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Research Article

Humeral Retroversion Angle and Its Relationship with Active Shoulder External Rotation Range-of-Motion in Volleyball and European Handball Players

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Abstract

The humeral retroversion angle is known as one possible morphological functional adaptation seen in overhead athletes. Based on the literature we hypothesized that in volleyball players the humeral retroversion angles would be less than in handball players. The dominant shoulder of 60 subjects (15 volleyball players, 15 handball players and 30 non-athletes) was submitted to a shoulder semi-axial radiograph in order to identify the humeral retroversion angle. Handball players showed significantly (p=0.03) less humeral retroversion than volleyball players which could be related with less external rotation ROM found on previous studies. On the other hand, volleyball players presented more retroversion angle, so more external rotation, allowing the correct alignment of the articular surfaces and glenohumeral stability, being able to have a cocking phase with more amplitude achieving maximal performance. Volleyball and Olympic handball players showed an increased humeral retroversion angle comparatively to a non-thrower population. The active shoulder external ROM was also high in the throwing groups comparatively to the non-throwers. However, the increment on the ROM does not seem to be related with the increased HRA observed on the athlete's group.

Keywords: Humeral Retroversion; Shoulder External Rotation; Overhead Athletes

Introduction

The humeral retroversion or Humeral Retroversion Angle (HRA) refers to the acute angle, in a medial and posterior direction, between the proximal and distal articular surfaces of the humerus [1-3]. The HRA, also referred to as "humeral torsion", describes the amount of "twisting" of the longitudinal axis of the humerus and is a measure of orientation of the humeral head with respect to the elbow joint [1,2].

Literature suggests a distinction between primary and a secondary humeral torsion. The primary or hereditary equates to be the amount of bony twist that is initially presented in fetal development.

The secondary humeral torsion or acquired torsion is due to the muscular forces exerting a pull *via* their attachments to various anatomic points on the humerus [3,4]. This humeral torsion involves the action of opposite forces exerted by the stronger internal shoulder rotators and weaker external rotators, which set up torsional stresses across the proximal humeral epiphysis. Some authors suggest that this secondary torsion is responsible for the deceleration in rate of de-rotation of the humerus [5,3]. The rate of humeral de-rotation can be slowed down to greater extent, resulting in a larger humeral retroversion angle, when the muscular activity increases around the glenohumeral joint, such as during repetitive overhand athletic activities. The work by Edelson seems to confirm this progression throughout the human life [6].

The work of Pieper et al. was the first to provide evidence about osseous adaptation of the humerus in the form of increased retroversion angle in the throwing arm of Olympic handball players [7].

The augmented retroversion angle seems to increase the available external rotation range-of-motion and at the same time reduces the ability of the rotator cuff to control high forces or velocities through the extremes to shoulder ROM which could lead to excessive humeral head translation and culminate in shoulder pain [8,9]. Kronberg et al. [10] found that, in normal shoulders, greater retroversion of the humerus was consistent related with an increased range of external rotation at 90° of shoulder abduction, but no differences were found between subjects' dominant and non-dominant shoulders for each tested range of motion.

Thus, the purpose of this study was to twofold: (1) to establish if humeral osseous adaptation measured by HRA is sports specific, adaptations are evident in the dominant arm of volleyball and handball players, and to (2) determine the relationship between humeral retroversion and humeral rotation range-of-motion of the glenohumeral and thoracohumeral joints.

Methods

Population and sample

The sample was composed of sixty volunteers, volleyball and handball European players, and athlete´s group recruited in the local community. Participants were divided into three groups: volleyball players (n=15), handball players (n=15) and the control group (n=30). All the members of the athlete´s group fulfilled a questionnaire

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concerning their sports activity ensuring that none had played high level overhead sports. They were selected among patients and their relatives in the private office of one of the authors (A.M.R.) and were examined in the same place. Sampling was consecutive.

Demographic data with respect to age, height and body mass, were compared across the groups using a one-way ANOVA (Table 1). As differences were found between the three groups concerning age, correlation analyses were performed between this demographic variable and the dependent variables of HRA and shoulder ROM. No significant correlation was found between either of these demographic variables (P >0.05) and the dependent variables, and as such, these group differences are not of concern as covariates.

No differences between groups were found concerning body mass and height.

On the three groups all the subjects were Caucasian except 5 athletes in the volleyball group that were South-American. Because previous studies [11,5] showed that the HRA is race related a Pearson correlation was performed between HRA in Caucasian subjects and HRA in south-American subjects. No relation was found (r=0.234; P=0.401), so south-American subjects were included in the sample used.

Subjects in either athletic group (volleyball or handball players) reported at least 6 years of practice at a high level of competition. An activity index (index of sports practice) was calculated considering the number of days, hours and years of training/competition (number hours per week* 4 weeks/month*12 months/year* years of practice). An independent t-test was performed to compare the activity index between groups (handball and volleyball players) (Table 1).

Also an independent t-test was run to compare the age commenced training between volleyball and handball players, and differences were found between these two groups (P<0.05) (Table 1).

Subjects also provided information regarding their arm dominance, retrospective injury history (an injury was regarded as any overuse injury that altered their training for more than a week [12], and relevant medical history. Subjects were excluded if a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) was recorded. Information about player spiking ability was provided by the coach *via* a questionnaire.

Procedures

The purposes of the study and the technique of examination were explained to the participants, and those who agreed to participate signed a free informed consent term. This study was approved by the Scientific Board of the Faculty of Human Kinetics, Technical University of Lisbon (Portugal). None of the men who met the inclusion criteria refused to participate.

Humeral retroversion angles measurements using x-ray recordings

Posterior-anterior semi-axial radiographs from the dominant shoulder of the subjects were recorded by x-ray equipment (Model: SHIMADZU UD150L-40E; X-Ray ampoule: 40-150 kv and 10 - 630 mA; Focus film distance: 1.5 m; Penetration: 75 keV; Exposure: 60 mA). Subjects were standing with the shoulder at 90° flexion and 20° horizontal abduction, while the forearm was kept fully supinated and elbow flexed to 90° (Figure 1).

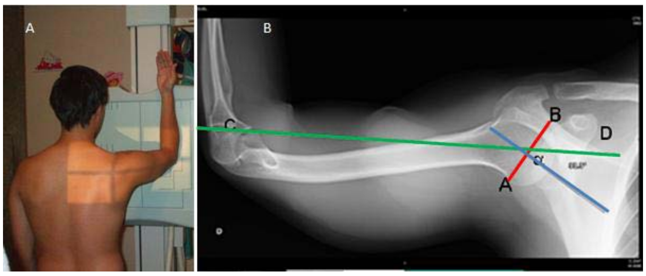


Figure 1: X-Ray Experimental set-up (A) and a semi-axial radiograph positioning (B) with reference lines used for the humeral retroversion angle calculation (see text for details).

The humeral retroversion angle was defined as an angle between the humeral head axis and the distal humeral axis. For humeral head axis estimation the first step consisted of the identification of the limits of the humeral head articular surface. On x-ray images, these limits were defined by the anterior and posterior points where the round articular surface of the humeral head becomes flat (Points A and B; Figure 1-B) and a line was drawn between these two points (Line AB; Figure 1-B). The humeral head axis corresponds to the perpendicular line to line AB. The distal humeral axis was determined by a line parallel to the anterior articular surface of the distal humerus (Line CD; Figure 1-B). The humeral retroversion angle was determined by calculating the angle between the intersection of the humeral head axis and the distal humeral axis represented, respectively, by the perpendicular AB line and by the CD line (α, Figure 1-B).

The use of semi-axial radiographs for measurement of HRV as shown in this study, was validated by [13,4] investigated the validity of the standing semi-axial method to determine the HRA using CT scan HRA measurement as a "gold-standard", on five subjects. The x-ray protocol used was similar to Oztuna et al., [14]. Results of the study include a high validity index of 0.97 along a low RMS error (1.4º) between the radiographic and CT measures of HRA.

External rotation range-of-motion recordings

Motion testing was performed with the Flock of Birds electromagnetic tracking sensors (Ascension Technology, Burlington, Vermont) and Motion Monitor software (Innovative Sports Training, Chicago, IL. Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor. The accuracy of our system is 1.8 mm for position and 0.15º for orientation.

A four-sensor setup was used: the thorax sensor firmly attached to the skin by a double-sided tape over T1; the arm sensor attached by means of a cuff just below the deltoid attachment; and the scapular sensor firmly adjusted on the superior flat surface of the acromion process. A 4th sensor mounted on hand-held stylus (6.5cm) was used for bony landmark digitalization (Table 2), with the participants in a seated position and the arm artificially supported (Figure 2-A) in an elevated position (±90º), with the elbow flexed (±90º) and the forearm perpendicular to the floor. The arm and forearm were strapped and connected to a square drive extension, mounted on a fixed wooden stand, which supported the weight of the arm. This digitization position was assumed as the initial position for external

Table 1: Mean (Standard error of mean) of subject demographic and sport background data by groups.

	Volleyball (N = 15)	Handball (N = 15)	Control (N = 30)	P - value
Age (years)	27.6 (1.6)	23.8 (0.8)	29.6 (1.1)	0.01*(a)(b)
Height (cm)	189.4 (2.7)	185.8 (1.5)	178.1 (1.2)	0.06*(a)(b)
BMI (kg/m²)	24.3 (0.5)	25.4 (0.5)	25.0 (0.7)	0.56*(a)(b)
Age (years) when training commenced	14.4 (0.4)	9.2 (1.3)	n.a.	0.01**
Sports index	8422.4 (1258.3)	6726.4 (408.9)	n.a.	0.21**

n.a. = not applicable

*Anova result

**t-test result

ANOVA results: (a) (F=5.42, df=2); (F=12.26, df=2); (F=0.55, df=2)

(b) Multiple comparisons: Age= handball and control are significantly different; height=control and handball are significantly different; BMI= control and volleyball are significantly different.

A B

Figure 2: Set-up for humeral external rotation range-of-motion recording. Subject in neutral position (A) and at the end-range of active shoulder external rotation (B).

rotation ROM assessment. Subjects were instructed to slowing reach the end-range of humeral external rotation while holding a dumbbell of 1.5 kg (Figure 2-B). On the basis of our digitization protocol, the zero point (0°) or neutral rotation was defined as the point when the subject´s forearm was perpendicular to the floor.

The digitized bony landmarks (Table 2,3) were then used to convert the sensor axes to anatomic axes or Local Coordinate System (LCS) on thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB) [15]. Using this procedure, sensors axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion.

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB [15] recommended rotation sequences (x, y', x''): arm elevation, plane of arm elevation and axial rotation. Continuous data were recorded and filtered (Butterworth filter; cut-off=10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of the humeral external rotation was considered for further analysis.

Statistical analysis

The humeral retroversion angle and the shoulder external rotation end-range relative to the thorax and scapula, respectively the end-range Thoracohumeral Angles (TH) and the end-range Scapulohumeral angles (SH), were used as dependent variables and compared across the groups. All dependent variables were checked for normality (Shapiro & Wilk test) and found to meet criteria for parametric statistics.

Table 2: Bony landmarks used for the definition of the local coordinate system of the thorax, scapula and humerus.

Segment	Bony Landmark	Abbreviations
Thorax	T8 spinous process	T8
	Xiphoid process of the sternum	XP
	C7 spinous process	C7
	Sternal notch	SN
Scapula	Acromial angle	AA
	Root of scapular spine	RS
	Inferior angle	IA
Humerus	Medial epicondyle	ME
	Lateral epicondyle	LE
	Glenohumeral rotation centre (*)	GH

(*) Estimated by motion recordings, calculating the pivot point of instantaneous helical axes of GH motion [31,33].

Data were described as means and Standard Error of mean (SE)

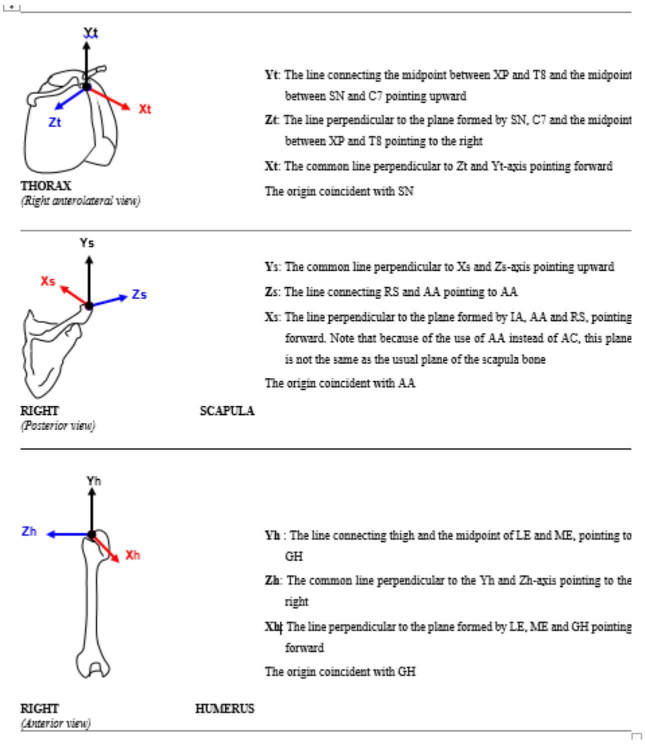
An independent sample t test was used to compare means between athletes and control group. Analysis of Variance (ANOVA), followed by the Tukey test, was used for comparisons between the three groups of subjects (volleyball players, handball players and non-athlete´s group). Additionally, the Pearson coefficient was calculated in order to analyze the relationship between HRA and shoulder external rotation range in the athletes and between HRA and the index of sports practice. The level of significance was set at 5% and statistical power at 95%. The Statistical Package fo Social Sciences (SPSS) version17 (Chicago, Illinois) was used to analyze data.

Results

Humeral head retroversion angles and range-of-motion

The athletes (volleyball and handball) showed significantly higher mean values of humeral retroversion angles than non-athletes (P=0.000; F (2,)=22.7; df=2). The volleyball players had more 9.17° humeral retroversion angle with respect to the non-athletes group, while the handball group showed more 7.40°.These difference had statistical expression (P= 0.000). No differences were found on the HRA between volleyball and handball players (P=0.572).

Results for active range of Thoracohumeral (TH) and Scapulohumeral (SH) external rotation motion are presented in Figure 3. Differences were found between groups on shoulder



THORAX (*Right anterolateral view*)	**Yt**: The line connecting the midpoint between XP and T8 and the midpoint between SN and C7 pointing upward **Zt**: The line perpendicular to the plane formed by SN, C7 and the midpoint between XP and T8 pointing to the right **Xt**: The common line perpendicular to Zt and Yt-axis pointing forward The origin coincident with SN
RIGHT (*Posterior view*) SCAPULA	**Ys**: The common line perpendicular to Xs and Zs-axis pointing upward **Zs**: The line connecting RS and AA pointing to AA **Xs**: The line perpendicular to the plane formed by IA, AA and RS, pointing forward. Note that because of the use of AA instead of AC, this plane is not the same as the usual plane of the scapula bone The origin coincident with AA
RIGHT (*Anterior view*) HUMERUS	**Yh** : The line connecting thigh and the midpoint of LE and ME, pointing to GH **Zh**: The common line perpendicular to the Yh and Zh-axis pointing to the right **Xh**: The line perpendicular to the plane formed by LE, ME and GH pointing forward The origin coincident with GH

Table 3: Bony landmarks used for the definition of the local coordinate systems of the thorax, scapula and humerus, according to Wu et al., [15].

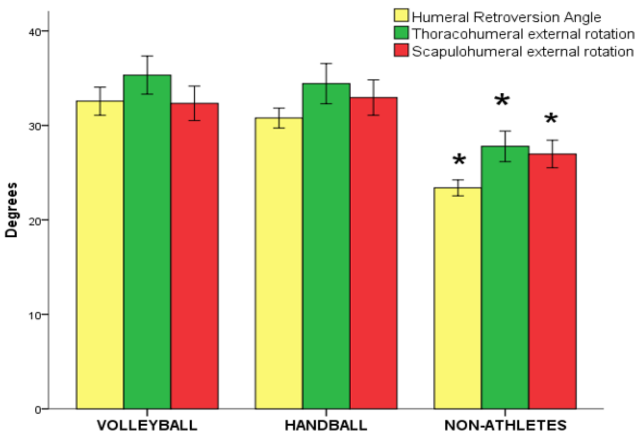


Figure 3: Mean and SEM of the Humeral Retroversion Angle and the Active Shoulder External Rotation ROM (Thoracohumeral and Scapulohumeral angles) on volleyball, handball and non-athlete´s groups. (*) – Values significantly different from volleyball and handball groups (p <0.05).

active external rotation ROM concerning the TH (P=0.008) and SH (P=0.02) angles. Results of multiple comparison test (Tukey HSD) revealed differences on TH rotation ROM between non-athletes and volleyball group (P=0.018; ES=0.411) and between non-athletes and handball group (P=0.042; ES=0.361). No differences were found between volleyball and handball players (P=0.954; ES=0.05).

Comparisons of SH between athletes and non-athletes were made, the handball group showed differences when compared with the non-athletes group (P=0.041; ES=0.367). No differences were found between volleyball and non-athletes group (P=0.074; ES=0.33) and between volleyball and handball groups (P=0.974). No correlations were found in the athletes group between humeral retroversion and TH or even with SH.

Additionally a positive correlation was found between humeral retroversion and sports index (r=0.642; p=0.000), which means that the ones with higher retroversion values have more training and practicing hours.

Results for Humeral Retroversion Angle (HRA) and Range-Of-Motion (ROM) are presented in Figure 3.

Discussion

Humeral retroversion angle

Athletes participating in unilateral overhead dominant sports are useful to investigate skeletal responses to mechanical loading. Throwing athletes overload their dominant upper extremity enabling the contralateral side to act as an internal control and load the bones of the upper extremity purely *via* the generation of internal (muscular) forces without superposition of externally applied loads [16]. In fact our results demonstrated that the group of overhead athletes (volleyball and handball players) showed higher Humeral Retroversion Angle (HRA), compared with non-athletes, which seem to indicate a certain level of osseous adaptation on the humerus associated with throwing. These results are similar of those found in baseball players [17,18,19,20] and handball players (Pieper) [7] regarding difference on HRA between the dominant and non-dominant shoulder while in our study comparison is between sports. Differences on HRA were also found between the non-athletes and both groups of volleyball and handball players. Once again sport-specific upper extremity strain, mostly unilateral, during growth may lead to adaptations in shoulder soft tissue and bone. In handball players the increase of HRA can be explained as an adaptation to extensive external rotation in throwing practice during growth. As been showed in Pieper [7] study the HRA is 14.4º high in the dominant arm of elite handball player comparatively with the non-thrower arm.

In our study the dominant shoulder of the athletes group was compared with the dominant arm of non-athletes instead of comparing dominant and non-dominant, so our non-athletes were subjects that were not exposed to any kind of overhead sports. In volleyball players group we also found an increase of HRA when comparing to the non-athletes group. Schwab et al. [20] found that the dominant arm of volleyball players had on average 9,6º more retroverted humerus comparing with non-dominant shoulder, in our study volleyball players showed more 9,17º retroverted humerus when comparing to non-athletes dominant shoulder.

Once more our findings seem to show an adaptation and athletes who do not adapt this way seem to have more strain on their anterior capsules at less external rotation and develop chronic shoulder pain because of anterior instability (Pieper) [7].

No statistically significant differences were found between volleyball and handball players with respect to the HRA. Explanation for this result could be addressed to the fact that handball is a throwing sport with a large demands placed on the shoulder joint, especially on the capsulolabral complex as a joint stabilizer. Forces applied during practice and competition will affect the joint, especially during the cocking phase of the throw (Pieper) [7]. Concerning our results, we propose as a hypothesis that volleyball and handball were different with respect to the kinematic and kinetic pattern of the throwing cycle and consequently in the repetitive stress imposed to the shoulder which is beneath osseous and soft tissue adaptation. This hypothesis was related to the throwing cycle that seems to be different in both sports. Although these differences, our results concerning retroversion do not show the same.

Another important point is that values presented by other authors were found in different experimental conditions. Our study uses X-Rays, others use ultrasound [20] (Schwab and Blanch), others used X-rays but in the lying position (Pieper) [7], so the magnitude of the results found cannot be compared, as long as different techniques could induce different results.

On both groups of athletes, the volleyball and the handball players group, no correlation was found between the age of commenced training and the HRA. The volleyball players started practicing at a mean age of 14 years and presented a mean HRA value of 32.6º. This mean age of commence training was similar to the one found by Schwab et al. [20], but in our study, no correlation was found between HRA and years of commenced training. The handball players on our study initiated their sports practice at a mean age of 9 years and presented a mean HRA value of 30.8º. Murachovsky et al. [21] in a study involving seventeen European handball athletes reported an average retroversion of 36º in players who started earlier practicing (10 years age) and 26º in the ones that started later in life practicing handball. Differences between early and late commence training players could be explained by results of Edelson [6] work who verified that the greater part of humeral retroversion osseous adaptation takes place, on average, by the age of 8 years (SD ± 2.12 years). After then, the development continues more slowly until the final adult dimensions are reached confirmed by the appearance of the radial groove at approximately 16 years of age.

Schwab et al. [20] on a study with 24 elite volleyball players found a moderate relationship between the HRA and age of commenced training ($r=0.41$; $p=0.045$). The authors initially hypothesized a possible correlation between both variables and they explain this result by the small number of players involved in the study (N=24). The absent of correlation observed on our study between HRA and age of commenced training, on the volleyball group, could also have the same explanation as suggested by Schwab et al., [20]. However, we assume that the effect of commence age of training on HRA could be stronger on overhead sports such as baseball, where the younger age commenced athletes demonstrate greater humeral retroversion changes. The trend age to start playing volleyball is, on average 13.3 years (Schwab and Blanch) [20], which is high when compared with those sports who start little league baseball at usually a younger age [22,23,17]. Furthermore, for the definition of a potential elite volleyball player, parameters such as height or performance measures such as vertical jump height may be more important than overhead arm motion.

Humeral external rotation range-of-motion

Differences were found between athletes (volleyball and handball players) and non-athletes concerning Thoracohumeral (TH) and Scapulohumeral (SH) angles, on shoulder active external rotation. The athletes group showed higher values of TH and SH external rotation. No differences were found between volleyball and handball players concerning TH and SH.

According to several studies [24,25,19], this increase on external rotation seems to be related to overhead sports practice. It was advocated that the augmented retroversion angle could increase the available external rotation ROM and at the same time reduces the ability of the rotator cuff to control high forces or velocities through the extremes to shoulder ROM which could lead to excessive humeral head translation and culminate in shoulder pain [22]. However, in this study no correlation was found between HRA and the increased ROM observed on athletes, instead both variables revealed statistical significant differences with respect the non-athletes group.

On the other hand, in the non-athletes group a correlation was found between humeral retroversion angle and thoracohumeral and glenohumeral external rotation, so in this group, in opposition to the athletes group, the retroversion angle could increase the available external rotation ROM at the same time reduces the ability of the rotator cuff to control high forces or velocities through the extremes to shoulder ROM. [9,26-37].

A positive correlation was found between HRA and the sports index calculated, which means that with higher HRA a higher sports index is associated.

Conclusion

Volleyball and Olympic handball players showed an increased humeral retroversion angle comparatively to a non-thrower population. The magnitude of this increase was 9.17º and 7.40º respectively for the volleyball and the handball group. The active shoulder external ROM was also high on the athlete's group comparatively to the non-athletes. However, the increment on the ROM does not seem to be related with the increased HRA observed on the athletes group.

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