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Relationship between Upper Limb Muscle Power and Shooting Velocity in Elite Male Youth Rink Hockey Players

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Abstract: The present study examined the relationship between upper limb muscle power and shooting velocity in elite male youth rink hockey players. Seventeen participants (age: 18.2 ± 1.44 years) underwent assessments of upper limb power and shooting velocity. Upper limb power was evaluated through bench press exercises, including indirect 1RM, mean power, and peak power. Shooting velocity was measured using a shooting test, including static drive shot, static slap shot, dynamic drive shot, and dynamic slap shot techniques. Results showed significant positive correlations between upper limb power and shooting velocity in static slap shot (r = 0.62, p = 0.04) and dynamic slap shot (r = 0.86; $p < 0.01$). Dynamic slap shot also correlated significantly with peak power (r = 0.63; p = 0.03). Differences in shooting velocity were observed among the techniques ($F_{(3,64)} = 23.7$; $p < 0.01$, $\eta_p^2 = 0.56$), with dynamic slap shot displaying the highest velocity and static drive shot the lowest. These findings highlight the positive association between upper limb muscle power and shooting velocity in elite youth rink hockey players. Developing upper limb power can enhance shooting performance. The choice of shooting technique significantly affects shooting velocity, underscoring the importance of optimizing technique for maximizing performance. These findings provide practical insights for coaches and practitioners, informing the design of targeted training programmes aimed at improving shooting velocity in rink hockey players.

Keywords: roller hockey; biomechanics; shooting technique; performance enhancement

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1. Introduction

The development of power in the upper limb muscles plays a crucial role in the performance of many team sports, especially in these sports which require shooting actions [1,2]. Rink hockey, also known as roller hockey, hardball hockey, or quad hockey, is an indoor team sport (two teams of four players and a goalkeeper face off in two periods of 25 min each), played on classic skates (two pairs of parallel wheels) with a stick used to handle a solid, round ball. In terms of physical demands, rink hockey is a fast-paced intermittent team sport [3,4] characterized by different unilateral high-intensity actions (accelerations, tackles, changes of direction, or sudden braking) [5] that requires players to execute powerful and accurate shots to score goals. Shooting velocity—defined as the speed at which the ball is propelled toward the goal—along with precision, is a key factor in success in most implement sports such as tennis [6,7], baseball [8], golf [9], and all hockey modalities [10–12], including rink hockey. The power of the shots has been increasing in relation to the physical evolution of the rink hockey athletes and improvements in sports equipment, reaching peak speeds around 115 km/h [13,14]. In rink hockey, as in many team sports, shooting velocity is influenced by several factors, including biomechanics, technical skills, and physical attributes [15]. Thus, understanding the factors affecting shooting velocity in rink hockey is essential for optimizing training strategies and player development [16].

Regarding shooting techniques, there are two primary types: the slap shot and the drive shot [15]. The slap shot is often seen as the more intuitive technique and is generally simpler to master. For a right-handed player, the ball is placed on the left side of the body, with the right hand positioned at the top of the stick. The player swings the stick backward before propelling it forward to hit the ball. This movement involves rotating the torso and shoulders to the right, while the right leg is placed forward to provide balance and support. This shot predominantly engages the muscles of the upper body, including the pectorals, deltoids, biceps, and triceps, to generate the necessary power and speed. Additionally, the torso muscles, such as the obliques and abdominals, are engaged to offer rotational strength and stability. The legs, particularly the left one, play a crucial role in generating force through momentum and weight transfer [15]. Conversely, in the drive shot, the ball is placed on the right side of the body for a right-handed player, and the stick is swung backward and then forward in a reverse motion. During this shot, the torso, shoulders, and hips rotate to the left, with the left leg providing stability and balance. Although the primary muscles involved are similar to those used in the slap shot, the obliques play a more significant role in generating the necessary rotation. The legs, especially the right one, are also vital for momentum and effective weight transfer during the shot [15].

Numerous studies have examined the physical determinants of throwing and shooting actions in various team sports. In handball, Marques et al. [17] reported that throwing velocity in elite players was significantly correlated with 1RM in the bench press exercise (r = 0.637, $p = 0.014$), as well as with peak power using 36 kg (r = 0.586, $p = 0.028$) and 46 kg (r = 0.582, $p = 0.029$), and peak bar velocity using 26 kg (r = 0.563, $p = 0.036$) and 36 kg (r = 0.625, $p = 0.017$). Similarly, Chelly et al. [18] found significant correlations between throwing velocity and 1RM in both the pullover (r = 0.56) and bench press exercises among male handball players. Hermassi et al. [19] further reported that the 1RM clean and jerk is a strong predictor of throwing velocity, showing high correlations with jump shot performance (r = 0.75), stationary throws (r = 0.62), and throws following a three-step run-up (r = 0.66). These studies suggest that maximal strength and power in upper body exercises are key contributors to throwing performance in handball. In cricket, Freeston et al. [20] found a significant relationship between throwing velocity and the distance achieved in a medicine ball chest pass (r = 0.67), although no such correlation was observed with 1RM bench press performance. This indicates that, while upper body power is important, traditional measures of strength alone may not fully explain throwing performance in cricket. Similarly, in ice hockey, strong associations have been reported between puck speed in various shot types and upper body strength and power in skilled senior male players [21]. These findings underline the crucial role that upper body strength and power play in sports requiring precise and forceful throwing or shooting actions.

However, despite the recent increase in rink hockey investigations [22,23], the relationship between these factors remains largely unexplored and, to the authors' knowledge, no studies analyzing the specific relationship between upper limb muscle power and shooting velocity in rink hockey players have been performed. The main objective of this study was to determine the relationship between the power and strength of the upper and lower limb muscles and shooting velocity in the different techniques (slap shot and drive shot), with players using both a running approach and shooting from a static position. A secondary objective was to determine the differences in shot velocity according to the techniques used and to study that relationship. Given the paucity of available data assessing this in rink hockey players populations, a true hypothesis was challenging to generate; however, based on the scientific background regarding this issue in other sports, we hypothesized that upper limb power would make significant contributions to such performance.

2. Materials and Methods

The current study employed a cross-sectional design to determine the relationship between upper limb power and shooting velocity in a group of elite youth rink hockey players. An end-of-season fitness testing battery over the course of two consecutive days was conducted. To determine upper limb power, 1RM, mean power, and peak power in a bench press exercise were assessed with a load progressive test. Shooting velocity was assessed with a shooting test. Both exercises are familiar to the players, as bench press exercises and shooting drills are regularly integrated into their training routines.

2.1. Sample

Seventeen elite youth rink hockey players were recruited to participate in this research: age (18.2 ± 1.44 years), body mass (73.5 ± 5.70 kg), height (1.76 ± 0.05 m), body mass index (23.69 ± 1.99 $kg \cdot m^{-2}$), sports experience (6.31 ± 1.73 years). A preliminary power analysis for a Pearson correlation was performed using G^*power to determine an adequate sample size. By establishing the alpha level set at 0.05, using a large target effect size (ES) of 0.6, a power of 0.80 and two tails, it was determined that 16 participants would be needed. All participants in the study adhered to a minimum training schedule of four sessions per week, totaling approximately 8 to 12 h weekly over a period of 8–9 months. Additionally, they participated in at least one game every weekend throughout the season. Notably, each training session included around one hour of strength training in the gym, where athletes wore athletic shoes, followed by an hour and a half of on-field practice. This well-rounded regimen focused on both general physical conditioning and specific on-field skills, enhancing their athletic development and technical proficiency throughout the season. The exclusion criteria for athletes included any injury (acute or chronic) or illness during the testing period that impaired their ability to exert maximal effort. All sports-related injuries sustained during matches or training sessions were carefully recorded and monitored using the Osics coding system [24]. Additionally, goalkeepers were excluded from the analysis as their performance is not influenced by this specific type of skill. Before the participation in the study, written informed consent was obtained from all participants and from their parents/tutors. The design of the research was in accordance with the provisions of the Declaration of Helsinki (revised in Fortaleza, Brazil, 2013), and was approved by the Ethics Committee of the Ramon Llull University in Barcelona (ref. no. 1819005D). In addition, the technical department of the club provided their consent for the study to be conducted.

2.2. Design and Procedures

2.2.1. Shooting Test

Shooting velocity was evaluated on an indoor court. Initially, all participants performed a standardized 15 min warm-up consisting of continuous moderate intensity running, joint mobility exercises for the trunk, shoulders, and wrists, as well as movements at different speeds on the track, and progressive speed changes up to maximum intensity. Subsequently, throwing velocity was measured for each technique: (1) static slap shot (without approach run); (2) static drive shot (without approach run); (3) dynamic slap shot (with approach run); (4) static slap shot (with approach run) (Figures 1 and 2). The order of the shot type and the participants were randomized using the a true random number generator programme [25].

(A) (B)

Figure 1. (**A**) Slap shot and (**B**) drive shot techniques without approach run.

(A) (B)

Figure 2. (**A**) Slap shot and (**B**) drive shot techniques with approach run.

Participants shot a standard rink hockey ball (mass 160 g, circumference 23 cm) as fast as possible toward a standard goal (without goalkeeper), using their personal style. Each subject performed a total of two attempts for each type of shot, with at least two minutes of rest between each attempt. The shoot was measured using a radar Stalker ATS systemTM (Radar Sales, Minneapolis, MN, USA) handheld at shoulder level. Immediately after each shot, the athlete was informed of the velocity achieved. The highest values obtained from the two attempts of the same technique were used for further analysis.

2.2.2. Bench Press

Maximum dynamic upper limb strength was estimated in session 2 using a progressive loading test [26]. Participants performed four progressive overload bench press sets as follows: five repetitions with 30 kg, five repetitions with 40 kg, five repetitions with 50 kg, and five repetitions with 60 kg. Rest periods of 5 min were provided between sets. Participants were instructed to lift the bar as quickly as possible without releasing it. If not all five repetitions were completed, the number performed was recorded. For bench press testing, participants were instructed to lie on the bench in a supine position (i.e., five-point body contact), grasp the barbell (Powerlifting Competition Bar—20 kg; Eleiko, Halmstad, Sweden) with a closed pronated grip shoulder-width apart, and perform repetitions with the barbell positioned over the chest with maximal effort. The test focused solely on the concentric phase of the exercise, with the bar starting at a position 3 cm above the nipple line. Throughout the movement, participants maintained their backs on the bench and their hips flexed at 90 degrees. The analysis of maximum speed was based on the best repetition recorded during the test. To estimate the one-repetition maximum (1RM), the predictive equation of González-Badillo et al. [27] was used (%1RM = $8.4326VMP^2 - 73.501VMP + 112.33$). A linear transducer (CLTP, Chronojump Boscosystem R©, Barcelona, Spain) was used to calculate the slope, theoretical average velocity at 0 kg, and theoretical load at 0 m/s^{-1}. Previous validation studies have shown the reliability and effectiveness of this encoder in measuring movement velocity and estimating power in strength and conditioning training exercises [28].

2.3. Statistical Analysis

Statistical analyses were performed using JAMOVI® v.2.3.24 software. For all variables, the data were expressed as mean and standard deviation (SD). The Shapiro–Wilk test was used to determine the normality of the variables. In addition, within-session reliability of test measures was analysed using a two-way random intraclass correlation coefficient (ICC) with an absolute agreement (95% confidence intervals). Intraclass correlation coefficient (ICC) values were interpreted according to Koo and Li [29] considering >0.9 = excellent, 0.75–0.9 = good, 0.5–0.75 = moderate, and <0.5 = poor, respectively. Additionally, the coefficient of variation (CV) was calculated, and a value of <10% was considered acceptable [30].

The differences in shooting speed according to the kind of technique used (static drive shot, static slap shot, dynamic drive shot, and static drive shot), were tested using a one-way analysis of variance (ANOVA). To observe the pairwise differences between groups, Bonferroni post-hoc tests were used. The significance level was set at $p < 0.05$ for all statistical analyses. Additionally, effect sizes were reported as partial eta-squared (η_p^2), with cut-off values of 0.01–0.05, 0.06–0.13, and >0.14 for small, medium, and large effects, respectively [31]. For pairwise comparison, Cohen's *d* effect size (ES) with 95% confidence intervals was calculated [31], and the magnitude of the ES was interpreted as <0.2 = trivial; 0.2–0.6 = small; 0.6–1.2 = moderate; 1.2–2.0 = large; >2.0 = very large [32].

Pearson's correlations were used to examine the relationship between bench press variables (1RM, mean power, and peak power) and shooting velocities (static drive shot, static slap shot, dynamic drive shot, and static drive shot). Statistical significance was established at $p \leq 0.05$. Correlations magnitudes were evaluated using the Hopkins scale and interpreted as follows: trivial (0.00–0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), and perfect (1.00) [32].

3. Results

Descriptive statistics and reliability measures for all tests are shown in Table 1. Almost all the tests showed good within-session ICC values (≥0.9) and had acceptable consistency with CV values < 10%.

Figure 3 shows the comparisons of shooting velocity (expressed in Km/h) according to the techniques used ($F_{(3,64)} = 23.7$ $p < 0.01$, $\eta_p^2 = 0.56$). The static drive shot reported a slower shot velocity than the static slap shot ($p < 0.01$; $d = -1.57$), a slower velocity than the dynamic drive shot ($p < 0.13$; $d = -1.18$), and a slower velocity than the dynamic slap shot ($p = 0.13$; $d = -3.05$). The dynamic slap shot showed a higher shot velocity than the static slap shot ($p < 0.01$; $d = 1.48$) and than the dynamic drive shot ($p < 0.01$; $d = 1.87$).

Table 1. Mean test scores and within-session reliability data.

	Mean ± SD	ICC	95% CI	CV (%)
Static drive shot (Km/h)	84.4 ± 8.78	0.90	0.74–0.96	10.4
Static slap shot (Km/h)	97.4 ± 8.51 *	0.85	0.59–0.94	8.74
Dynamic drive shot (Km/h)	94.1 ± 7.10 *	0.85	0.59–0.94	7.54
Dynamic slap shot (Km/h)	110 ± 8.58 *†‡	0.88	0.67–0.95	7.83
1RM Bench press (Kg)	79.1 ± 12.6			10.88
Mean Power Bench press (N)	490 ± 99.1			15.86
Peak Power Bench press (N)	746 ± 159			19.44

Key: ICC = intraclass correlation coefficient; CI = confidence intervals; CV = coefficient of variation. *—statistically different from static drive shot; †—statistically different from static slap shot; ‡—statistically different from dynamic slap shot.

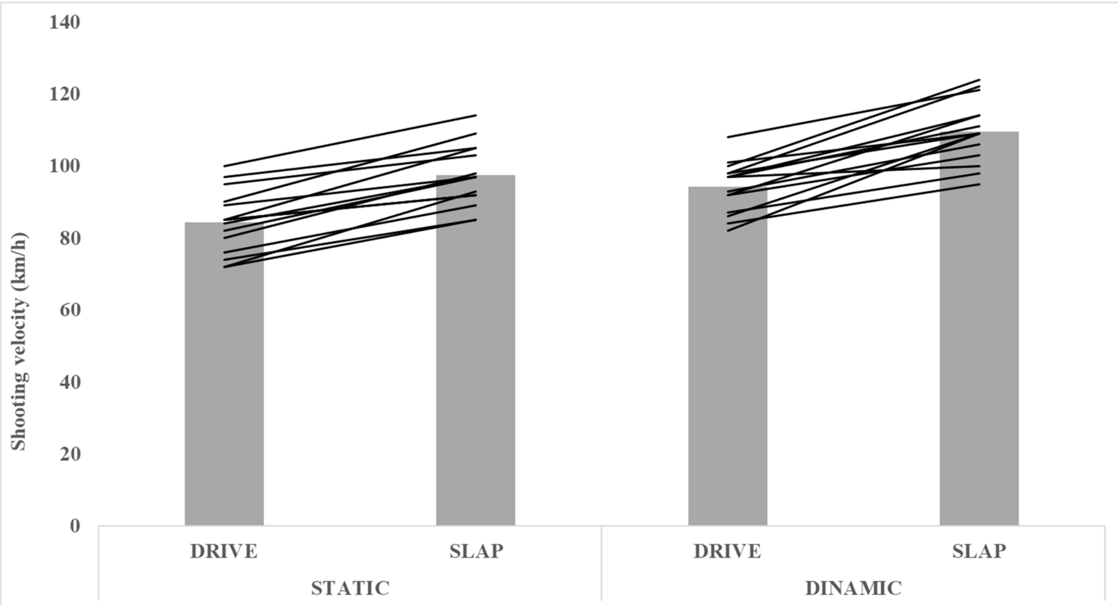

Figure 3. Individual comparison between the slap and drive techniques.

Pearson r correlations (with its confidence intervals) between shooting velocity and bench press test scores are shown in Table 2. The results showed a significant positive correlation with a large magnitude between 1RM and static slap shot (r = 0.62 (0.03 to 0.89); $p = 0.04$); and a significant positive correlation with a very large magnitude between 1RM and dynamic slap shot (r = 0.86 (0.58 to 9.97; $p < 0.01$). Moreover, dynamic slap shot and peak power showed a significant correlation with a large magnitude (r = 0.63 (0.05 to 0.89); $p = 0.03$).

Table 2. Pearson r correlations (r) between shooting velocity and bench press test scores.

Test	1RM	Mean Power	Peak Power
Static drive shot	0.23 (−0.43–0.73)	0.26 (−0.41–0.74)	0.35 (−0.32–0–79)
Static slap shot	**0.62** * (0.03–0.89)	0.37 (−0.29–0.8)	0.52 (−0.11–0.85)
Dynamic drive shot	0.60 (0.02–0.88)	0.58 (−0.03–0.88)	0.59 (−0.02–0.88)
Dynamic slap shot	**0.86** ** (0.58–0.97)	0.41 (0.21–0.81)	**0.63** * (0.05–0.89)

Key: * ($p < 0.05$); ** ($p < 0.01$).

Table 3 displays the correlation matrix between the different shooting velocities according to the techniques used. All the variables correlated except the static drive shot velocity and the dynamic slap shot velocity.

Table 3. Pearson r correlations (r) between the different shooting velocities according to the techniques used.

	Static Drive Shot	Static Slap Shot	Dynamic Drive Shot
Static slap shot	**0.84** ** (0.58–0.95)		
Dynamic drive shot	**0.60** * (0.12–0.85)	**0.73** ** (0.35–0.91)	
Dynamic slap shot	0.38 (−0.17–0.75)	**0.71** ** (0.32–0–90)	**0.62** * (0.15–0.86)

Key: * ($p < 0.05$); ** ($p < 0.01$).

4. Discussion

The present study aimed to investigate the relationship between upper limb muscle power and shooting velocity in elite youth rink hockey players. Additionally, the study aimed to determine the differences in shooting velocity according to the techniques used. The main findings reveal significant associations between upper limb strength and shooting velocities in both static and dynamic drive shot techniques. Furthermore, the study observed significant differences in shooting velocities across various techniques, with the dynamic slap shot reaching higher velocities compared to other techniques.

The results demonstrated significant positive correlations between 1RM in the bench press exercise and both static and dynamic slap shot velocities (r = 0.62 and r = 0.86, respectively). Furthermore, a significant correlation (r = 0.63) between dynamic slap shot velocity and peak power in the bench press exercise was found. As one can expect, the ability to generate high power in the upper limb muscles is particularly relevant for executing dynamic shots with maximum velocity. These findings align with existing research in other team sports that emphasize the importance of upper body strength and power in executing high-velocity throws or shots. For instance, in handball, Marques et al. [17] demonstrated significant correlations between throwing velocity and upper body strength and power, as measured by 1RM bench press and peak bar velocity. Similar findings by Chelly et al. [18] and Hermassi et al. [19] highlight that strength in upper body exercises, such as the bench press and clean and jerk, is a crucial determinant of throwing performance. These consistent results across different sports underline the importance of upper body muscle power in generating forceful and accurate shots, which is also reflected in our study's findings for rink hockey.

Conversely, the results showed no significant relationship between any bench press variable and drive shooting velocities (either dynamic or static). These differences between drive and slap techniques could be explained by the specificity of the motor patterns of both types of shots and by the biomechanical similarities and similar muscle involvement between slap shot and bench press variables. The bench press exercise primarily involves the arm and shoulder muscles, which are crucial in generating power for shooting actions in rink hockey [15]. The dynamic slap shot involves rapid and forceful movements, requiring players to exert maximal power in a short period. Therefore, athletes with greater peak power are better equipped to execute powerful and fast dynamic slap shots, which can be advantageous during gameplay, especially in goal-scoring situations or set-piece actions (one of the most important offensive actions in rink hockey games) [33–35]. However, the drive shot involves a different movement pattern, for which the player uses a rotational motion and trunk rotation to generate power. Although the arm and shoulder muscles are still involved, the primary emphasis in the drive shot is on rotational power and coordination and there is a higher involvement of the stabilators and core muscles [15]. Therefore, the correlation between bench press values and drive shot performance is weaker, indicating that other factors, such as rotational strength and technical proficiency, might play a more significant role in the execution of this particular technique. This finding aligns with Freeston et al. [20], who observed that, while the medicine ball chest pass showed a strong correlation with throwing velocity (r = 0.67), traditional strength metrics (such as 1RM in the bench press) did not fully account for throwing performance in cricket. Instead, they emphasized the importance of exercises that enhance rotational power and co-ordination. The fact that certain techniques have a stronger relationship with strength metrics than others has also been observed in ice hockey. Bežák et al. [21] found a significant relationship between sweep shot puck speed and 1RM bench press performance (r = 0.64), but no significant correlation between slap shot puck speed and bench press 1RM (r = 0.46). The authors suggest that sweep shot speed in skilled players depends primarily on their strength and power abilities, whereas slap shot speed is influenced more by shooting technique. Although rink hockey and ice hockey share similar shot techniques, differences in stick materials, stick size, and the contrast between a rink hockey ball and an ice hockey puck may explain the discrepancies between Bežák et al.'s findings and the results of our study.

The comparative analysis of shooting velocities according to the techniques used demonstrated differences in shot velocity. Not surprisingly, the slap shot technique showed higher velocities compared to the drive shot. This finding can be explained because the slap shot is the dominant side for most rink hockey players. Furthermore, the dynamic shots showed higher velocities than the static shots due to the inertia of the approach run (110 $\pm$ 8.58 km/h vs. 97.4 $\pm$ 8.51 km/h for the slap shots and 94.1 $\pm$ 7.10 km/h vs. 84.4 $\pm$ 8.78 km/h for the drive shots). These results are in line with those of Vaz et al. [13] who reported similar values (115.4 $\pm$ 7.2 km/h vs. 102 $\pm$ 4.6 km/h) with a sample of top elite rink hockey athletes.

Finally, the positive correlations between shooting velocities across the various techniques suggest a consistent relationship between the different types of shots. This finding implies that players who excel in one type of shot are also likely to perform well in other shot techniques. Therefore, training interventions that target specific shooting techniques are likely to have a positive impact on overall shooting performance in rink hockey players.

Despite the utility of these findings, it is important to acknowledge some limitations of the present study. Firstly, the sample size was relatively small, and the study focused exclusively on elite youth male rink hockey players from a specific club. Therefore, caution should be exercised when generalizing these results to other player populations or to different standards. Future research should seek to replicate these findings with players of different age groups and competitive levels to better understand how these factors may influence performance. It is also important to include female players in future studies, as there is currently a significant gap in the literature regarding rink hockey in women [36]. Investigating female athletes could provide valuable insights, especially given the increasing participation of women in the sport and the potential differences in physical and technical demands between male and female players. Secondly, this study utilized a cross-sectional design, which did not allow for the establishment of causal relationships. As such, the results of the present research represent only the point in time that the measurements occurred (end-season). The results may vary depending on season timing. Given the potential influence of season timing [37], particularly in youth athletes [38], longitudinal studies would be beneficial. Such studies could include a control group to compare training effects and track changes in muscle power and shooting performance over time. Additionally, the study assessed upper limb power and shooting velocity only, neglecting other potentially influential factors such as lower limb power, coordination and accuracy. Moreover, the displacement speed of the players during the dynamic shots was not evaluated, and a 3D biomechanical analysis of the shooting technique was not conducted. Further investigations considering a more comprehensive set of variables would provide a more holistic understanding of shooting performance in rink hockey. It is worth noting that the specific muscle involvement during shooting actions may vary depending on the technique used [15]. Future studies utilizing electromyographic (EMG) analysis could provide further insight into the muscle activation patterns during different shooting techniques in rink hockey. This would enable a more comprehensive understanding of the biomechanical aspects underlying shooting performance and potentially identify specific muscle groups that make a greater contribution to shooting velocities.

5. Conclusions

The current study revealed a significant relationship between upper limb muscle power and shooting velocity in elite youth rink hockey players. The findings highlight the importance of developing upper limb strength and power to enhance shooting performance in rink hockey. Furthermore, the study demonstrated that different shooting techniques significantly influence shooting velocities, emphasizing the need for technical training programmes that optimize shooting biomechanics.

Considering these results, rink hockey coaches and strength and conditioning specialists might consider prioritising upper limb power development in training programmes to enhance shooting performance. Exercises targeting the muscles involved in arm extension and trunk rotation, such as bench presses should be emphasized throughout the training programmes to improve upper limb strength and power. However, while this study focused on upper limb power and shooting velocity, it is important to consider other factors that may influence shooting performance, such as lower limb power, co-ordination, and accuracy. This may include assessing lower limb strength and power, co-ordination drills, and accuracy training to ensure a well-rounded approach to improving shooting performance.

Finally, these training programmes might consider also focussing on optimizing shooting techniques to maximise ball speed. Players should receive coaching on proper body positioning, arm and shoulder coordination, and trunk rotation to generate the greatest amount of force and precision during shots. Incorporating biomechanical analyses (such as motion capture technology) could provide valuable feedback and help players refine their shooting techniques.

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