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Relative Scapular-Muscle Ratios During Maximal Isokinetic Shoulder-Girdle Strength Performance in Elite Field Hockey Players

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Context: The shoulder joint and girdle are highly loaded during field hockey play. To optimize performance and to better substantiate preventive programs, it is important to gain insight into shoulder-girdle muscle function and balance in this athlete population.

Objective: To evaluate relative scapular muscle-activity ratios through surface electromyography during maximal isokinetic strength testing in elite male field hockey players compared with nonathletes.

Design: Cross-sectional study.

Setting: Institutional laboratory.

Patients or Other Participants: Twenty-five elite field hockey players from the Belgian National Team and 25 age- and sex-matched nonathletes.

Intervention(s): We measured bilateral activity in 4 scapular muscles (upper trapezius [UT], middle trapezius [MT], lower trapezius [LT], and serratus anterior [SA]) during an external-internal rotation and protraction-retraction isokinetic shoulder protocol.

Main Outcome Measure(s): Relative scapular muscle-activity ratios, or balance ratios, of the UT : MT, UT : LT, UT : SA, SA : MT, and SA : LT.

Results: We noted lower ratios bilaterally in the athlete group compared with the control group for the UT : MT, UT : LT, and SA : MT ratios during protraction, retraction, and external rotation, respectively, and unilaterally (dominant side only) for the UT : LT ratio during protraction. No consistent trend was present for established side differences in the studied balance ratios.

Conclusions: Compared with nonathletes, elite field hockey players had altered intramuscular (within the trapezius) and intermuscular (between the trapezius and SA) balance ratios during maximal shoulder-girdle contractions, with relatively more MT and LT activity. This may reflect a sport-specific adaptation to optimize coordinated activity of the scapulothoracic muscles, meeting the specific demands of field hockey movements and simultaneously better protecting the shoulder against injury. Our results can assist in optimizing high-performance training and in supporting injury-prevention programs, which are key to both successful and long-lasting athletic careers.

Key Words: muscle activity ratios, shoulder, electromyography, elite athletes

Key Points

- Elite field hockey players demonstrated altered intramuscular and intermuscular scapular balance ratios during maximal shoulder-girdle contractions.
- They displayed more middle and lower trapezius activity than nonathletes.
- These results may reflect a sport-specific adaptation, aimed at simultaneously optimizing performance and better protecting the shoulder against injury.

In field hockey, the shoulder joint and shoulder girdle are highly loaded during practice and competition,[1] and optimal upper limb function is an important requirement for these athletes.[2] On both the glenohumeral and scapular levels, optimal muscle strength, activity, and balance are necessary for high performance and injury prevention.[3] Field hockey is a "right-handed" sport, whereby the head of the stick is flat on the left-hand side only. Consequently, the stick is swung from right to left during the downswing of the "classic" hit. Therefore, regardless of hand dominance, the stick is held in the same way by all field hockey players, which leads to a specific, and different, loading of each shoulder during play. While performing a forward hockey hit, for example, the right shoulder is moved from an externally rotated and retracted position (during the backswing phase) to an internally rotated and protracted position (during the downswing and follow-through phase). The left shoulder, in contrast, moves from an internally rotated and protracted (backswing) to an externally rotated and more retracted (downswing and follow-through) position. In summary, field hockey players use their upper extremities extensively, in both a closed chain and open chain manner. The upper extremities are continuously used to drive, guard, pass, and receive the ball. While the athlete is handling the ball, the shoulder girdle needs to be adequately stabilized to retain control over the ball, simultaneously allowing for controlled shoulder movement, so that adjustments to the ball's trajectory can be made when necessary. However, shoulder muscle function remains largely unstudied in these players.

To optimize performance and to better substantiate injury-prevention programs, we must gain insight into the muscle function and balance in this athlete population compared with a nonathlete population. A frequently used method of evaluating muscle recruitment and activity is electromyography (EMG),[4,5] which allows assessment of individual muscles as well as calculation of intermuscular balance ratios. Because scapular muscles do not work in isolation but rather synergistically to produce controlled scapular motion and stability, characterizing the relative scapular-muscle activity, or so-called scapular balance ratios, of the synergistic muscle pairs provides valuable information.[6] The most frequently described relative scapular muscle-activity ratios are the upper trapezius (UT) : middle trapezius (MT), UT : lower trapezius (LT), and UT : serratus anterior (SA) ratios,[6–9] but other ratios, such as the LT : SA[6] and MT : LT,[10] have been described as well.

Frequent practice of shoulder-loading sports leads to specific adaptations in muscle-related variables, including muscle strength.[11] This was recently confirmed in a study[2] comparing the glenohumeral and scapular strength of field hockey athletes and control participants. Yet the literatures regarding muscle activity in healthy athletes versus healthy nonathletes is scarce. Whether repetitive, high levels of shoulder loading and weight training result in sport-specific adaptations in scapular-muscle activity remains unknown. This lack of knowledge also extends to field hockey players. Research is needed to characterize scapular muscle-activity values and ratios in this athletic population to establish normative values and to compare these values with those of a nonathletic population to enhance insight into the sport-specific profile of these athletes, support performance, and aid in the substantiation of injury-prevention programs.

Therefore, the purpose of our study was to (1) evaluate relative scapular muscle-activity ratios using EMG in elite male field hockey players during maximal (isokinetic) contractions while performing external and internal shoulder rotation as well as protraction-retraction movements and (2) compare the results with an age- and sex-matched control group. Side differences within each group were of interest as well. We hypothesized that field hockey athletes would display altered scapular balance ratios compared with healthy nonathletes but were uncertain about the nature of these alterations. To our knowledge, this is the first study addressing this topic among field hockey players.

METHODS

Participants

We recruited field hockey players (n = 25) through communication with the head coach and physiotherapist of the national field hockey team. Their mean age was 24.0 years (range = 18–28 years), height was 180.5 cm (range = 172–191 cm), and body mass was 77.2 kg (range = 69–88 kg). They averaged 19.2 ± 2.80 years of field hockey experience and practiced 19.1 ± 3.81 hours of field hockey per week. A control group of healthy volunteers (n = 25), matched for age and sex, was recruited through social media. Their mean age was 23.0 years (range = 19–28 years), height was 181.8 cm (range = 170–190 cm), and body mass was 75.7 kg (range = 61–101 kg). All participants in both groups were right handed.

A history of shoulder complaints or injury did not constitute grounds for exclusion from the field hockey group as long as no shoulder complaints were present at the time of testing. Control participants could practice shoulder-loading activities a maximum of 3 h/wk. Control participants were excluded if they had experienced shoulder complaints in the past 6 months or had a history of any type of shoulder injury (eg, rotator cuff tear) or shoulder-related intervention (eg, shoulder rehabilitation).

Independent *t* tests showed no differences between the field hockey players and control participants with respect to age, height, body mass, or body mass index (BMI). A questionnaire was used to gather demographic, sport-specific, and shoulder-specific information from all participants. Before testing, all participants read and signed an informed consent form. The study was approved by the Ethical Committee of Ghent University (B670201523201).

Procedures

While the participants performed maximal contractions during internal and external shoulder rotation as well as during scapular protraction and retraction, EMG data were collected.

Data Collection. We collected EMG data using an 8-channel EMG receiver type (model Myosystem-1400; Noraxon USA, Inc, Scottsdale, AZ). Before electrode application, the skin was shaved, scrubbed, and cleaned with disinfectant to reduce impedance. Bipolar surface electrodes (model Blue Sensor P, REF P-00-S/50; Ambu A/S, Ballerup, Denmark) were placed bilaterally over 4 scapulothoracic muscles (UT, MT, LT, SA), longitudinal to the muscle fibers, with a 1-cm interelectrode distance (see Appendix). A reference electrode was placed on the spinous process of C7 (see Figure 1A and 1B). Once positioned, the electrodes were connected to the EMG receiver. The sampling rate was 1000 Hz, and all raw myoelectric signals were preamplified (overall gain = 500; common rate rejection ratio $>$100 dB; signal-to-noise ratio $<$1 μV root mean square baseline noise). Before the measurements, we verified correct electrode placement and EMG signal quality through visual inspection of the signal during muscle-specific movements, including scapular elevation, retraction, and protraction. After confirmation of good signal quality, calibration was completed with the participant in a standardized position (seated upright on a chair, feet flat on the floor, hands resting on the thighs, and shoulders relaxed).

Determination of Maximal Voluntary Isometric Contractions. Four tests were executed bilaterally to determine the maximal voluntary isometric contraction (MVIC) of each muscle, as a means of normalizing muscle-activity data measured during the maximal contractions at a later stage. The MVIC measurements were obtained according to the protocols of De Mey et al,[12] Cools et al,[13] and Castelein et al.[14] The test positions for the 4 muscles are described in the Appendix. Two tests were performed with the participant in a seated position (feet flat on the ground, back straight, test arm in correct test position, other arm relaxed on the thigh or beside the body). The participant was clearly instructed not to use the contralateral arm. Two

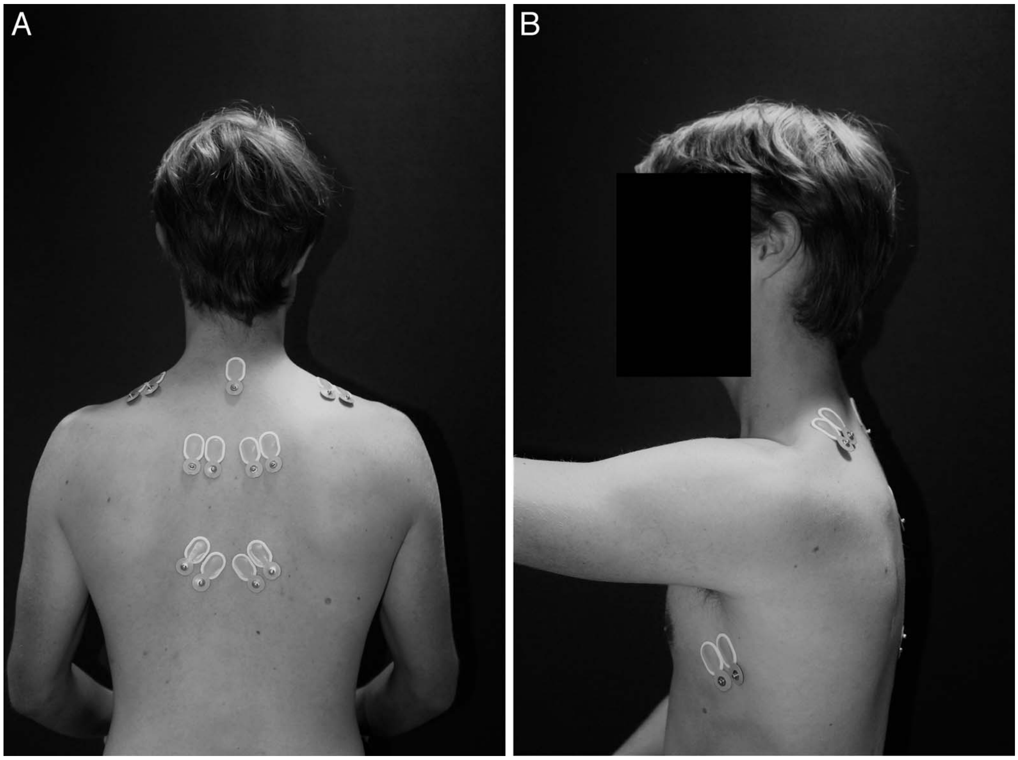

Figure 1. A. Back view of the electrode placement. B, Side view of the electrode placement.

tests were performed by the participant in prone position (small rolled-up towel at the level of the sternum to avoid friction of the anterior electrodes, test arm in correct test position, other arm relaxed in 90° of abduction, elbow flexed 90° across the table edge). The tests were completed in a fixed order: first, the MVICs with the participant in seated position (UT and SA) and, second, the remaining 2 muscles (MT and LT) with the participant in prone position. The dominant side was always tested first, followed by the nondominant side. The MVICs were performed against manual resistance, always provided by the same researcher, ensuring isometric execution.

Before data collection, participants were familiarized with the different test positions. One practice trial was allowed for each position (followed by a resting period of 10 seconds) before 3 trials of 5-second MVICs at each position were completed, with 20-second pauses between tests. The participants were asked to reach their maximal effort in 2 seconds, sustain it for 5 seconds, and then relax in standardized position (prone, feet flat on the ground, back straight, hands resting on the thighs, shoulders relaxed or the arm resting beside the body) until the next repetition was performed. The investigator counted the seconds out loud in time with a metronome. During testing, we checked for maximal effort and compensations. If necessary, we corrected the participant, and the trial was repeated.

Maximal Contractions With Simultaneous EMG Recording. The isokinetic strength tests were performed using an isokinetic dynamometer (model 4; Biodex Medical Systems, Shirley, NY), according to the protocols of Cools et al.[10,11] Two movements were tested, namely internal and external shoulder rotation and scapular protraction and retraction; all participants completed 5 repetitions of each movement. Rotations were performed in a modified neutral position, and protraction-retraction movements were performed in 90° of abduction in the scapular plane. All movements were tested in a concentric-concentric mode and at low velocity, translating to an angular velocity of 60°/s (rotations) or a linear velocity of 12.2 cm/s (protraction-retraction). Simultaneously with these maximal contractions, EMG data were collected, using the same setup described earlier. Movement direction and turning point were determined using the goniometer of the isokinetic dynamometer.

The participant was seated against the backrest of the chair. To minimize contact between the upper back and the backrest, additional back support was provided by 2 small rolled-up towels: 1 towel was placed vertically, alongside the spine, on the contralateral side, and the other towel was placed horizontally across the middle of the lower back, beneath the LT electrodes. In this way, friction between the electrodes on the upper back and the chair was avoided. Moreover, the electrodes of all 4 muscles were supported with Hypafix (BSN Medical GmbH, Hamburg, Germany) for extra fixation. Trunk stabilization was provided by a strap running from the contralateral shoulder across the chest to the ipsilateral hip. To fix the lower limb in place, the contralateral leg was stabilized using another strap. To reduce friction between the skin and fixation straps, towels were inserted. The contralateral hand rested on the thigh, and we clearly instructed the participant not to grasp the handgrip on the side of the chair or to use this hand in any way during the testing. Figures 2 and 3 show the starting positions for the rotational and protraction-retraction movements, respectively.

The EMG data collection was initiated 10 seconds before the start of the maximal contractions, while the participants

Figure 2. Starting position for the isokinetic shoulder rotations.

Figure 3. Starting position for the isokinetic protraction-retraction movements.

were sitting relaxed in the starting position. Three practice trials were performed before the actual testing.

Electromyographic Signal Processing

Signal processing was performed using MyoResearch software (version 3.6 Master Edition; Noraxon USA, Inc). For the EMG signals during both the MVICs and the maximal contractions, cardiac artifact reduction was performed, followed by rectification and smoothing (root mean square, window = 100 milliseconds) of the signals. For each muscle, the average EMG value was calculated over a window of the peak 3 seconds of each 5-second MVIC test. The mean of the 3 trials per muscle was used for analysis. In that way, we determined the maximal EMG value of the 4 muscles during each MVIC test for each side. Based on these values, the highest value for each muscle was selected for the dominant and nondominant sides, according to Castelein et al.[14] These highest values represented the maximal EMG amplitude produced by each muscle (MVIC). We then used these MVICs to express all EMG data, measured during the maximal contractions, as a percentage of this MVIC per muscle, resulting in normalized EMG data for all muscles.

Outcome Variables

Mean values and standard deviations for the normalized EMG activity of all 4 muscles during all maximal contractions were determined. Subsequently, as the outcome variables of interest, 5 relative scapular muscle-activity ratios were calculated: UT : MT, UT : LT, UT : SA, SA : LT, and SA : MT. These scapular balance ratios were obtained by dividing the mean activity value of the first muscle by the mean activity value of the second muscle. This was calculated for each movement direction and for the dominant and nondominant shoulders in both the athlete and control groups. Mean values and standard deviations of all 5 ratios were determined.

Data Analysis

Data control was performed, and all normalized EMG data were controlled for normal distribution using the Shapiro-Wilk test and visual control of the related histograms. We conducted parametric statistics because the data were normally distributed. An independent *t* test with $\alpha = .05$ was performed to analyze group differences in age, height, weight, and BMI. A general linear model 2-way analysis of variance (ANOVA) with repeated measures was used for statistical analysis of the 5 relative scapular muscle-activity ratios. The within-participant factor was side (2 levels: dominant side, nondominant side) and the between-participants factor was group (2 levels: field hockey players, control participants). Interaction effects of group and side, as well as main group and side effects, were of interest. In the presence of an interaction effect, group differences and side differences were tested post hoc at each level of the interacting variable using a Bonferroni adjustment. In the absence of interactions, main effects of group and side were analyzed. The α level was set at .05 for the ANOVA. All statistical analyses were performed with SPSS (version 24.0; IBM Corp, Armonk, NY).

RESULTS

The means and standard deviations of the relative scapular muscle-activity ratios during the maximal contractions are presented in Tables 1 and 2. The scapular balance ratios are summarized during shoulder rotations (Table 1) and the protraction-retraction movements (Table 2) separately for the athlete and control groups.

Internal and External Rotation

Statistical analysis revealed no significant interaction effects during the rotational movements for any of the 5 calculated relative scapular muscle-activity ratios. However, significant main group and side effects were established for 2 ratios: 1 main group effect for the SA : MT ratio and 2 main side effects for the UT : SA ratio.

During external rotation, the field hockey players had a lower SA : MT ratio ($P = .029$) on both sides compared with the control participants. During this same movement, a higher UT : SA ratio ($P = .002$) was noted in both groups on the dominant side than the nondominant side. In contrast, the UT : SA ratio was lower ($P = .001$) in the dominant versus the nondominant shoulder during the internal-rotation movement in both groups. No significant effects were found for the UT : MT, UT : LT, or SA : LT ratios during these rotational movements.

Table 1. Relative Scapular Muscle-Activity Ratios During Shoulder Rotations by Side

Variables	Ratio, Mean ± SD			
	External Rotation		Internal Rotation	
	Dominant	Nondominant	Dominant	Nondominant
Field hockey players				
UT : MT	0.66 ± 0.485	0.61 ± 0.180	0.66 ± 0.253	0.78 ± 0.450
UT : LT	0.74 ± 0.421	0.67 ± 0.290	1.21 ± 0.648	1.21 ± 0.529
UT : SA	2.89 ± 2.101[a]	2.03 ± 1.052[a]	0.63 ± 0.381[a]	0.89 ± 0.450[a]
SA : LT	0.31 ± 0.156	0.28 ± 0.121	2.06 ± 0.660	1.90 ± 0.937
SA : MT	0.31 ± 0.247[b]	0.26 ± 0.143[b]	1.28 ± 0.728	1.05 ± 0.456
Control participants				
UT : MT	0.70 ± 0.455	0.76 ± 0.332	0.77 ± 0.333	0.96 ± 0.570
UT : LT	0.64 ± 0.327	0.62 ± 0.180	1.63 ± 1.429	1.26 ± 0.527
UT : SA	2.21 ± 1.413[a]	1.62 ± 1.217[a]	0.75 ± 0.418[a]	1.03 ± 0.735[a]
SA : LT	0.37 ± 0.184	0.38 ± 0.196	2.53 ± 2.017	2.22 ± 1.410
SA : MT	0.39 ± 0.244[b]	0.41 ± 0.257[b]	4.83 ± 17.658	1.51 ± 1.465

Abbreviations: LT, lower trapezius; MT, middle trapezius; SA, serratus anterior; UT, upper trapezius.

[a] Significant side effect.

[b] Significant group effect.

Protraction and Retraction

The general linear model 2-way ANOVA with repeated-measures design revealed 1 significant interaction effect ($P = .016$) for the UT : LT ratio during the protraction movement. Post hoc testing using a Bonferroni adjustment indicated a higher UT : LT ratio on the dominant side compared with the nondominant side in the control group. This finding did not extend to the athlete group. In addition, a significant group difference was noted for this ratio, with a lower UT : LT ratio in the athletes compared with the control participants during protraction but only for the dominant side.

Along with the interaction effect, 2 additional significant main group effects as well as 3 significant main side effects were revealed. One significant main group effect was noted during protraction for the UT : MT ratio. The field hockey players had a lower UT : MT ratio ($P = .015$) than the control participants on both the dominant and nondominant sides. During the retraction movement, 1 significant main group effect was found for the UT : LT ratio, and 3 significant main side effects were established for the UT : MT, UT : SA, and SA : MT ratios. During scapular retraction, the UT : LT ratio was lower ($P = .031$) in the athlete group than in the control group on both sides. Concerning the side differences, a higher UT : SA ratio ($P = .024$) was noted on the dominant side versus the nondominant side in both groups, whereas the opposite result occurred for both the UT : MT ($P = .039$) and SA : MT ($P = .023$) ratios. No effects were revealed for the SA : LT ratio during either of these scapular movements.

DISCUSSION

We investigated and compared 5 relative scapular muscle-activity ratios in and between a group of elite field hockey players and an age- and sex-matched control group

Table 2. Relative Scapular Muscle-Activity Ratios During Protraction and Retraction by Side

Variables	Ratio, Mean ± SD			
	Protraction		Retraction	
	Dominant	Nondominant	Dominant	Nondominant
Field hockey players				
UT : MT	0.73 ± 0.350[a]	1.02 ± 0.560[a]	1.50 ± 1.159[b]	1.80 ± 0.830[b]
UT : LT	2.11 ± 1.733[a]	2.38 ± 1.783	3.69 ± 3.028[a]	3.92 ± 2.898[a]
UT : SA	0.30 ± 0.208	0.36 ± 0.253	4.13 ± 2.465[b]	3.19 ± 2.085[b]
SA : LT	9.44 ± 8.778	10.39 ± 8.160	1.18 ± 1.196	2.32 ± 4.066
SA : MT	3.72 ± 3.056	3.64 ± 1.811	0.43 ± 0.312[b]	0.75 ± 0.853[b]
Control participants				
UT : MT	1.16 ± 0.536[a]	1.22 ± 0.774[a]	1.63 ± 0.738[b]	2.36 ± 2.177[b]
UT : LT	4.63 ± 3.115[ab]	3.22 ± 2.656[b]	7.32 ± 7.927[a]	5.55 ± 4.570[a]
UT : SA	0.37 ± 0.223	0.41 ± 0.262	3.03 ± 1.895[b]	2.60 ± 1.765[b]
SA : LT	14.47 ± 11.177	12.42 ± 6.619	3.53 ± 4.755	2.58 ± 2.658
SA : MT	3.90 ± 2.013	4.25 ± 2.534	0.72 ± 0.445[b]	0.91 ± 0.833[b]

Abbreviations: LT, lower trapezius; MT, middle trapezius; SA, serratus anterior; UT, upper trapezius.

[a] Significant group effect.

[b] Significant side effect.

of healthy nonathletes during maximal internal or external rotation and protraction or retraction contractions. To our knowledge, this is the first study addressing shoulder-girdle muscle activity in this elite population.

Because group differences were of interest, the main results were bilaterally lower UT : LT, UT : MT, and SA : MT ratios in hockey players compared with control participants during retraction, protraction, and external-rotation contractions, respectively. The same conclusion was reached concerning the UT : LT ratio during protraction contractions but only for the dominant shoulder. Because 3 of these 4 group differences occurred during the scapular-protraction and -retraction movements, we identified a greater contrast between the athletes and control participants during these movements versus the glenohumeral rotational movements. Even though muscle recruitment is dominance dependent, no consistent trend was found for side differences in the scapular balance ratios.

Group Differences in Scapular Balance Ratios

Our results suggested altered intramuscular (within the trapezius) and intermuscular (between the trapezius and SA) scapular balance ratios during maximal shoulder-girdle contractions in the field hockey players compared with matched controls. In particular, lower UT : LT, UT : MT, and SA : MT ratios may reflect relatively decreased UT and SA activity in this population, relatively increased MT and LT activity, or both. This might indicate a sport-specific adaptation due to intense field hockey play and accompanying weight training to optimize coordinated activity among the scapulothoracic muscles and meet the specific demands of field hockey. However, because criterion standards in scapular muscle-recruitment patterns among field hockey players are unknown, we have no data for comparison, and therefore, conclusions must be drawn with caution.

For all group differences, lower ratios were found in the hockey players compared with their control cohorts, independent of the movement during which the maximal contractions were performed.

The largest difference between the populations was in the UT : LT ratio during protraction and retraction, which was up to 55% lower in the athlete group. The UT : MT ratio (during protraction) and the SA : MT ratio (during external rotation) were 16% to 38% lower in the field hockey players. This translates to relatively more LT or MT activity compared with either UT (in the UT : LT and UT : MT ratios) or SA (for the SA : MT ratio) activity in these athletes during the maximal contractions. In general, low UT : MT and UT : LT ratios are preferable[6,10,13] because high UT : MT and UT : LT ratios, suggesting excessive activation of the UT and decreased activity of the MT and LT, are factors proposed to contribute to abnormal scapular motion and linked to shoulder injury.[6,8,13,15] Although the clinical relevance of these altered muscle-activity ratios is unclear, the lower ratios in the athlete group might reflect more optimal shoulder muscle function, possibly reducing the risk of injury to the shoulder girdle and enhancing the ability to meet the high shoulder demands of field hockey through optimal scapular-muscle performance.

Our results for the protraction movements were similar to those of Cools et al,[16] who investigated the nondominant sides of overhead athletes (including tennis and volleyball players) with dominant-side injuries. However, Cools et al[16] reported a distinctly lower UT : LT ratio (2.80 versus 3.92), SA : MT ratio (0.46 versus 0.75), and mainly SA : LT ratio (0.83 versus 2.32) during retraction than we did. For the latter 2 ratios (ie, SA : MT and SA : LT), relatively greater SA muscle activity in relation to MT or LT activity in field hockey athletes compared with overhead athletes during retraction movements can explain these differences. Concerning the UT : MT (0.90 versus 0.61) and UT : LT (0.77 versus 0.67) ratios during external rotation among overhead athletes (including swimmers and tennis and volleyball players), the results of Cools et al[10] were higher than ours. Again, Cools et al[10] could study only the athletes' nondominant sides because the dominant sides were injured. Study protocols were similar (protraction-retraction,[16] external rotation[10]); however, the populations were not, as field hockey players are not considered overhead athletes. Shoulder loading in these populations differs from that during field hockey. Therefore, even though no more suitable data are available, illustrating the research gap for this population, comparisons should be cautious.

Two comments concerning hand dominance and comparable body mass between groups are important. All of the field hockey players in our investigation were right handed. Given the fact that in general, 10% of the population is left-handed, it is a rarity for a sample of 25 athletes to lack a single left-handed person. However, this was a mere coincidence, for which no explanation can be provided. The control participants were matched to the athletes in hand dominance, which resulted in a total sample of 50 right-handed individuals. Additionally, no differences in height, body mass, or BMI between the athlete and control groups were identified. Mean heights and ranges were similar (athletes: height = 180.5 cm [range = 172–191 cm], controls: height = 181.8 cm [range = 170–190 cm]). Mean body mass was also comparable (athletes = 77.2 kg, control participants = 75.7 kg), but body mass range differed, being narrower in the athlete group (69–88 kg) compared with the control group (61–101 kg). The range difference involved both the lower and upper limits, though, which might explain the comparable overall body masses and BMIs in both groups.

Limitations

Some limitations of this study need to be mentioned. Caution must be exercised when extrapolating our results to more functional situations because isokinetic protocols do not totally reflect normal functional shoulder movement.[10,16] Even though isokinetic maximal exercises are often used to examine EMG muscle activity in the surrounding muscles,[10] which is especially appropriate in a high-performance population, muscle loading during functional shoulder tasks differs from loading during maximal contractions in a controlled laboratory environment. Therefore, our findings cannot be extrapolated without attention to circumstances in which the shoulder girdle moves in a more functional manner, such as during hockey. Second, the study protocol did not allow us to measure the deeper layer of the scapular muscles, such as the pectoralis minor and levator scapulae. Third, the use of surface EMG had typical limitations such as cross-talk and movement artifacts. However, the study design provided maximal standardization, ensuring sufficient reliability and validity of the measured EMG signals. The highly variable EMG data, illustrated by the relatively high standard deviations, was consistent with prior work[6] on scapular-muscle activity. Fourth, the sample size of the tested athletic population was rather small, with 25 elite field hockey players; however, the group included the entire male national field hockey team. The national team comprises the most elite athletes; adding athletes who were not part of this team would have reduced the performance-level heterogeneity. Last, the athlete group consisted of male hockey players only; no female athletes were assessed.

Suggestions

Future researchers should try to reinforce the study sample and extend the population to female athletes. Field hockey is also a very popular female team sport, so evaluating female athletes is a logical next step; additionally, it would allow for comparison of data between sexes.

CONCLUSIONS

From a clinical perspective, our findings may assist coaches and sports physicians in understanding the sport-specific profile of the elite field hockey player. Knowledge concerning muscle function, activity, and balance is extremely important in optimizing the high performance level of these athletes and in supporting injury-prevention programs, both of which are key to extending their athletic careers. These results are a first step in providing reference values for scapular balance ratios in this athletic population. Sport-specific reference values allow for the comparison with results in similar populations and are necessary for relevant and informative interpretations. Such comparisons can prompt intervention or further investigation when relevant deviations from these reference values are noted.

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Appendix. Electrode Placements for Electromyographic Data Collection and Test Positions for Maximal Voluntary Isometric Contraction Measurements

Muscle	Electrode Placement	Test Position
Upper trapezius	In the middle of the line between the spinous process of C7 and the posterior angle of the acromion, longitudinal in the fiber direction	Seated, shoulder abducted to 90° with elbow flexed to 90° as resistance is applied perpendicularly at the distal part of the upper arm, in a downward direction to resist abduction
Middle trapezius	Horizontal placement, in the middle of the line between the spinous process of T3 and the spina scapulae	Prone position, shoulder in 90° abduction and maximal external rotation, with elbow fully extended; resistance is applied proximal to the elbow, perpendicular to the upper arm, to counteract horizontal abduction of the arm
Lower trapezius	Laterocranial and mediocaudal placement in the middle of the line between the spinous process of T7 and the inferior angle of the scapula	Prone position, shoulder abducted to 145° with elbow fully extended, as resistance is applied proximal to the elbow, perpendicular to the upper arm, to resist horizontal abduction of the arm
Serratus anterior	Oblique upward placement on the superficial fibers at approximately ribs 6–8	Seated, shoulder anteriorly flexed to 135° and elbow fully extended, as resistance is applied proximal to the elbow to oppose further anterior flexion