Original Article

Factors associated with shoulder deficit in total rotational motion (DTRM) in adolescent athletes

VALÉRIA MAYALY ALVES DE OLIVEIRA ✉, ANA CAROLINA RODARTI PITANGUI, RODRIGO CAPPATO DE ARAÚJO

University of Pernambuco–Petrolina, Pernambuco, Brazil

ABSTRACT

Deficit in Total Rotational Motion (DTRM) is a frequent condition in athletes which is directly associated with risk of shoulder injury. However, the identification of risk factors for DTRM in adolescent athletes is not yet established. Thus, the aim of this study was to identify which factors are associated with shoulder deficit in total rotational motion among adolescent athletes. This is an observational cross-sectional study which recruited 178 male adolescent volleyball, handball, swimming, basketball and judo athletes. Information on age, dominance, training frequency, practice time and duration of each session were recorded. The evaluation was composed of a scapular kinematic analysis according to the observational method in order to identify dyskinesis and external and internal rotation amplitude of the glenohumeral joint to assess the presence of internal rotation deficit (GIRD) and DTRM, both using the passive goniometry method. Data analysis was performed using the STATA software in which binary logistic regression was performed with the outcome DTRM and inputting the independent variables of age, training frequency, duration of each session, practice time, modality, scapular dyskinesis and GIRD to identify possible factors. Results shows that adolescent athletes with a weekly training frequency of more than three times a week and affected by GIRD were 2.68 [1.27;5.63] and 9.28 [3.03;28.15] times more likely to present DTRM, respectively. Based on these results, the presence of DTRM was associated with modifiable factors. Physical fitness strategies are advisable in order to control such factors and prevent injuries associated with DTRM. **Keywords:** Joint range of motion; Upper extremity; Risk factors; Sports medicine.

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✉ **Corresponding author.** *Helio Falcão Avenue, 623; 16º floor – Boa Viagem, Recife – PE, Postal Code: 51.021-070. Brazil.* *https://orcid.org/0000-0001-8562-483X*
E-mail: valeria.mayaly@gmail.com
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INTRODUCTION

Athletes in sports modalities who overuse their upper limbs, especially overhead athletes, require efficient glenohumeral (GH) arthrokinematics to withstand high loads and movement speeds with minimal risk of injury to the shoulder (Kibler, Sciascia, & Thomas, 2012; Lubiatowski et al., 2014; Shanley et al., 2011; Wilk et al., 2010). Specifically, the rotational GH kinematics represented by external (ER) and internal rotation (IR) movements play an important role in maintaining the positioning of the humeral head at the glenoid cavity, and optimum shoulder rotation amplitudes reflect better performance and results by athletes (Borsa, Laudner, & Sauers, 2008; Kibler, Sciascia, & Thomas, 2012; Wilk et al., 2010).

As these athletes are subjected to repetitive movements and conditioned to large training volumes and low recovery time, inadequate adaptations in the GH joint components may occur, compromising local arthrokinematics and increasing the risk of injuries in the shoulder complex (Clarsen et al., 2014; Kibler, Sciascia, & Thomas, 2012; Shanley et al., 2011).

In literature it has been well established that the main changes are due to the increase in ER amplitude and decreased IR in the athletes' dominant side/limb (Borsa et al., 2008; Hibberd et al., 2014; Ruotolo et al., 2006). These changes in amplitudes are expressed as movement deficits when compared to the non-dominant limb, and are characterized as Glenohumeral Internal Rotation Deficit (GIRD) and deficit in total rotational motion (DTRM). Since the first time GIRD was reported in 1990 by Chandler et al., studies have shown the relationship between this deficit and training volume, the risk of athlete shoulder injuries (Kibler, Sciascia, & Thomas, 2012), as well as alterations in scapular kinematics (Amin et al., 2015; Clarsen et al., 2014).

On the other hand, DTRM has also revealed clinical importance. Described for the first time by Wilk et al. (2002), it is characterized by the difference between the total rotation arches (ER + IR) of the dominant and non-dominant limb. Such a difference is predictable and expected; however, when it exceeds 5º, it can increase the chances of shoulder injuries by 2.5 times (Wilk et al., 2010). Thus, the aforementioned authors believe in the importance of evaluating the DTRM, considering that in addition to determining the amplitude discrepancy between the limbs, it presents correlations with GIRD and it may change according to the training volume and the athlete's exposure time.

Despite advances in the concepts and of the importance of investigating total shoulder arch deficit in athletes, most of the studies have been directed towards elite athletes. It is worth considering that athletes in the stage of musculoskeletal maturation, such as adolescents, are subject to repetitive torsion forces during sports practice which, in turn, can lead to delayed humeral anteroversion and adaptations in adjacent soft tissues (Kibler, Sciascia, & Thomas, 2012). Considering that adolescent athletes are subject to joint adaptations provoked by the sports demand and that the determination of the factors that may be associated with DTRM at this age group is not well established, the objective of the present study is to verify which factors are associated with shoulder DTRM among adolescent athletes.

MATERIALS AND METHODS

Study design

This is a cross-sectional analysis of baseline data from a project titled "*Shoulder pain in athletes: associated factors*" (Oliveira et al., 2017), which included adolescent athletes of both genders from five sport modalities (volleyball, basketball, handball, judo and swimming) from sports centres and public and private schools of the municipality of Petrolina - Pernambuco, during the months of May and August of 2016.

Participants

The inclusion criteria for the study were: a) male subjects; b) aged between 10 and 19 years; c) athletes in the sport modalities of: volleyball, basketball, judo, handball and swimming for a minimum of one year; and d) who provided consent and/or assent forms duly dated and signed. The exclusion criteria were subjects who refused to participate in any of the evaluations.

Measures and Procedures

Information collected from the subjects was regarding: a) age (years); b) upper limb dominance (right or left); c) sports practice time (years); d) duration of each training session (less than one hour per day or equal to/greater than one hour per day); e) weekly training frequency (less than three times a week or more than three times a week).

Shoulder rotation motion range was measured according to the passive movement technique using a goniometer. The volunteer was positioned according to the guidelines of Wilk et al. (2009) and Myklebust et al. (2011). The measurement was performed by a single evaluator, who was submitted to training with experienced professionals prior to the collection and was then submitted to an evaluation of 25 adolescents in a pilot study, presenting excellent inter-reliability values (ICC = 0.82 to 0.91, SEM = 4.2-7.1). Three measurements were performed on both limbs and a final value was determined based on the mean angles. The IR values of the dominant limb were subtracted from the non-dominant limb in order to calculate GIRD. A difference equal to or greater than 18° was stipulated according to Wilk et al. (2010) for categorizing the subjects with internal rotation deficit. The sum of IR and ER of the dominant shoulder was subtracted from the sum of the IR and ER of the non-dominant shoulder in order to calculate the DTRM. Values equal to or greater than 5º determine the presence of deficit in total rotational motion (Wilk et al., 2010).

Scapular kinematics were evaluated by the dynamic observational method. In this method, the subject was asked to remain in the orthostatic position and perform three repetitions of the bilateral movement of the arm elevation in the scapular plane up to 90 degrees. The movement execution was recorded in posterior view by a digital camcorder with sampling frequency of 60 Hz (SONY model DCR-SX21), positioned on a tripod 1-meter above the ground and at a distance of 2.85 meters from the subject (Kibler & Sciascia, 2010). Categorization of the type of scapular dyskinesis was performed in accordance with Kibler et al. (2002). Visualization of the prominence of the scapula’s inferior angle was interpreted as type I; type II represents the increase in the prominence of the medial border; type III by excessive elevation of the upper angle; and type IV indicating the absence of scapular dyskinesis. A properly calibrated evaluator (Kappa = 0.99) classified dyskinesis into one of these four types based on the predominant pattern (Uhl et al., 2009). In a second moment, all subjects classified with scapular dyskinesis (type I to III) were grouped into a single category of “Having scapular dyskinesis”; and those classified as type IV were included in the category “No scapular dyskinesis” (Uhl et al., 2009).

This study was approved by the Ethics and Research Committee of the University of Pernambuco under protocol CAAE 38321114.0.0.0000.5207. All institutions involved presented an Informed Consent Form. Legal representatives of adolescents aged under 18 years and adolescents between the ages of 18 and 19 received and signed the clear and Informed Consent Form. Adolescents aged less than 18 years received the Term of Assent.

Study size

For this project 317 adolescents between 10 and 19 years were evaluated, being randomly selected after a probabilistic sampling procedure which determined a minimum sample of 290 athletes based on the representativeness of the five modalities. The sample of the present study was only composed of male adolescents (n=180). Therefore, the sample power calculation was carried out *a posteriori* through the GPower program for the purposes of this analysis.

Statistical Analysis

The collected data were imported into the STATA statistical program. A descriptive analysis of the variables was initially performed to observe the frequencies and to determine the possible categorizations. Thus, the theoretical model to verify the possible factors associated with deficit in total rotational motion (DTRM) was composed by one dependent variable: deficit in total rotational motion (absent = 0; present = 1) and by the following independent variables: a) age (10-14 years = 0; 15-19 years = 1); b) modality (judo and swimming = non-pitchers = 0; volleyball, basketball and handball = throwers = 1); c) sports practice time (1st tertile = 0; 2nd tertile = 1; 3rd tertile = 2); d) training frequency (less than 3 times a week = 0; 3 or more times a week = 1); e) duration of each training session (less than 1 hour per day = 0; 1 or more hours per day = 1); f) internal rotation deficit (absent = 0; present = 1) and g) scapular dyskinesis (absent = 0; present = 1). The chi-square test was performed in order to compare the frequency presence of deficit in total rotational motion according to the independent variable categories.

A binary logistic regression analysis was used to verify possible factors associated with DTRM by Odds Ratio (OR), and their respective confidence intervals (95% CI). A bivariate association model (crude analysis) was previously constructed in order to verify the presence and/or magnitude of the associations between each independent variable with the dependent variable. A linear trend was verified for the variable "sports practice time". Binary logistic regression modelling was carried out by the manual backward method. The permanence or removal of the variables in the model was determined by the analysis of OR values, statistic deviance, changes in the p-value of the variables and confidence interval. We came across two competing models according to this model; the criterion for choosing the best model was based on the lowest values observed in the AIC and BIC statistics (*Akaike information criterion and Bayesian information criterion*). Age and sport modality were variables tested as possible moderation factors; however, the interaction values remained non-significant. Finally, an evaluation of the model fit quality was determined by multicollinearity analysis by the variance inflation factor (VIF), *Hosmer-Lemeshow* and analysis of influential points.

RESULTS

Data from 180 athletes were evaluated in this study, however two subjects were excluded due to refusal to evaluate scapular kinematics, totalling a final sample of 178 subjects. A *posteriori* sample power based on the final logistic regression model indicates that for $\alpha = 0.05$ with three predictors and $R^2 = 0.1013$, a minimum sample of 174 subjects would be required; therefore, the statistical power of this study represents 97%.

The adolescent athletes evaluated were on average 14.58 years of age. The most practiced sport modality was handball (27.0%) followed by basketball (24.7%). The average time of practicing sports was 4.76 years. Regarding the prevalence of shoulder rotational motion deficits, 32.78% of the sample presented DTRM and 23.73% were classified as GIRD.

In the adjusted analysis, the significant variables presented similar behaviour to the crude analysis, only modifying the magnitude of the associations. Thus, the variables that promoted the best adjustment of the final model were the training frequency, internal rotation deficit and scapular dyskinesis. An evaluation of the adjustment quality of the model indicated that the proposed model presented an inflation factor of the mean variance of 1.01, indicating that independent variables can independently explain the association. The model quality was confirmed by the Hosmer-Lemeshow value of 0.678 with an accuracy of 73%. It was also possible to observe an absence of outliers and influential points (*Leviance* statistics < 0.20).

Table 1 below represents the crude and adjusted binary logistic regression analysis for the association between the altered shoulder total range of motion and the independent variables of the 178 evaluated athletes. The main results indicate that adolescent athletes who train more than three times a week and who present internal rotation deficits of the shoulder are respectively 2.68 and 9.23 times more likely to have their total range of motion altered.

Table 1. Binary logistic regression analysis (non-adjusted and adjusted analysis) for association between presence of deficit in shoulder total range of motion and independent variables in 178 adolescent athletes

Independent Variable	%	n	non-adjusted OR	CI 95%	adjusted OR	CI 95%
Age (years)						
10-14	47.07	26	1			
15-19	55.93	33	1.06	[0.56; 1.98]		
Modality						
Non-pitchers	23.73	14	1			
Pitchers	76.27	45	1.36	[0.66; 2.78]		
Training frequency (per week)						
Less than 3 times	66.10	39	1		1	
More than 3 times	33.90	20	2.07	[1.03; 4.17]*	2.68	[1.27; 5.63]*
Training duration (hours per day)						
Less than 1 hour	16.95	10	1			
More than 1 hour	83.05	49	0.97	[0.42; 2.23]		
Sports practice time (tertile-years)$^{\delta}$						
1st tertile	33.87	21	1			
2st tertile	31.82	21	0.91	[0.43; 1.90]		
3st tertile	30.00	15	0.83	[0.38; 1.87]		
Internal rotational deficit						
Absent	76.27	45	1		1	
Present	23.73	14	7.22	[2.45; 21.20]*	9.23	[3.03; 28.15]*
Scapular Dyskinesis						
Absent	43.86	25	1		1	
Present	56.14	32	0.96	[0.51; 1.82]	0.84	[0.42; 1.66]

δ Linear trend; OR = Odds Ratio; CI 95% = Confidence Interval of 95%
* Variables that presented statistical significance ($p \leq 0,05$)

DISCUSSION

Considering the clinical and scientific context, it is important to recognize total range of motion deficit and its potential risk factors in adolescent athletes. This was the first study to establish the factors associated with DTRM in adolescent athletes of different sport modalities. It was possible to observe that the DTRM is a common event among young athletes (32.8%).

The present study observed that one of the factors associated with the presence of DTRM in adolescent athletes was internal rotation deficit. The magnitude of this odds ratio reached almost 10 times. Although these variables present a similar nature which would imply in the presence and greater strength of association, Manske et al. (2013) reported that a shoulder with GIRD concomitant to DTRM should be considered a pathological shoulder. Lubiatowski et al. (2014) reinforce that the coexistence between these conditions increases the stressing shear and torsion forces of the rotator cuff muscles, which may lead to increased risk of injury. From the biomechanical point of view, articular alterations in athletes can arise from changes in the soft tissues or bone adaptations, with the latter being more considered among young athletes (Crockett et al., 2002; Hibberd et al., 2014; Meister et al., 2005).

According to Wolff's law, bone growth is influenced by the mechanical forces applied to the muscular tissues or by external forces (Carter, 1987). In this sense, it is believed that the greatest adaptations in the bone architecture occur when athletes still have skeletal immaturity. Mair et al. (2004) observed changes in the rotational motion of the shoulder compared to the non-dominant limb in young athletes (8 to 15 years of age), as well as radiographic asymmetries in the proximal humerus epiphysis. The maximum peak of bone growth combined with multiple attempts to improve sports movements lead to high volumes and intensity in training which may make pre-adolescents and adolescents subject to these adaptive changes (Shanley & Thigpen, 2013).

Among main bone alterations, we can highlight humeral retroversion that is reflected in the increase of ER in the humerus distal segment without requiring increases in the IR range of motion; conditions that precede the onset of DTRM and GIRD (Crockett et al., 2002; Greenberg, Fernandez-fernandez, & Mcclure, 2015). Such adaptation may be considered a protective mechanism for the shoulder since it contributes to reducing stress between the stabilizers of the anterior and lateral portion of the shoulder and the probability of subacromial impact. However, excessive bone stimuli may exceed the protective threshold and favour reduction of posterior capsule flexibility, leading to GIRD and DTRM (Greenberg, Fernandez-fernandez, & Mcclure, 2015).

Despite the impossibility of inferring the cause-effect on the training frequency and articular modifications, it is speculated that large training volumes may potentiate soft tissue retractions, bone adaptations and joint limitations, since repetitive movements and short recovery times lead to modifications in the osteomioarticular components of athletes (Wilk et al., 2010).

The present study observed that adolescent athletes who train for a period equal to or greater than three times a week are almost three times more likely to present DTRM. Kibler et al. (2012) report that the duration of the throw-rest-throw cycle should be somewhat modifiable, since short cycles contribute to possible changes in the shoulder's range of motion. Thus, it is possible to affirm that athletes with high training frequency tend to decrease their use-rest cycle, and this contributes to developing a deficit in total range of motion.

Based on the assumption that all overhead athletes (baseball) could present adaptive changes in shoulder range of motion after the sports season, in a cohort study Freehill et al. (2011) did not observe statistically significant changes in the range of motion of adult athletes throughout the course of a complete season. However, the authors observed that initial pitchers presented better rotational motion values when compared to "relief" pitchers after the season. The authors justify that the way initial pitchers carry out their physical preparation is composed of stretching and especially an increased rest interval, which could delay the evolution of conditions such as DTRM and GIRD.

Therefore, it is worth noting that the frequency of training risk factor can be controlled through strategies that focus on adequate physical training and balance during rest periods. Manske et al. (2013) suggest a warm-up, stretching and joint mobility techniques as strategies to reduce joint restrictions.

Ruotolo et al. (2006) found significant loss of IR and DTRM in the shoulder of overhand throwers who reported that pain affected their sports performance. According to the authors, such a finding is consistent with the "shoulder at risk" theory, and they argue that loss of movement and GIRD are results of soft tissue contractions. Based on these findings, it is worth reflecting that injury prevention strategies should focus on identifying and controlling the factors that lead athletes to present DTRM. Faced with the present result, it is possible to consider that the factors associated with DTRM in adolescent athletes are modifiable, which implies in an easier elaboration of strategies that can act on these factors.

It is important to emphasize that the studies focused on analysing total shoulder movement of athletes are mostly focused on elite overhead athletic modalities such as baseball (Amin et al., 2015; Hibberd et al., 2014). This reinforces the importance of this and future studies that include athletes of different modalities and sports levels. Moreover, much of the evidence presents a small sample size as limitations. Although the present study reaches a sampling power equivalent to 97%, other weaknesses can be pointed out: we did not control whether adolescent athletes presented pain complaints and/or shoulder injuries for possible comparisons; the cross-sectional design of the study does not allow to establish causal relations between the outcome and the variables of interest; all athletes were amateurs in their sporting level, which limits comparisons between sports levels; and female athletes were not part of the study, restricting extrapolation of data for this population.

Despite the limitations, the present study brings important contributions to the theme. This study encompassed a population that was often neglected from the point of view of sports assessment and brought unpublished and relevant results regarding the identification and nature of the risk factors for DTRM. In addition, the present study extends the possibility of new studies directed at intervention from both the therapeutic point of view and in the performance of the throw-rest cycle. Thus, the information generated from this study can serve as an alert and control of the potential factors that lead to the DTRM condition, and consequently to the risk of injury to athletes' shoulders.

CONCLUSIONS

The factors associated with deficit in shoulder total range of motion in adolescent athletes are the training frequency (greater than three times a week) and the presence of Glenohumeral Internal Rotation Deficit (GIRD). These factors are considered as modifiable risk factors which can be easily identified and included in control, prevention and rehabilitation strategies of athletes.

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