ORIGINAL ARTICLE

Nr 2024;14 (1):168-179

Peculiarities of Adolescent, Qualified Female Volleyball Players' Shoulder Girdle

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DOI:
10.32098/mltj.01.2024.14

LEVEL OF EVIDENCE: 3

SUMMARY

Background and purpose. Many regularly performed spikes and serves lead to a shoulder girdle adaptation that could be sport-specific and result in traumatic events. The aim was to evaluate shoulder joints' range of movements (ROM), peak isometric strength of arm muscles, submaximal force repetition error, and upper body dynamic stability in adolescent female volleyball players.

Materials and methods. 15 qualified, 17.7 ± 2.1-year-old, female volleyball players participated. The shoulder active ROM of internal rotation (IR), external rotation (ER), flexion, extension, abduction, adduction, horizontal abduction (HABD), and horizontal adduction (HADD) were measured. The peak force and the ability to repeat the same submaximal force of IR, ER, and extension were determined. Dynamic stability was detected by the Y-upper-body dynamic balance test (Y-UBDST).

Results. The ER ROM was increased but the IR and HADD ROMs were decreased on both shoulders**.** The extension and adduction ROMs were smaller in the dominant (D) shoulder ($p < 0.05$). The D arm's IR, ER, and extension muscles developed greater peak forces ($p < 0.05$). ER/IR muscles' peak forces ratio was 0.94 ± 0.18 in both shoulders. The ER and extension muscles submaximal force repetition error was smaller in the D arm ($p < 0.05$). The mean score of the normalized reaching distances in the Y-UBDST was symmetrical: 95 ± 6% in the D and 94 ± 7% in the non-dominant (ND) arm. The correlation between the rotators' peak force and the Y-UBDBT was not significant.

Conclusions. The shoulder girdle characteristics were optimal and adaptable for volleyball spike and serve movements in those adolescent qualified female volleyball players without pathological changes in pre-season.

KEY WORDS

Muscles strength; proprioception; range of movements; shoulder; volleyball.

INTRODUCTION

Shoulder pain syndrome represents the third of the most common injuries among female and male volleyball athletes and is the second most common overuse-related condition, accounting for 8-20% of all volleyball injuries (1, 2).

There is body of evidence indicating that volleyball players' performance depends on highly developed qualities like strength, power, speed, and agility. Thus, to be at their best level of performance, volleyball players need to spike the ball stronger and faster (3) by reaching an internal rotation velocity in the shoulder joint of about 7,000°/s (4).

The main factor of the successful spiking technique in a competitive environment is the ability to produce a large range of motion (ROM) before the ball is hit (5). The considerable evidence shows that excessive external rotation movement may be a reason for overloading the surrounding muscles and ligaments, therefore causing the injury (6). Athletes with regular overhead movements of the upper extremities have demonstrated altered shoulder internal (IR) and external rotation (ER) ranges of motion, thus indicating the reduction of IR and the increase of ER in the dominant (D) arm when compared with the non-dominant (ND) arm. These shoulder joint ROM changes contribute to alterations of the bones (humeral retroversion), joint capsule (posterior thickening), and increase of muscle passive stiffness (7). When the IR ROM is decreased for more than 18°-20° or the total arc of motion is decreased for 5°-8° in the D shoulder in comparison with the ND shoulder, a pathological glenohumeral IR deficit (GIRD) or total arc of motion deficit develops (8). This could cause alterations in the technique of sports movements with consequent risk of shoulder injury growth (8, 9). Schmalzl *et al*. (10) observed that GIRD larger than 10° led in nearly 75% of the male volleyball and handball players to a decrease in total range of motion and a high rate of postero-superior impingement. Controversially, Challoumas *et al*. (11) and Keller *et al*. (12) in their review articles did not determine a statistically significant increase of shoulder injury risk in those overhead movement athletes with the glenohumeral IR deficit and ER gain. Mizoguchi *et al*. (13) determined that there was no association between shoulder injury and GIRD among adolescent male and female volleyball players. Mizoguchi *et al*. (13) observed significantly larger ROM in shoulder ER-IR movement and a higher prevalence of shoulder injuries in adolescent volleyball female players (8.5% in the previous year) than in males (4.0%). The effect of volleyball players' sex on shoulder joint adaptation to training and/or competitive conditions in volleyball has not been fully investigated. It has been established, that females' joints possess lower stiffness during the co-contraction of muscles, and they have smaller muscle mass, especially in the upper extremities (14).

In comparison with the non-dominant shoulder, the D shoulder produces a higher strength within IR muscles, which leads to a relative shoulder ER/ IR muscle torque ratio reduction. Thus, worsening the stability in comparison with the ND shoulder. This is especially observed in those elite male volleyball players (without shoulder injury), who play in the attacker and blocker positions (3, 15, 16, 17). Continuous overhead movements with eccentric contractions of the rotator cuff muscles can cause an overload on the glenohumeral joint, which, as follows, can lead to the formation of micro-damage to the muscles and limited joint ROM (18, 19). Many authors have suggested that the reduction of shoulder ER/ IR muscle torque ratio is related to the increase of injury risk in athletes with regular overhead movements of the upper extremities (11, 16, 20). Based on the results, obtained by Hadzic *et al*. (21), there was significant preseason weakness of ER and decreased ER/IR strength ratio in the first and second national league male volleyball players, who experienced shoulder injuries during the previous season. Moreover, athletes with shoulder GIRD had a lower ER/ IR peak torque ratio (0.56) than athletes without GIRD (0.83) (22).

In sum, the shoulder girdle is exposed to tremendous cumulative load as the result of repetitive spiking and serving movements. The glenohumeral joint is capable of an exceptional range of motion but, unfortunately, possesses anatomical instability. The strength of muscles (dynamic stabilizers of the scapula and the humeral head) is one of the main factors in maintaining the functional integrity of the glenohumeral joint, and the ability to successfully spike and serve a ball (2).

Y- upper body dynamic balance test (Y-UBDBT) in volleyball is a popular functional movement indicator to measure dynamic stability of the upper extremity in a weight-bearing position, thus identifying factors for risks of injury (23-27). It is well known that proprioception plays a decisive role in shoulder stability and motor control of the upper limbs (28). Proprioception includes sub-modalities like joint position sense (the ability to reproduce joint angles actively or passively), kinesthesia (sense of movement), sense of force, and sense of change in velocity (29, 30). Proprioception could influence the final phase of throwing or spike as it plays a crucial role in ensuring the correct hand positioning and modulating the speed and trajectory of the throw or spike in athletes who regularly repeat overhead movements of their upper extremities (31). A proprioceptive deficit could alter the recruitment of the shoulder muscles, causing an over-activation or under-activation of the rotator cuff muscles, ultimately predisposing an athlete to injury (31).

Mendez-Rebolledo *et al*. (28) evaluated possible correlations between shoulder position sense and the performance in the Y-UBDST in 18-26-year-old male and female college volleyball players who trained ≥ 12 hours per week. They observed that better results of active joint position sense at 90° of shoulder IR (when 90° of the arm abduction is present) are associated with the better performance of the Y-UBDST in superolateral, inferolateral direction, and composite score.

Shoulder IR and ER force reproduction tests are found to be highly reliable, with interclass correlation coefficients of 0.849 in patients with rotator cuff tendinopathy and 0.909 in healthy subjects; the errors of ER were significantly larger than those of IR, and relative IR and ER force reproduction errors were similar in both groups of participants (32). Sense of force differentiation has not been investigated on a wide scale in athletes who perform regular overhead movements of the upper extremities.

Hypothesis: volleyball training would lead to an increase of ER ROM and reduction of IR ROM, an increase of the arms muscles' strength and force differentiation ability, improvement of the upper body dynamic stability, and significant side-asymmetry of these characteristics in adolescent female volleyball players with high-performance levels.

The aim was to evaluate shoulder joints' range of movements (ROM), peak isometric strength of arm muscles, submaximal force repetition error, and upper body dynamic stability in adolescent female volleyball players.

MATERIALS AND METHODS

The present study used a cross-sectional research design. Data collection took place in Murjani Sports Gymnasium and occurred in the pre-season period.

Participants

The total number of participants was fifteen. They were female first-league volleyball players - students of the sports gymnasium.

Those adolescent female volleyball players who were playing in the first league (the highest league in Latvian volleyball) and participating in the training sessions and games at least five times per week were included in the research. Their mean age was 17.7 ± 2.1 years, and training experience 5.9 ± 2.6 years. They participated in training sessions during the last six months at least five times per week, a number of training hours from eight to 12 hours per week (mean 10.2 ± 2.0 hours/week), and additionally games at the weekends. Participants weekly training volume (10.2 ± 2.0 hours per week in five training sessions with one training session per day) coincided with the minimal training volume of the international performance-level volleyball players (33).

The exclusion criteria for all participants were acute or chronic shoulder or arm pain, present or recent (*i.e.*, emerged in the last month) upper extremity or back injury, and previous surgery in the last 12 months. These exclusions were assessed by questionaries.

The participants were informed of the possible risks of the tests, and all of them signed an informed consent form to take part in the investigation and voluntarily participated in the study. The study was proved by the local Ethics Committee and performed in accordance with the Declaration of Helsinki (Protocol No.137/42722 - date of approval: May 28, 2021).

Assessment procedures

Anthropometry assessment

The height of athletes was measured in centimeters (cm) using an Ultrasound Height Measuring Unit MZ10020 (ADE, Hamburg). Body mass was measured in kilograms (kg) in athletes wearing briefs and brasseries using a Body Composition Analyzer BC-418 (Tanita Corporation, Japan). The same tester measured all 15 participants' half-arm spans by tape in a standing vertical position with the shoulder abducted to 90°, the elbow fully extended, and the hand in a neutral position. The tester measured a distance from the processus spinosus of the seventh cervical vertebra C7 to the tip of the middle finger. The half-arm span was used in the Y – dynamic stability test to calculate the normalized reach distances of the arms and composite score (25). Then tester measured arm length from the posterolateral acromion process of the scapula to the distal ulnar styloid process and forearm length from the olecranon to the distal ulnar styloid process. These data were necessary to shoulder muscles exerted torque calculation (34).

Range of motion assessment

Before the shoulder flexibility, strength, and upper body dynamic stability measurements the participants performed general warm-up exercises, local warm-up, and active stretching for shoulders and arms for 20 minutes.

The active shoulder ROM was evaluated in IR-ER, flexion-extension, abduction-adduction, and horizontal abduction-adduction using a Jamar Plus Digital Goniometer (Performance Health, United Kingdom). The participants were placed in a standard position. They were asked to perform certain active motions as far as possible (35). A measurement of the movement was taken at the end of ROM. Shoulder IR-ER ranges were measured with the participants in a supine position with the shoulder abducted to 90°, the elbow flexed to 90°, and the forearm in a neutral pronation/supination position (36). To measure IR ROM, the forearm was placed perpendicular to the supporting surface, and the palm faced the feet. The full length of the humerus rested on the examining table. A pad was placed under the humerus to keep the humerus horizontal to the floor. The shoulder was active maximally internally rotated by moving the forearm anteriorly, bringing the palm toward the floor. The center of the goniometer was placed on the olecranon process of the humeral bone, the proximal arm of the goniometer was positioned perpendicularly to the floor, but the distal arm was placed parallel to the ulnar bone from the olecranon to the ulnar styloid process. ER ROM was measured in active rotation of the shoulder externally by moving the forearm posteriorly, bringing the dorsal surface of the palm toward the floor. Assistance was given to keep the shoulder on the table during the IR and ER motion, preventing compensatory use of the shoulder protractor muscles.

Active shoulder flexion was assessed with the participants in the supine position, with the palm facing upward and the elbow extended, with the arm over the side of the table (36). The active flexion was performed by lifting the humerus off the examining table and bringing the hand up over the individual's head. The arm was maintained in neutral abduction and adduction during the motion. The center of the goniometer was placed on the acromion process, the proximal arm was positioned parallel to the floor, but the distal arm was placed parallel to the humeral bone from the acromion to the lateral epicondyle of the humeral bone.

Active shoulder extension was investigated in the prone position, with the face turned away from the shoulder being assessed. The shoulder was placed in 0 degrees of abduction, adduction, and rotation. The elbow was positioned in slight flexion. The forearm was placed in 0 degrees of supination and pronation so that the palm faced the body. The active shoulder extension was performed by maximally lifting the humerus off the examining table. The position of the goniometer was the same as in the shoulder flexion ROM measurement (36).

Active shoulder abduction was assessed with the participants in a supine position, with the shoulder in external rotation and 0 degrees of flexion and extension so that the palm was faced anteriorly. The elbow was extended. The active shoulder abduction was performed by maximally moving the humerus laterally away from the participant's trunk. The arm was maintained in external rotation and neutral flexion and extension during the motion. The center of the goniometer was placed on the acromion process, the proximal arm was positioned parallel to the sternal bone, but the distal arm was placed parallel to the medial midline of the humeral bone from the acromion to the medial epicondyle of the humeral bone. Active shoulder adduction was assessed with the participants standing in a vertical position, with the elbow extended and the palm facing to the front. The endpoint was determined by the participant's maximal active range, the arm was positioned posterior to the body. The center of the goniometer was placed on the acromion process, the proximal arm was positioned parallel to the sternal bone, but the distal arm was placed parallel to the medial midline of the humeral bone from the acromion to the medial epicondyle of the humeral bone (36).

Active shoulder horizontal abduction was measured with the participants in a supine position, with the shoulder in 90° of abduction and the elbow in 90° of flexion. The participant performed maximal active horizontal abduction by moving his arm downwards as far as possible. The center of the goniometer was placed on the acromion process, the proximal arm was positioned perpendicular to the floor, but the distal arm was placed parallel to the humeral bone from the acromion to the medial epicondyle of the humeral bone. To assess active horizontal adduction the participant performed maximal active horizontal adduction by moving his arm upwards as far as possible (37).

Each active ROM measurement was performed twice, and the mean value was calculated.

Force and peak torque assessment

The peak force and the ability to repeat the submaximal force of IR, ER, and extension muscles were determined in isometric contractions using a handheld dynamometer (MicroFET2 Wireless; Hoggan Health Industries, West Jordan, USA) in newtons (N). The shoulder IR and ER or extension muscle force were measured in the vertical (sitting or standing) positions of each participant who pushed the dynamometer against the door frame with as much force as possible (34). The participant was sitting on the chair during measurements, and shoulder IR and ER peak forces were tested in the scapular plane or 30° from the frontal plane. The force assessment was performed with the shoulder positioned in 90° of abduction in the scapular plane and 90° of ER, the elbow in 90° of flexion, and the forearm in a neutral position to accommodate the handheld dynamometer force pad. Test position was selected to replicate the sport-specific position of a volleyball hit. Participants were asked to sit as erect as possible. The dynamometer was placed against the door frame for enhanced stability. Each participant fixed the dynamometer on the palmar surface of the tested hand with the curved surface of the device positioned against the distal heads of metatarsal bones to measure IR muscle force. To assess the ER muscle force, the dynamometer was fixed on the dorsal surface of the tested hand with the curved surface positioned against the distal heads of metatarsal bones.

To measure the extensor muscle force, the participant was standing near the door frame. The arm muscle extension force was evaluated with the shoulder positioned in 180° abduction, elbow extended, and forearm in a neutral position to accommodate the dynamometer force pad. The dynamometer was fixed on the palmar surface of the tested hand with the curved surface of the device positioned against the distal heads of metatarsal bones (38).

Each participant performed three repetitions of the peak shoulder extension, IR, and ER force production, pushing the dynamometer against the door frame with as much force as possible continuously for five seconds with each arm, a rest break with a duration of 60 seconds was given between the force measurement trials. The largest muscle-generated force depended on the degree of voluntary effort of the participant. Therefore, the value of the error of the peak force assessment could be underestimated due to the lack

of motivation of the player. To exclude this factor the peak force was measured in three trials, and the participant was encouraged to push the dynamometer as strongly as possible. The highest force of shoulder extension, IR, and ER muscle-developed force measurement in each shoulder was selected for further analysis.
Two practice trials were allowed to familiarize the participants with testing procedures. The order of the isometric force testing in the D and ND shoulder was randomized.
Shoulder IR and ER muscle peak torque values were calculated using the best repetition force and multiplied by the forearm length measurements (distance from olecranon to ulnar styloid process). Extensor muscle peak torque values were calculated using the best repetition force and multiplied by the arm length measurements (distance from acromion to ulnar styloid process). Then the torques were divided by body mass (Nm/kg) to obtain relative peak torques. Shoulder torque ratios were expressed as shoulder ER muscles' peak torque divided by IR muscles' peak torque (34).
Each participant performed three pairs of submaximal IR, ER, and extensor muscle force exertion trials in the same positions as the peak force assessment. They had to reproduce the same force (the same effort of the muscles) in approximately 50% of the maximal voluntary contraction continuously for five seconds twice, with a 30-second rest break between the two measurements in each trial. A timed rest break between the three different trials was 60 seconds. The mean force repetition error of the three measurement trials was calculated.

Upper body dynamic stability assessment

To evaluate participants' upper body dynamic stability the Y-upper body dynamic stability test (Y-UBDST) for assessment modified kit elaborated by Cramer *et al.* (25) was used. Three cloth measuring tapes were fixed to the floor precisely matching the angles using a goniometer between the two tapes, one of 90° and two of 135°, an athletic tape was used to secure the measuring tapes and mark the starting point for the stationary hand, three wooden blocks measuring 2 × 4 × 8 cm were employed to determine the reach directions.
Each participant was provided a demonstration of the procedures and allowed three practice trials of the Y-UBDST in each direction on their D and ND arm before data collection. Participants performed the testing procedures barefoot. Three trials for the test were recorded for the ND and the D stationary arm at each of the three reach directions: superolateral, medial, and inferolateral. While maintaining a push-up position with the feet at shoulder width, the participant performed maximal effort to reach with the free hand in three directions (medial, superolateral, and inferolateral). The distance reached in each direction was recorded. The mean of three trials was used for analysis (25).
The mean reached distance in each of the three directions was divided by the half-arm span and multiplied by 100 (25), thus normalizing reaching distance in percent (%). Then the mean normalized reaching distance or composite score for all three directions was calculated in % from the half-arm span.
The data distribution normality of the anthropometrical characteristics, shoulder active ROM, maximal shoulder muscle force, and error of the submaximal force repetitions was established by the Shapiro-Wilk test from the RStudio program. The mean values and standard deviations were calculated for all characteristics. A t-test for paired samples was employed to determine differences between the mean characteristics of the dominant and non-dominant arms. The correlations between the shoulder ROM and muscle peak forces, between the muscle peak forces and the submaximal force repetition errors, and between the muscle peak force and dynamic stability test results were calculated. The differences were considered significant at $p < 0.05$. Microsoft Excel 2010 was applied to perform descriptive statistics, t-tests, and correlation analysis.

RESULTS

The anthropometrical characteristics of the participants are shown in **table I**.
A significant shoulder ROM side-asymmetry was observed in the arms' extension and adduction of the female volleyball players with larger ROM in the ND shoulder ($p = 0.04$) (**figure 1**).
The ER ROM (97° ± 12° in the dominant D, 95° ± 10° in the nondominant ND shoulder) was increased (the cut-off value was 90° referred to by Loudon *et al.* (39)). The IR ROM (54° ± 12° D and 62° ± 8° ND) was decreased (the cut-off value was 70° referred to by Loudon *et al.* (39)), and HADD ROM (34° ± 8° D and 35° ± 10° ND) was decreased (the cut-off value was 40° referred to by Loudon *et al.* (39)). The mean total ER – IR ROM of the D shoulder was 151° ± 20°, and of the ND shoulder it was 157° ± 13°, the difference was not statistically significant ($p > 0.05$; $p = 0.126$).
IR, ER, and extension muscles developed significantly greater peak forces, peak torques, and relative peak torques, respectively, in the D arm in comparison with the ND arm of the volleyball players ($p < 0.05$) (**table II**). The mean ER/ IR peak torque ratio was 0.94 ± 0.18 (the lowest ratio observed in one participant was 0.61, but the highest was 1.34) in the D and the same: 0.94 ± 0.18 (the lowest ratio observed in one participant was 0.61, but the highest was 1.23) in the ND shoulder ($p > 0.05$). ER/ IR peak torque ratio of the D

Table I. Mean anthropometric characteristics with standard deviation of qualified adolescent female volleyball players.

Body mass, kg	Height, m	Body mass index, kg/m²	Half-arm span, m	Arm length, m	Forearm length, m
66.5 ± 8.4	1.75 ± 0.08	21.7 ± 1.6	D 0.89 ± 0.05 ND 0.89 ± 0.05	D 0.58 ± 0.04 ND 0.58 ± 0.04	D 0.27 ± 0.03 ND 0.27 ± 0.03

D: dominant arm; ND: non-dominant arm.

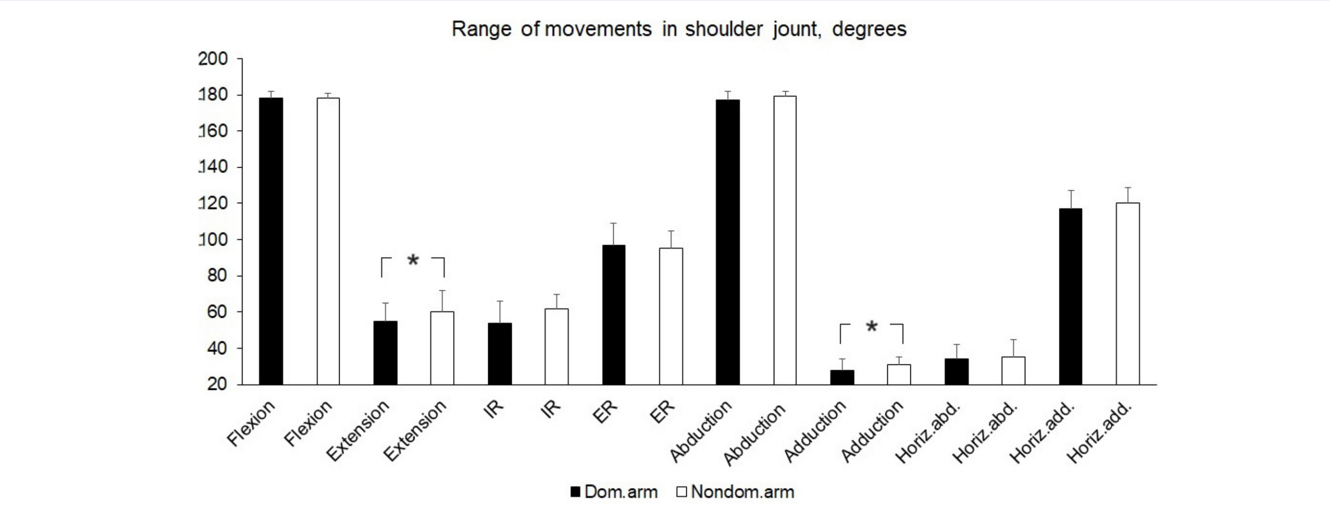

Figure 1. Range of movements of the shoulder joint in the adolescent, qualified female volleyball players.
*p = 0.04 or < 0.05.

shoulder exceeded 0.8 in 14 participants from 15 and was higher than one in three players. In the ND shoulder ER/ IR peak torque ratio exceeded 0.8 in 13 participants out of 15 and was higher than one in five players.
A significant correlation was observed between the IR ROM and the peak force of IR muscles only for the D arm ($r = 0.59$; $p = 0.01$), this correlation was not significant for the ND arm.
Significant correlations were not detected between ER ROM and the peak force of ER muscles, extension ROM and the peak force of extensor muscles, ER ROM and the peak force of IR muscles, flexion ROM and the peak force of extensor muscles for both arms of the participants ($p > 0.05$).
The submaximal force reproduction error was significantly smaller in the extensor and ER muscles of the dominant

Table II. Mean strength characteristics with standard deviation of shoulder girdle muscles in adolescent, qualified female volleyball players.

Muscle group	Arm	Peak force, N	Peak torque, N × m	Relative peak torque, N × m/kg
Extensors	D ND	50 ± 9 46 ± 9	29 ± 6 27 ± 6	0.44 ± 0.08 0.41 ± 0.07
P-value		0.036	0.040	0.041
IR	D ND	50 ± 8 46 ± 9	14 ± 3 13 ± 3	0.21 ± 0.03 0.19 ± 0.03
P-value		0.002	0.002	0.0008
ER	D ND	47 ± 11 43 ± 12	13 ± 3 12 ± 4	0.19 ± 0.03 0.17 ± 0.04
P-value		0.0005	0.0006	0.0003

arm in comparison with the non-dominant arm ($p \leq 0.025$) (**figure 2**). This error did not differ significantly in the IR muscles of both shoulders ($p = 0.724$).

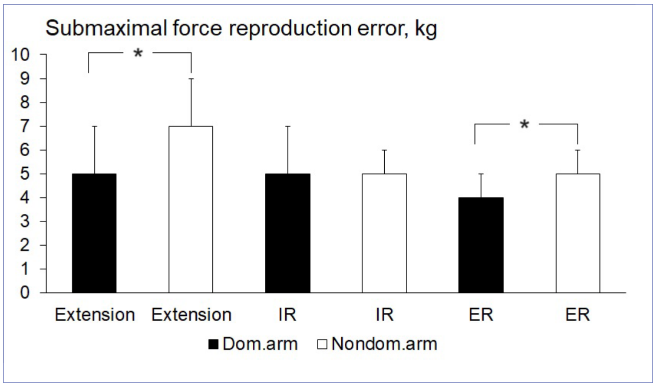

Figure 2. The submaximal force reproduction error of IR, ER, and extension muscles in the dominant and the non-dominant arm of the adolescent, qualified female volleyball players.

A significant correlation was detected between the peak force of ER muscles and the submaximal force repetition error in the D arm ($r = 0.82$; $p < 0.0001$). Correlations between the peak force of IR, extensor muscles, and their submaximal force repetition errors were not significant ($p > 0.05$).

In the Y-UBDST the largest reach distance was determined in the medial direction (104 ± 10 cm supported the body on the D arm and 102 ± 7 cm – on the ND arm), in the inferolateral direction the mean distances were the same for both arms (80 ± 11 cm), but the shortest distance was observed in the superolateral direction (70 ± 7 cm supported the body on the D arm and 68 ± 8 cm – on the ND arm) (**figure 3**). Any significant side-asymmetry between the reached distances of the D and ND was not detected in each direction ($p < 0.05$).

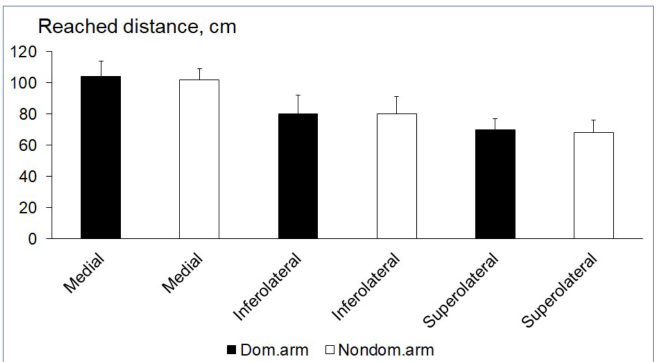

Figure 3. Y-upper body dynamic balance test reaching distances (cm) in the three directions in the adolescent, qualified female volleyball players.

The mean Y-UBDST composed (normalized) scores were 95 ± 6% in the D and 94 ± 7% for the ND arm, symmetrical on both sides ($p = 0.045$).

Correlations between the shoulder IR, ER muscles peak forces, and the mean composite score of the Y-dynamic balance test for the upper body were not detected ($p > 0.05$). A significant negative correlation was observed between the extensor muscles' peak force and the composite score of this test only for the D arm ($r = -0.59$; $p = 0.02$). For the ND arm this correlation was not significant ($p > 0.05$).

DISCUSSION

The ER ROM (97° ± 12° in the D, 95° ± 10° in the ND shoulder) was increased (the cut-off value 90°). The IR ROM (54° ± 12°D and 62° ± 8°ND) was decreased (the cut-off value 70°), and HADD ROM (34° ± 8°D and 35° ± 10° ND) was decreased (the cut-off value 40°) in female volleyball players (the cut-off values referred to by Loudon *et al.* (39)). The mean total ER-IR ROM did not differ significantly in the D shoulder: 151° ± 20° and 157° ± 13° in the ND shoulder. The extension and adduction ROMs were smaller in the D than in the ND shoulder.

The D arm's IR, ER, and extension muscles developed significantly greater peak forces, peak torques, and relative peak torques in the D arm in comparison with the ND arm. The mean ER/ IR peak torque ratio was the same on both shoulders: 0.94 ± 0.18, but this ratio varied on a large scale among the participants from 0.61 to 1.34.

The D arm's submaximal force repetition error was smaller than the ND arm's in the ER and extensor muscles, but this was not determined for IR muscles. A significant correlation was detected between the peak force of ER muscles and the submaximal force repetition error only in the D arm.

The composed scores of reaching distances of the Y-upper body dynamic stability test were 95 ± 6% in the D and 94 ± 7% in the ND arm, symmetrical on both sides.

The ROM changes of volleyball players in the present study coincided with normal anatomical adaptation of the shoulder girdle in athletes who perform regular overhead movements of the arms: increased ER together with decreased IR or GIRD (8, 10, 11).

The IR ROM was decreased for 16° in the D shoulder and 8° in the ND shoulder which was less than in the pathological GIRD: 18°-20°, but the total ER-IR ROM was not significantly lower in the D shoulder (6°) than in the ND shoulder (the border of cut-off values = 5°-8° referred by Manske *et al.* (8).

The ER ROM of our adolescent qualified female volleyball players (97° ± 12° in the D, 95° ± 10° in the ND shoulder) was smaller in comparison with adolescent (15-17-year-old) female high school league volleyball players from the study performed by Mizoguchi *et al*. (13) (118.1° ± 12.0° in the D and 106.2° ± 10.3° in the ND shoulder) and with adult female first division volleyball players from the data of Ness *et al*. (34) (105.0° ± 10.7° in the D shoulder). The IR ROM (54° ± 12° D and 62° ± 8° ND) in our participants also was smaller than in the volleyball players from the same investigation: 65.7° ± 10.8° in the D and 75.1° ± 12.9° in the ND (13), but larger than in the adult participants from the study of Ness *et al*. (34) respectively 47.4° ± 10.8° in the D shoulder. Therefore, the total ER-IR ROM in our players was smaller than in the data from Mizoguchi *et al*. (13): 183.8° ± 17.6° in the D and 181.3° ± 17.5° in the ND shoulder, but like the adult players from the data of Ness *et al*. (34) study, respectively 152.4° ± 11.6° D arm (34). The HADD ROM (34° ± 8° in the D and 35° ± 10° in the ND arm) was lower in our participants than in the players measured by Mizoguchi *et al*. (13): 50.8° ± 13.6° in the D and 55.3° ± 13.9° in the ND arm. The arm flexion ROM was the same in our and Mizoguchi *et al*. (13) studies: close to 178° in both arms of our players and close to 179° in both arms of the players in the Mizoguchi *et al*. (13) study. Shoulder IR and HADD ROMs were smaller in the D arm than in the ND arm in our and Mizoguchi *et al*. (13) study. Mizoguchi *et al*. (13) investigated not only females but also males and observed significantly larger ROM in shoulder ER-IR and a higher prevalence of shoulder injuries in adolescent females than males.

The D arm's IR, ER, and extension muscles developed significantly greater peak forces, peak torques, and relative peak torques in comparison with the ND arm of our volleyball players. The relative shoulder IR peak torque was 0.21 ± 0.03 N × m/kg in the D arm and 0.19 ± 0.03 N × m/kg in the ND arm. The relative shoulder ER peak torque was 0.19 ± 0.03 N × m/kg in the D arm and 0.17 ± 0.03 N × m/kg in the ND arm. These data were slightly lower in comparison with the results measured on adult female volleyball players by Ness *et al*. (34), who were using the same method of strength measurement: the relative isometric shoulder IR peak torque in their study was 0.22 ± 0.04 N × m/kg and the ER peak torque was 0.22 ± 0.04 N × m/kg in the D arm at the end of the preparation period. Later during the season IR peak torque increased to 0.33 ± 0.06 N × m/kg, but ER peak torque decreased to 0.19 ± 0.04 N × m/kg (34). We did not observe shoulder muscle strength changes during the competition season.

Hadzic *et al*. (17) observed significantly larger isokinetic peak torques of the shoulder IR in the D side than in the ND but did not detect significant side-asymmetry in the ER in adult female (first and second-division national-level volleyball players). Measurements were performed at the rotational velocity of 60°/s in the concentric contractions of the muscles. The mean isometric ER/IR peak torque ratio of our participants was the same on both shoulders: 0.94 ± 0.18 (varied among the participants from 0.61 to 1.33). These results were higher in comparison with the isokinetic ER/IR peak torque ratio of adult female volleyball players from the research performed by Hadzic *et al*. (17) where the ratio was 0.75 ± 0.15 in the D shoulder and 0.72 ± 0.15 in the ND. In the Ness *et al*. (34) study, the isometric ER/IR peak torque ratio was 0.97 ± 0.13 (varied among the participants from 0.81 to 1.13), which was close to our results. Furthermore, Ness *et al*. (34) observed a worsening of the ER/IR peak torque ratio during the competition season. The ratio decreased to 0.7 ± 0.1 in the post-season (varied from 0.57 to 0.82 among the players). Hadzic *et al*. (17) observed that female volleyball athletes playing at a higher level (first *versus* second national division) were 3.43 times more likely to have an abnormal strength ratio. This could be explained by the larger number of performed spikes and hours spent in training sessions in the athletes with higher performance levels. Based on the research of Ellenbecker and Davies (40), Wilk *et al*. (41), and Hurd *et al*., (42) the range of optimal ER/ IR muscle strength ratio in the overhead athlete is 0.66 to 0.75, and the ratio is higher in the nondominant than in the dominant arm. Corrective exercises could be an effective method in reducing shoulder girdle and spine abnormalities, thus improving the performance of volleyball players. This was confirmed by Firouzjah *et al*. (43) who concluded that execution of correction exercises for 10 weeks (three sessions per week with a duration of each session 30-70 minutes) was an effective tool in shoulder girdle and spine abnormality reduction, thus improving performance in adolescent volleyball players with the upper cross syndrome.

The D arm's submaximal force repetition error of the ER was smaller than in the ND arm (4 N in the D shoulder and 5 N in the ND shoulder) and in the extensor muscles (5 N in the D arm and 7 N in the ND arm), but this was not determined for IR muscles (5 N in both shoulders). Based on Maenhout *et al*. (32) data, the errors of shoulder ER were significantly larger than those of IR, and the relative IR and ER force reproduction errors were similar when compared to healthy participants with patients of rotator cuff tendinopathy. This was not determined in our volleyball players: the submaximal force reproduction error of IR and ER muscles was the same in the ND arm and even smaller in ER than IR in the D arm. If compared our study with other sports disciplines, it has been established, that the shoulder IR muscle's submaximal force reproduction error is similar on both sides in male qualified swimmers, triathletes, and the controls (44), but larger (from 7 to 10.5 N) in comparison with volleyball players from the present research.

Nevertheless, the extensor muscles force reproduction error in the swimmers and triathletes has been determined larger (from 8 to 11.5 N) than in volleyball players (44), but similar (close to 7 N) in the control group and volleyball players. Therefore, we could suggest that volleyball training leads to improvement of the shoulder rotator muscles' force differentiation ability when compared with the young physically active people who do not regularly perform overhead movements of their arms or swimmers who perform overhead movements of their arms in a water-denser environment.
A significant correlation was detected between the peak force of ER muscles and the submaximal force repetition error only in the D arm. This could be explained by a volleyball spike technique: the ER muscles of the D arm exert maximal force to stretch the IR muscles so that IR can achieve the maximal spike power. Therefore, the force differentiation ability of ER muscles is not that important. The aforementioned correlation was not significant in the ND arm ($p > 0.05$).
The composed score of Y-UBDST reaching distances was 95 ± 6% in the D and 94 ± 7% in the ND arm, which is symmetrical on both sides. The norm is > 85.2% ± 11.7% according to the data of Westrick *et al*. (27). The correlations between the shoulder rotators' peak force and the Y-UBDBT results were not significant. Only a significant negative correlation was observed between the extensor muscles' peak force and the composite score of this test for the D arm ($r = -0.59$; $p = 0.02$). For the ND arm this correlation was not significant ($p > 0.05$). Therefore, it can be assumed, that the strength of the shoulder rotator and extensor muscles does not substantially affect the dynamic stability of the upper body in volleyball players.

Limitations of the study

The number of participants was small. All the participants were from the same school and trained by the same coaches. The changes in shoulder ROM, muscle strength, proprioception, and dynamic stability during all training season stages were not detected.
Shoulder IR, ER, and extension muscle isometric peak force and the submaximal force reproduction error assessment in the static mode were not specific for volleyball spike-like highly dynamic motion. Research showed that there was a significant correlation between the shoulder muscles' peak isometric and the peak dynamic strength characteristics in athletes who regularly performed overhead movements of the arms (45). Nevertheless, in the investigations performed in recent years, authors used more precise methods of Mathematical Statistics and proved that the real correlation between the peak isometric and dynamic strength did not exist (46). The peak dynamic strength depends on many variables, the most important is precise motor control of the sport-specific movement or sports technique: involvement of all muscles with the maximal amount of working motor units participating in this motion simultaneously to achieve greater power and faster speed of motion (spike, throw, passing a ball); types of muscles' contractions in dynamic motions are different (concentric and eccentric). Therefore, there was a recommendation for coaches to measure not only the isometric but also the dynamic strength of the muscles in conditions that are like real sports situations not only in the laboratory but also in field tests (46). The peak isometric strength measurement alone does not provide objective athletes' performance characteristics.

Practical application of the dynamometry method

Shoulder rotator muscles are the most important stabilizers of this joint during movements (47) which is especially important to volleyball players and other athletes who perform regular overhead movements of the arms in a large ROM. A useful tool in shoulder joint stability assessment is the ER/IR peak strength ratio because training with a large number of overhead movements of the arms leads to selective IR strength increase and reduction of the ER/IR peak strength ratio (3, 15-17). An overuse shoulder injury could occur because of weak ER strength (11, 16, 20). A gold standard and the most precise method to measure dynamic muscles' strength and their ratios in a laboratory is isokinetic dynamometry (48) but this equipment is expensive and non-portable. Therefore, each physiotherapist and coach have no access to the isokinetic devices.
On the other hand, the peak isometric strength measurement is a simple, time-efficient, safe (49), inexpensive method to assess muscles' strength with a portable, handheld dynamometer in a training place. There is a good standardization of isometric test conditions with high test-retest reliability (50). The shoulder ER/IR peak strength ratio is possible to measure by handheld dynamometer in the isometric type of muscle contractions. The measurement is more reliable if the peak isometric strength is determined in the joint angles that are specific to certain sports movements, for example, a ball release during a volleyball spike (34). Therefore, the shoulder muscles' peak isometric strength and submaximal strength differentiation ability measurement in sport movement-specific angles are recommended for the daily practice of physiotherapists to evaluate the shoulder joint stability, strength side-asymmetry, and acuity of the strength differentiation sense if the isokinetic dynamometry assessment is not available. The changes in these characteristics in different training periods could be observed on time to prevent shoulder overuse injuries in athletes. The normative data

of the adolescent qualified female volleyball players will be useful as reference data to estimate the rehabilitation process of shoulder injuries in volleyball players.

The hypothesis of our research was confirmed: adolescent qualified female volleyball players possess their shoulder girdle adaptation typical for team sports athletes who perform regular overhead movements of the arms, increased ER ROM, decreased IR ROM, optimal upper body dynamic stability, and ER/ IR muscles strength ratio but the significant side-asymmetry of these characteristics was not observed; shoulder IR, ER, and arm extensor muscles were significantly stronger in the D arm in comparison with the ND arm ($p \leq 0.041$), and the error of submaximal force reproduction was significantly better in the shoulder ER and extensor muscles of the D arm than of the ND arm muscles ($p \leq 0.025$).

CONCLUSIONS

Regular repetition of volleyball spikes led to an increase in ER, a decrease in IR and HADD ROMs, and muscle strength and its differentiation ability improvement, especially, in the D arm. The action of shoulder ER and IR muscles was balanced. The upper body dynamic stability was the norm and did not depend on the rotator and extensor muscles' strength. Therefore, the shoulder girdle characteristics were optimal and adaptable for volleyball spike and serve movements in those adolescent qualified female volleyball players without pathological changes in pre-season.

Regular check-ups of the shoulder joint are recommended in all volleyball players during all training season stages, especially in athletes with shoulder pain, injury, or surgery in anamnesis, to determine any deficits in the ROM, weaknesses of the muscles and proprioception, balance decrease, or side-asymmetries to correct these pathologies and to prevent worsening of the performance and diminish the risk of overuse injuries.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

IP: study design. KES: data collection. KES, IP: writing – original draft. AL: writing – review & editing. KES: data analysis. AL: discussion section improvement.

ACKNOWLEDGMENTS

We thank all the volleyball players who participated in this research, as well as their coaches.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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