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Influences of Sex on Muscle Architecture and Performance in Elite Field Hockey Players

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Abstract: The aim of this study was to compare muscle architecture and performance between male and female elite Field Hockey players and to investigate the relationships between echo intensity and performance. Twenty-one male (24.3 ± 3.6 y; 75.1 ± 8.5 kg; 176.8 ± 6.4 cm) and nineteen female players (27.4 ± 3.9 y; 61.2 ± 7.4 kg; 164.4 ± 4.9 cm) were tested for muscle thickness (MT) and echo intensity (EI) of trapezius (Trap) and vastus lateralis (VL) muscles. Participants were also assessed for bench press power, and 30 m sprint. Results showed a higher VLMT and TrapMT in male players compared to female players (+22.1%; $p = 0.004$ and +25.8%; $p = 0.001$ for VLMT and TrapMT, respectively). A lower VLEI was detected in male players compared to female players (−20.7%; $p = 0.001$), while no significant differences were detected for TrapEI. Male players were faster than female players in a 30 m sprint and more powerful at the bench press ($p < 0.001$). Significant correlations were detected between VLEI and 30 m sprint (r = 0.74) in female players only. Results indicate that differences exist between male and female elite Field Hockey players in the EI of lower body muscles, while these differences are not present in the upper body muscles. EI, together with other sprint and power assessments, may represent an important parameter for elite Field Hockey players.

Keywords: muscle architecture; team sport; sprint; echo intensity

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1. Introduction

Field Hockey is a fast moving, territorial game in which power and sprint capabilities represent key factors to support the success of players at the international level [1]. Although a relevant variability exists between the different field positions and sexes, strength and power of both the upper and the lower body have been indicated as important contributors for essential skills such as the drag flick and sprint [2].

Differences in strength and power between men and women have been widely investigated in both trained [3,4] and untrained individuals [5]. Women are known to be less strong and powerful than men, especially in the upper body [4,5]. However, these disparities become less evident when strength is considered in relation to lean body mass or muscle architecture [6]. Recently, muscle ultrasound has been used to investigate the relationships between muscle architecture and performance in male Field Hockey players competing at the national level [7]. Significant correlations between muscle architecture of vastus lateralis and sprint and change of direction capabilities were reported by these authors (r = 0.5; $p = 0.034$ and r = 0.62; $p = 0.006$, between fascicle length and sprint and change of direction, respectively). Unfortunately, in that study, echo intensity (EI) was not considered. This parameter, calculated by the darkness of the ultrasound image [8], has been recently indicated as a strong predictor of muscle quality [9,10]. Hirsch and colleagues [11] reported significant correlations between EI, sprint performance, and strength, in track and field athletes. EI is influenced by the characteristics of both contractile and noncontractile components of muscles [12] and by the training status. Although aging has been associated with increased EI levels [13], training tends to reduce this parameter at any age [14]. An elevation in EI in trained athletes has been associated with reduced functionality and may increase the chance of muscle injuries [15]. Some studies have reported higher values of EI (indicating a lower muscle quality) of the vastus lateralis in women compared to men (71.2 ± 12.8 and 60.4 ± 12.6 in women and men, respectively) [10]. However, other studies conducted on middle-aged and old individuals did not find significant differences in EI between the sexes [16].

Although some studies have investigated the differences in muscle architecture and EI between men and women, only a few considered highly trained individuals [3,7] and, to the best of our knowledge, none have been conducted on elite Field Hockey players of both sexes. Thus, the first aim of the present study was to compare male and female elite Field Hockey players for muscle architecture, EI, strength and power, and sprint and change of direction performance. A second aim of the present study was to investigate the relationships between muscle architecture and performance in elite Field Hockey players. Since sex is known to influence muscle adaptations to sport training and muscle quality, the authors hypothesize that significant differences may also exist in EI between male and female elite Field Hockey players. The authors also hypothesized that EI may be significantly correlated with strength and power performance in both male and female players.

2. Materials and Methods

2.1. Study Design

This study consisted of a cross-sectional experimental design in which all the assessments were performed in the same visit at the Human Performance Laboratory. Testing protocol and approximate duration of each measurement are reported in Figure 1. Participants were assessed for anthropometric measures, body composition, muscle architecture, agility, sprint, 1 repetition maximum (1-RM), and power at the bench press. All the assessments were performed before the beginning of the European Cup. Based upon previous investigations of our research group [3], the estimated sample size was 20 to ensure a between-group difference of 200 w and of 30 kg in upper body power and strength, respectively. The best performances registered in each test were then analyzed.

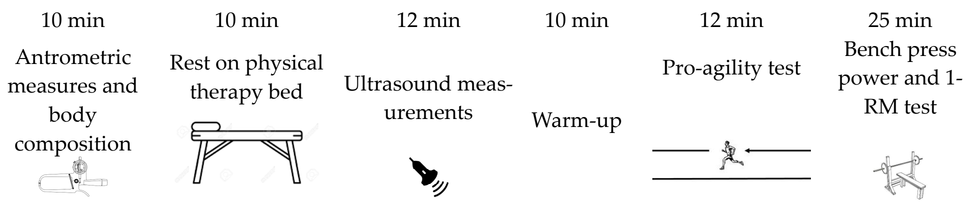

Figure 1. Assessment protocol and approximate duration of each measurement.

2.2. Subjects

Participants were elite Field Hockey players who had participated in regular resistance training a minimum of 3 times per week in the last 2 years prior to the study. Participants included twenty-one men (n = 21; 24.3 ± 3.6 years; body mass: 75.1 ± 8.5 kg; height: 176.8 ± 6.4 cm) and nineteen female players (n = 19; 27.4 ± 3.9 years; body mass: 61.2 ± 7.4 kg; height: 164.4 ± 4.9 cm) that were recruited from the Italian Senior National Teams. Players were tested at the end of the in-season period, at least 1 week following the last official game and 72 h following the last training session. All subjects were between the ages of 18 and 35 years and signed an informed consent document after the risks and benefits of the study were explained. Exclusion criteria included injuries that occurred in the year before the investigation. Subjects were regularly tested for performance-enhancing drugs. Participants were asked to abstain from caffeine, alcohol, and any intense physical activity in the 24 h previous to the tests. Participants were also asked to maintain their habitual nutritional behaviors before the tests and were allowed to eat ad libitum. The study was approved by the local University Review Board. Two participants of the Female group were taking oral contraceptives.

2.3. Body Composition and Muscle Architecture Assessments

Body composition, anthropometric, and muscle architecture assessments were performed at the beginning of the assessment session. Body measurements included body mass, body fat, and height. Body mass was measured to the nearest 0.1 kg (Seca 769, Seca Scale Corp., Munich, Germany). The percentage of fat mass (%FM) was estimated by skinfold caliper (Harpenden skinfold caliper, CMS Instruments, London, UK) measures using the equation of Evans et al. [17].

Skeletal muscle ultrasound images were collected from each participant's right side. Before image collection, all anatomical locations of interest were identified using standardized landmarks for the vastus lateralis muscle (VL) and trapezius muscle (Trap). The VLMT was measured along its longitudinal distance midway between the superior margin of the patella and the most prominent point of the great trochanter of the femur, with the knee bent 10° [18]. The probe was positioned on the skin surface without depressing the dermal layer (gain = 50 dB; image depth = 5 cm). Muscle thickness of the Trap was measured at the midpoint of the muscle belly between T1 and the posterior acromial edge, where the muscle borders were parallel [19].

Participants were asked to lie on a physical therapy table for a minimum of 10 min before images were collected. The same qualified investigator performed all landmark measurements for each participant. A 12 MHz linear probe scanning head (Mindray MD20, Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China) was coated with water-soluble transmission gel to optimize spatial resolution and used to collect all ultrasound images. All ultrasound images were taken and analyzed by the same investigator. MT measures were obtained using a longitudinal B-mode image, and three consecutive MT images were captured and analyzed for each muscle. For each image, MT was measured with a single perpendicular line from the superficial aponeurosis to the deep aponeurosis.

Echo intensity (EI) was assessed by computer-aided grey-scale analysis using ImageJ (National Institute of Health, Bethesda, MD, USA, Version 1.45). The raw EI values were determined for the VL and Trap muscles as the corresponding index of muscle quality ranging between 0 and 255 a.u. (black = 0; white = 255). Thickness of subcutaneous adipose tissue was quantified with ImageJ's straight line function as the distance between the skin–muscle interface and the superior border of the muscle's aponeurosis [20]. The mean of three subcutaneous thickness values from each image was utilized. The raw EI values were then corrected for subcutaneous adipose thickness using the equation previously published by Young et al. [21]:

$$\text{Corrected EI (cEI)} = \text{RawEI} + (\text{subcutaneous fat thickness in cm} \times 40.5278)$$

This correction was applied to VL and Trap muscles. The average of the 3 MT and EI measures was used for statistical analyses. Intraclass correlation coefficients were 0.96 (SEM = 0.63 mm), CI: 0.841; 0.983 and 0.97 (SEM = 0.55) CI: 0.853; 0.992 for TrapMT and VLMT, respectively. Intraclass correlation coefficients were 0.94 (SEM = 1.21 a.u.), CI: 0.838; 0.960 and 0.95 (SEM = 1.05 a.u.) CI: 0.855; 0.963 for TrapEI and VLEI, respectively.

2.4. Change of Direction Speed and Sprint Testing

Prior to each testing session, participants performed a standardized warm-up consisting of five min on a cycle ergometer against a light resistance, 10 body weight squats, 10 body weight walking lunges, 10 dynamic walking hamstring stretches, and 10 dynamic walking quadriceps stretches [22]. Following the anthropometric assessments and the warm-up, participants were tested for agility and sprint, and for maximum strength and power at the bench press.

A pro-agility test was performed as previously described by Foster et al. [23]. Briefly, for the pro-agility run, the participants sprinted 4.57 m to the left, then 9.14 m to the right, and 4.57 m back to finish the test as they crossed the centerline. Participants were asked to start from a 3-point stance with the left foot 30 cm behind the start/finish line and to touch the lateral lines with the respective hand. Timing started when the participant turned 90 degrees to the left and ran through timing gate. Each participant was asked to perform one familiarization attempt and two attempts with a 2 min recovery time between each one. Sprint performance was tested using a 30 m sprint with a self-selected start. Participants were asked to sprint as fast as possible from 30 cm behind the starting line, starting from a standing position using the preferred foot and a 3-point stance. They performed 2 successive attempts with a recovery time of 2 min. In both pro-agility and 30 m sprint tests, time was measured using an electronic timing system to the nearest 0.01 s (Microgate Witty Timing, Microgate Corporation, Bolzano, Italy) and the best performance was recorded. In the 30 m sprint, timing gates were placed at the starting line and at 30 m, using a tripod at a height of 60 cm. Both assessments were conducted on a Field Hockey specific surface with the same clothing and footwears. Intraclass correlation coefficients were 0.92 (SEM = 0.21 s), CI: 0.808; 0.948 and 0.94 (SEM = 0.14 s) CI: 0.835; 0.953 for pro-agility and 30 m sprint, respectively.

2.5. Strength and Power Testing

Following the 30 m sprint test, participants performed a bench press maximal strength and power test (BPP). Bench press testing was performed in the standard supine position using a free barbell. The participant lowered the bar to mid-chest, then pressed the weight until their arms were fully extended. The 1-RM test was performed using an incremental method beginning from a baseline of 20 kg and continued until failure in 10 kg increments [24]. Participants were required to perform one repetition with each load, observing a rest time of 2 min between attempts. During each repetition, the power produced was measured and a force–power curve was constructed after attainment of the 1-RM. Area under the curve (AUC) was calculated using a standard trapezoidal technique. An optical encoder (Tendo Unit model V104, Tendo Sports Machines, Trencin, Slovak Republic) was used for power assessment. The peak power was also registered. In addition, the maximum strength and power relative to body mass were also calculated (Rel 1-RM and Rel Pow, respectively).

2.6. Statistical Analyses

A Shapiro–Wilk test was used to test the normal distribution of the data. Data of the two groups were compared using independent sample *t* tests. The partial eta squared statistic was also reported as the effect size (ES), and 0.01, 0.06, and 0.14 represent small, medium, and large effect sizes, respectively, according to Stevens [25].

Pearson's correlation coefficients were used to examine selected bivariate relationships. According to Mukkaka [26], correlation coefficients (r) of 0.3, 0.5, 0.7, and 0.9 were interpreted as low, moderate, high, and very high relationship, respectively. Where appropriate, percent differences were calculated as follows: ((M mean $-$ F mean)/M mean) $\times$ 100. All data were analyzed using SPSS 20 for Windows (SPSS Inc., Chicago, IL, USA) and are reported in the text as mean $\pm$ SD. The reliability of all measurements was determined and the intra-class correlation coefficient, confidence intervals, and standard error of measurement (SEM) were reported. Significance level was set for $p \leq 0.05$.

3. Results

3.1. Body Composition and Muscle Architecture

All the results of body composition and muscle architecture assessments are reported in Table 1. A significantly lower %FM was registered in male players compared to female players ($p < 0.001$; $\eta^2 = 0.673$; CI: -12.622; -8.989). Significant differences between the groups were detected for VLMT ($p = 0.007$; $\eta^2 = 0.182$; CI: 0.811; 0.469) and TrapMT

($p = 0.001$; $\eta^2 = 0.284$; CI: 0.104; 0.342). Both values were more elevated in male players compared to female players, by 22.1% and 25.8% for VL and TRAP muscles, respectively. VLEI was significantly lower in male players compared to female players (−20.7%; $p < 0.001$; $\eta^2 = 0.361$; CI: −15.575; −6.011), but not in Trap ($p = 0.375$; $\eta^2 = 0.021$; CI: −4.612; 1.778). When EI was corrected for subcutaneous fat (cEI), significant differences were detected between male and female players in VL ($p < 0.001$; $\eta^2 = 0.370$; CI: 18.008; 33.172), but not in Trap ($p = 0.798$; $\eta^2 = 0.002$; CI: −5.420; 5.070). Figure 2 shows ultrasound images of the VL collected from a typical participant in both the male and female group.

Table 1. Data of the body composition and muscle architecture assessments. FM = fat mass; MT = muscle thickness; VL = vastus lateralis; Trap = trapezius; EI = echo intensity; cEI = corrected EI; a.u. = arbitrary units. * indicates a significant difference ($p \leq 0.05$) from the Female group.

Assessment	Male Group	Female Group	Groups Comparison (p; η^2; CI)
%FM	9.69 ± 3.05 *	20.51 ± 3.31	≤0.001; 0.673; −12.622, −8.989
VLMT (mm)	1.49 ± 0.29 *	1.22 ± 0.31	0.007; 0.182; 0.811, 0.469
TrapMT (mm)	1.12 ± 0.21 *	0.89 ± 0.15	≤0.001; 0.284; 0.104, 0.342
VLEI (a.u.)	41.22 ± 6.64 *	52.01 ± 7.89	<0.001; 0.361, −15.575
TrapEI (a.u.)	30.75 ± 2.70	32.16 ± 6.19	0.375; 0.021; −4.612, 1.778
VLcEI (a.u.)	52.64 ± 8.8 *	77.35 ± 13.71	≤0.001; 0.370; 18.008, 33.172
TrapcEI (a.u.)	38.93 ± 2.74	39.58 ± 9.72	0.798; 0.002; −5.420, 5.070

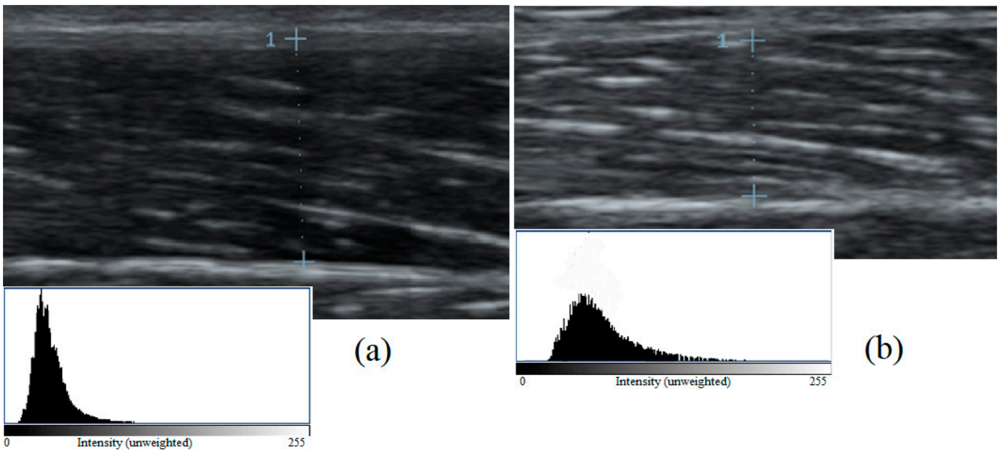

Figure 2. Ultrasonography image and pixel intensity histogram of the vastus lateralis from a typical male (**a**) and female (**b**) elite Field Hockey player participating in the present study.

3.2. Change of Direction Speed and Sprint Testing

All the results of pro-agility and sprint assessments are reported in Table 2. Performance was significantly lower in female players compared to male players in both pro-agility ($p \leq 0.001$; $\eta^2 = 0.390$; CI: 0.176; 0.411) and 30 m sprint ($p \leq 0.001$; $\eta^2 = 0.650$; CI: −0.763; −0.456). The difference between the two groups was an average of 0.29 s and 0.61 s for the pro-agility and 30 m sprint tests, respectively.

Table 2. Data of the performance assessments. * indicates a significant difference ($p \leq 0.05$) from the Female group.

Assessment	Male Group	Female Group	Groups Comparison (p; η^2; CI)
Pro-agility (s)	4.72 ± 0.21 *	5.01 ± 0.16	≤0.001; 0.390; 0.176, 0.411
30 m sprint (s)	4.19 ± 0.19 *	4.80 ± 0.25	≤0.001; 0.650; −0.763; −0.456

3.3. Strength and Power Testing

All the results of strength and power assessments are reported in Table 3. A significant difference between male and female groups was detected for bench press 1-RM ($p \leq 0.001$; $\eta^2 = 0.942$; CI: 27.038; 45.689), bench press AUC ($p \leq 0.001$; $\eta^2 = 0.427$; CI: 5244.44; 11,687.43), and bench press peak power ($p = 0.002$; $\eta^2 = 0.843$; CI: 221.96; 297.61). Male players were superior to female players by an average of 88.4%, 150.6%, and 120.0% for bench press 1-RM, bench press AUC, and bench press peak power, respectively. Male players were also superior to female players in Rel 1-RM ($p \leq 0.001$; $\eta^2 = 0.448$; CI: 0.78;−0.95) and in Rel Pow ($p \leq 0.001$; $\eta^2 = 0.186$; CI: 3.98–5.05).

Table 3. Data of the performance assessments. AUC = area under the force–power curve; a.u. = arbitrary units. * indicates a significant difference ($p \leq 0.05$) from the Female group.

Assessment	Male Group	Female Group	Groups Comparison (p; η^2; CI)
Bench Press 1-RM (kg)	77.50 ± 20.48 *	41.13 ± 8.15	≤0.001; 0.942; 27.038, 45.689
Bench press AUC (a.u.)	5623.63 ± 1960.16 *	1493.57 ± 1381.60	≤0.001; 0.427; 5244.44, 11,697.43
Bench press peak power (W)	476.26 ± 74.44 *	216.47 ± 34.87	0.002; 0.843; 221.96; 297.61
Rel 1-RM	1.07 ± 0.30 *	0.67 ± 0.10	≤0.001; 0.448; 0.78,−0.95
Rel Pow (w·kg)	5.26 ± 2.30 *	3.61 ± 0.57	≤0.001; 0.186; 3.98–5.05

3.4. Correlations between Variables

Significant correlations were detected between 30 m sprint time and VLcEI (r = 0.76; $p \leq 0.001$ in both male and female groups) and %FM (r = 0.89; $p \leq 0.001$ and r = 0.56; $p = 0.019$ in male and female group, respectively). Significant correlations were found between TrapMT and bench press peak power, bench press AUC, and bench press 1-RM in the female group only (r = 0.50, $p = 0.0039$; r = 0.62; $p = 0.007$; and r = 0.55, $p = 0.014$ for bench press peak power, bench press AUC, and bench press 1-RM, respectively). Significant correlations were also found between %FM and VLEI in both groups (r = 0.56; $p = 0.019$ and r = 0.49; $p = 0.05$ in male and female group, respectively), but not between %FM mass and TrapEI (r = 0.26; $p > 0.05$). No other significant correlations were observed.

4. Discussion

The aim of the present study was to compare male and female elite Field Hockey players on muscle architecture, EI, and performance, and to study the relationships between these parameters. The main findings were that significant differences exist between male and female players for EI of the VL muscle while no differences were detected on this parameter for the Trap muscle. To the best of our knowledge, this is the first study to compare muscle architecture and performance in male and female elite Field Hockey players.

Since in ultrasound imaging, muscle tissue appears black and adipose tissue white, EI is mainly influenced by intramuscular adipocytes [27]. However, some authors have demonstrated that this parameter may be also affected by subcutaneous adipose tissue that may alter adsorption and reflection of ultrasound waves [21]. Thus, these authors suggested applying a correction factor for subcutaneous adipose tissue thickness. In the present study, however, participants were elite Field Hockey players with low %FM (an average of 9.69% and 20.51% for male and female players, respectively) and subcutaneous fat may not have a relevant influence on EI. This is supported by the comparison of the EI corrected for subcutaneous fat (cEI) between male and female players. Studies in which the correction factor was applied involved untrained participants with a %FM between 8.1 and 46.8% [19]. Thus, the difference between male and female players detected in the present study on EI of the lower body muscles may be mainly related to intramuscular adipocytes [26]. The intramuscular fat content may be influenced by the hormonal profile of women that promotes lipogenesis mostly in the abdomen, glutes, and the upper lateral part of the thigh [28]. Thus, the present study shows that the difference in muscle quality between men and women appears greater in the muscle groups located in the lower limbs (e.g., the VL) than in the upper body muscles (e.g., the trapezius muscle) in elite athletes.

Curiously, muscle thickness of Trap and VL were similar between the elite female Field Hockey players evaluated in the present study, and female strength and power athletes previously tested by our research group (0.89 cm and 0.88 cm for elite female Field Hockey players and female strength and power athletes, respectively) [3]. On the contrary, the difference between these athletic populations on VLMT was higher compared to Trap MT (1.22 cm and 1.49 cm for elite female Field Hockey players and female strength and power athletes, respectively) [3]. Consistently, the differences between male Field Hockey players and male strength and power athletes were more evident on VLMT than on Trap MT.

As expected, men were stronger and more powerful than women at the bench press, and faster in the 30 m sprint and pro-agility tests. Results of the present study showed that male players were superior to female players in upper body strength and power by an average of 49.9% and 54.5% for 1-RM bench press and bench press peak power, respectively. Male players were also superior to female players when upper body strength and power were adjusted for body mass. This is consistent with previous studies conducted on strength and power athletes [3].

Elite male players participating in the present study showed a 30 m sprint and a pro-agility performance similar to what was recently recorded in Division I male Italian Field Hockey players [7,29] and in elite Chinese players [30]. The average performance was 4.19 s and 4.72 s in 30 m sprint and 4.3 s and 4.7 s in pro-agility in elite Chinese male and Division I Italian Field Hockey players, respectively. Since sprint and change of direction are crucial components of Field Hockey, these data may represent normative data for high level male Field Hockey players. A recent study by Kapteijns et al. [31] reported an average time of 4.57 s on 30 m sprint in elite Belgian female Field Hockey players. In our study, an average time of 4.80 s was registered on the same distance. However, in our investigation, two goalkeepers (with an average time of 5.42 s on 30 m sprint) were tested. The average time of the female outfield players was 4.74 ± 0.14 s. It is therefore clear that a time below 4.8 s in 30 m sprint appears desirable in high level female Field Hockey players. The lower performances detected in female players compared to male in sprint and agility may be partially related to sex differences in strength and power [32]. This, together with the big gap in upper body strength and power between female and male Field Hockey players, suggests that the conditioning program of female players should place great emphasis on strength and power training. In addition, these components may be also important for shooting speed [2].

Finally, our data showed significant correlations between muscle architecture, EI, and performance. Interestingly, VLEI was correlated with %FM while TrapEI did not show a relevant correlation with %FM. This may be due to a different distribution of fat mass between men and women. In addition, when VLEI was corrected for subcutaneous fat, a significant correlation (0.76) with 30 m sprint was detected in both male and female groups. On the contrary, raw VLEI was only correlated with sprint performance in the female group ($r = 0.62$). These finding show that %FM may represent a crucial factor for sprint performance mainly for female player, while this parameter may be less important when male players are considered. Differences in the hormonal milieu, physical size, and social behavior between the sexes may impact muscle quality, size, and performance of the different muscle groups in male and female athletes [33].

A possible limitation of the present study is that the power of the lower body was not assessed. Countermovement jump, a test that is usually performed for this purpose, is not generally used to assess Field Hockey players since vertical jumps are not frequent during the game. In the present study, female players were not assessed for the phase of their menstrual cycle at the time of the evaluations. Since performance may be influenced by the hormonal changes that occur during the menstrual cycle, this may represent another limitation of the present study.

5. Conclusions

In conclusion, this is the first study to investigate EI and performance in elite Field Hockey players of both sexes. Male players were characterized by a more elevated muscle quality in lower limb muscles, compared to female players. Contrarywise, no significant differences in EI were detected in upper body muscles. In both male and female players, a low VLcEI (corrected for adipose tissue) was associated to good sprint performances.

Since strength and power are known to play a key role in sprint and agility, resistance exercise should be emphasized within the conditioning programs of female Field Hockey players. The present study also provided useful benchmarks for performance and muscle architecture of trained athletes. In particular, values of EI measured in this study may indicate a normal range for healthy players that coaches and therapist may use to guide the rehabilitation process following injury.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the University of Bologna (protocol number: 23222; 26 January 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

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