect of the impact depends critically on the amount of force applied at the collision moment, which directly depends on the relative velocity of the bodies to one another(39). Since the strokes are commonly executed against an almost “stationary target” (i.e., the opponent’s body), the “arm-acceleration/velocity” has a central role in generating force during punching. In fact, the MPP BT and MPP BP are strongly associated with the impact obtained in all punch techniques (from 0.70 to 0.79, for FJ, FC, SSJ and SSC), confirming the importance of developing the ability to apply high amounts of force at high velocities using the upper limbsin boxers.

It is worth noting that the MPP BT and MPP BP did not differ significantly, in either sex. As described in the Methods section, we only considered the propulsive phase of the movement to assess the muscle power outputs (34). Hence, even though the BP presents a deceleration phase, this phase was not considered for further analyses (the linear transducer standard software automatically excluded the deceleration phase). In addition, it is important to emphasize that the power production is optimized when one or both components of the equation *(power = force x velocity)* are optimized. In ballistic exercises (BT), for instance, the velocity is highly enhanced. Therefore, the power production is more dependent on this vectorial variable (i.e., velocity), which results in higher values of muscle power generated by means of lower loads. Conversely, in traditional non-ballistic exercises (BP) (in comparison to the ballistic BT) the maximum values of muscle power are generated using higher loads, (consequently) moved at lower velocities. It is highly possible that these mechanical differences (in conjunction with the isolation of the propulsive phase of the movements) balanced the BT and BP power outputs, thus explaining the similar results presented by both exercises in terms of MPP.

It is important to emphasize that, in complex movements such as jabs and crosses, the impact forces are the resultant of the sum of the forces applied simultaneously by the upper and lower limbs. When boxers punch at higher velocities, the ability to transfer the momentum of force from the legs to the arms is determinant in achieving high values of impact (15, 19, 20, 43). This is consistent with our results that showed ≈ 82% of shared variance between lower limb muscle power assessed in the jump squat exercise (MPP JS) and all performed impact-tests. Importantly, among the 4 variables collected in maximal isometric assessments (MIF BP, MIF Squat, RFD BP and RFD Squat), only MIF Squat presented significantly high correlations with punching impact (from 0.68 to 0.83, for FJ, FC, SSJ and SSC), reinforcing the importance of the lower limbs in applying force during punches.

On the other hand, the absence of relationships between MIF BP and the impact forces may be associated with the kinematic and kinetic characteristics of the boxing techniques. When the boxers punch, they initiate the movement by applying force against the ground, then rotating the hips and trunk to finally extend their arms to hit the opponent (15, 19). This sequential movement pattern influences the magnitude of the resultant velocity in the arms, determining that the arm-extension occurs at an extremely high speed. Conversely, the lower limb segmental extension starts from “zero-velocity”, being directly dependent on the ability to apply a great amount of force against the ground, to overcome the inertia and accelerate the body in a vertical trajectory (4). Based on these mechanical concepts, and considering that the maximal isometric measurements are strongly associated with the maximal dynamic tests (which occur at very low-velocities) (2, 22), it is reasonable to expect that the punching impact may be more related to MIF Squat than to MIF BP.

Vertical jumps (i.e., SJ and CMJ) are commonly used by strength and conditioning coaches to assess lower limb explosiveness in athletes from different sports disciplines (1, 3, 45). To some extent, this can be explained by the extensive list of correlations presented between these exercises and actual athletes’ performance (21). In combat sports, vertical jumping ability has been shown to be significantly related to specific fighting techniques (i.e., punching acceleration in karate, throwing techniques in judo) (20, 46, 47). The results of this study confirm and extend previous findings suggesting that both SJ and CMJ exert important influence on punching impact (20), being able to explain ≈ 75% of the magnitudes of forces applied by elite boxers during jab and cross executions. It should be noted that the strength-power qualities play an important role in vertical jumping performance and, even in this group of combat athletes, the subjects able to perform better in squats and jump squats are also able to jump higher (Table 3) (8, 45). Taken together, these facts strongly suggest the inclusion of plyometric exercises in training routines that aim to increase fighting-specific neuromechanical capacities in elite “strikers” (i.e., boxers, kickboxers, muay-thai athletes, karate athletes, etc.) due to their effectiveness in eliciting positive adaptations in a wide range of factors related to power performance (e.g., stretch-shortening cycle and muscle recruitment pattern)(6, 29, 30).

Importantly, the relationships between the boxers' body mass and the punching impact forces were much weaker ($r \approx 0.58$) than the correlations found between strength-power measurements and these respective variables. This implies that heavier fighters do not necessarily hit their opponents with more impact, but rather, the stronger and more powerful athletes have more chances/probability of knocking out their adversaries, which highlights the importance of developing neuromuscular abilities in boxers. However, training strategies to improve strength-power capacities in boxers should be carefully selected (19, 43). Due to the need of most boxers to rapidly lose weight prior to the events, training methods inducing large hypertrophy can be extremely counterproductive(31, 36). Additionally, strength training regimensthat prioritize repetitions performed at low-velocities, short-resting intervals and fatigue (i.e., hypertrophic sets), have been shown to be ineffective in increasing explosiveness and, consequently, in inducing positive adaptations towards the high-velocity/low-force end of the force-velocity curve (i.e., area of the curve where very-rapid movements such as punches and/or kicks are situated/executed) (12, 19, 33, 35, 41, 43). In contrast, the power-oriented methods - that typically use light/moderate loads moved at high velocities - may provoke greater adaptations in this portion of the force-velocity curve, with the advantage (in this specific case) of reducing the hypertrophic muscle responses (12, 33, 36, 41).

As reported previously in a wide range of studies involving many sports disciplines (17, 24, 42), the male boxers presented superior performance to the females in both neuromechanical and impact assessments (Table 1). Even in the absence of significant differences in MPP JS and MIF BP, the large differences observed in the effect size calculations between the groups - for all measurements, in favor of the men - demonstrated that gender has an important effect on physical abilities and specific performance of elite boxers. Nevertheless, since the correlation coefficients (between strength-power and impact tests) did not differ between the groups, it is highly recommended that fighters from both genders include in their training programs strategies capable of enhancing neuromuscular performance. In combination with the technical sessions, this training routine will provide the boxers with the capacity to punch more effectively, producing higher levels of impact forces when hitting their opponents.

Finally, the fact that only the jabs presented higher impacts under self-selected distances (when compared to the fixed distances), may be related to the technical characteristics of this type of punch. Jabs are considered “preparatory strokes”, being commonly executed immediately prior to complementary and more powerful punches (i.e., crosses). For this reason, jabs are frequently executed in conjunction with rapid leg displacements (to find the best punching distance), whereas crosses are mostly executed “at the proper distance” (relative to the opponents’ body position), with the boxers’ feet fixed on the floor. These technical aspects probably explain our findings, determining that the “non-static position” increases the impact forces only during the preparatory strokes (i.e., jabs).

To conclude, our findings suggest that elite boxers can improve their punching performance by adding to their training routines methods oriented to develop maximal strength and power of the major muscle groups of the upper and lower extremities. Remarkably, as already reported in other studies involving combat athletes (19, 20, 43), it appears that lower limbs play a central role in generating impact during the punches, by transferring the linear momentum of force from the ground to the legs and, sequentially, to the arms. Although these neuromechanical capacities may substantially influence the boxers' performance, the movement pattern (i.e., segmental extension from the lower to the upper limbs) is determinant in producing higher impact forces during the punches. Since this motor pattern is specific to each stroke, coaches are encouraged to develop technical training sessions able to optimize the transference from the strength-power qualities to the punching performance.

PRACTICAL APPLICATIONS

Due to the large to very large correlations found between strength-power measurements in the lower and upper extremities and the impact forces produced/applied by elite amateur boxers when executing jabs and crosses, strength and conditioning coaches are strongly encouraged to implement specific training strategies to improve performance in such variables. Both the upper and lower limbs have to be effective at applying high levels of force at high velocities for generating superior levels of muscle power. Accordingly, basic power exercises such as the jump squat, bench press and bench throw, using a range of loads capable of increasing the power outputs,could be implemented to enhance the impact of the techniques. In addition, athletes should develop maximal strength by using methods able to elicit positive adaptations in the lower limbs, focusing on methods that induce neural adaptations rather than hypertrophic responses. Further studies should investigate the possible chronic and specific adaptations of using neuromuscular stimulus (i.e., strength-power exercises, plyometrics, etc.) as the priming for the execution of punches, since recent research has shown the effectiveness of complex or contrast methods in other sports specialties, based on the post-activation potentiation phenomenon (13, 23, 35).

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FIGURE LEGEND

Figure 1. Equipment for punching impact assessment. *Note:* The athlete is determining the appropriate distance before performing a jab, starting from the standardized position.

Table 1. Comparisons of punching impacts, muscle power, and isometric test performances between man and women.

	Men	**Women**	**ES (*Rating*)**
FJ (N)	1152.22 ± 246.87*	902.50 ± 213.49	1.08 (*Large*)
FC (N)	1331.67 ± 234.49*	994.17 ± 221.14	1.48 (*Large*)
SSJ (N)	1212.22 ± 269.62*	933.33 ± 164.76	1.28 (*Large*)
SSC (N)	1368.33 ± 266.27*	987.50 ± 192.19	1.66 (*Large*)
SJ (cm)	36.78 ± 5.37*	26.24 ± 3.34	2.42 (*Large*)
CMJ (cm)	37.42 ± 4.75*	27.07 ± 3.30	2.57 (*Large*)
MPP JS (W)	670.05 ± 186.95	456.63 ± 91.30	1.53 (*Large*)
MPP BT (W)	511.58 ± 130.05*	296.39 ± 83.64	2.01 (*Large*)
MPP BP (W)	509.49 ± 115.26*	295.51 ± 74.41	2.26 (*Large*)
MIF SQUAT (N)	2609.56 ± 950.81*	1807.67 ± 314.18	1.27 (*Large*)
MIF BP (N)	1017.67 ± 26.20	727.00 ± 94.65	1.64 (*Large*)
RFD SQUAT ($N.ms^{-1}$)	460.33 ± 81.91*	288.83 ± 95.80	1.93 (*Large*)
RFD BP ($N.ms^{-1}$)	247.44 ± 50.43*	160.17 ± 44.17	1.85 (*Large*)

Note: FJ = fixed jab; FC = fixed cross; SSJ = self-selected jab; SSC = self-selected cross; SJ = squat jump; CMJ = countermovement jump; MPP = mean propulsive power; JS = jump squat; BT = bench throw; BP = bench press; MIF = maximum isometric force; RFD = rate of force development. *Different from women (P < 0.05).

Table 2. Correlations between punching impact indices and muscle power, and maximal isometric force.

	FJ	**FC**	**SSJ**	**SSC**
SJ	0.67 (0.30 - 0.93)	0.77 (0.46 - 0.96)	0.77 (0.46 - 0.91)	0.78 (0.48 - 0.95)
CMJ	0.67 (0.34 - 0.90)	0.79 (0.48 - 0.96)	0.72 (0.50 - 0.88)	0.80 (0.50 - 0.95)
MPP JS	0.76 (0.54 - 0.95)	0.84 (0.66 - 0.96)	0.83 (0.68 - 0.94)	0.85 (0.64 - 0.95)
MPP BT	0.70 (0.30 - 0.94)	0.76 (0.52 - 0.95)	0.75 (0.39 - 0.92)	0.78 (0.54 - 0.94)
MPP BP	0.70 (0.29 - 0.94)	0.78 (0.53 - 0.95)	0.76 (0.38 - 0.94)	0.79 (0.53 - 0.95)
MIF SQUAT*	0.68 (0.28 - 0.92)	0.83 (0.49 - 0.93)	0.69 (0.32 - 0.94)	0.73 (0.45 - 0.95)

Note: FJ = fixed jab; FC = fixed cross; SSJ = self-selected jab; SSC = self-selected cross; SJ = squat jump; CMJ = countermovement jump; MPP = mean propulsive power; JS = jump squat; BT = bench throw; BP = bench press; MIF = maximum isometric force; *Non-normal data; $^{\#}P < 0.01$ for all tested correlations.

Table 3. Correlations between jump height and lower limb muscle power and maximal isometric force.

	SJ	CMJ
MPP JS	0.92 (0.84 - 0.97)	0.88 (0.74 - 0.96)
MIF SQUAT*	0.79 (0.43 - 0.95)	0.79 (0.44 - 0.96)
RFD SQUAT	0.80 (0.55 - 0.93)	0.76 (0.46 - 0.90)

Note: SJ = squat jump; CMJ = countermovement jump; MPP = mean propulsive power; JS = jump squat; MIF = maximum isometric force; RFD = rate of force development. *Non-normal data; #P < 0.01 for all tested correlations.


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