Telles R, Cunha RA, Yoshimura AL, Pochini AC, Ejnisman B, Soliaman RR. Shoulder Rotation Range of Motion and Serve Speed in Adolescent Male Volleyball Athletes: A Cross-Sectional Study. *IJSPT*. 2021;16(2):496-503. doi:10.26603/001c.21243

Original Research

Shoulder Rotation Range of Motion and Serve Speed in Adolescent Male Volleyball Athletes: A Cross-Sectional Study

Rafael Telles, PT[1a], Ronaldo Alves Cunha, PT, MS[1], André Lima Yoshimura, PT[1], Alberto Castro Pochini, MD, PhD[1], Benno Ejnisman, MD, PhD[1], Renato Rozenblit Soliaman, PT, MS[1]

[1] Sports Traumatology Center, Federal University of São Paulo

Keywords: volleyball, shoulder, range of motion, athletes, movement, athletic performance

https://doi.org/10.26603/001c.21243

International Journal of Sports Physical Therapy

Vol. 16, Issue 2, 2021

Background

Throwing athletes present alterations in shoulder rotation range of motion (ROM), but not much is known about the relationship between these alterations and performance measurements in volleyball practitioners.

Purpose

To compare the passive ranges of motion of internal rotation (IR), external rotation (ER), and total rotation motion (TRM) of the shoulder in dominant and nondominant limbs of young volleyball athletes and to investigate their relationship with ball speed during serves with and without precision (inside and outside court, respectively). The possible association of anthropometrics and competitive practice time with these velocities was also investigated.

Study Design

Cross-sectional study.

Methods

Fifty-seven male volleyball athletes (mean age 17.11 ± 1.88 y; weight 74.68 ± 9.7 kg; height 1.87 ± 0.09 cm) were evaluated for shoulder IR and ER with a bubble goniometer and serve speed inside and outside court was measured with a radar gun. Simple and multiple regression analyses were applied to investigate associations of ROM, anthropometrics, and competitive practice time with serve speed.

Results

Dominant shoulders had diminished IR ROM compared to nondominant shoulders (59.1º ± 16.7º vs 66.4º ± 16.9º; $p < 0.001$) as well as diminished TRM (173.5º ± 31.8º vs 179.1º ± 29.9º; $p < 0.001$). Simple regression showed negative association between dominant ER and serve speed outside the court ($p = 0.004$). Positive associations existed between age and serve speed in both conditions ($p < 0.001$), BMI and speed inside ($p = 0.009$) and outside the court ($p = 0.008$), and between competitive practice time and speed inside ($p = 0.008$) and outside court ($p = 0.003$). However, multiple analysis confirmed only age ($p < 0.001$) and BMI to be associated with ball velocities (inside court $p = 0.034$; outside court $p = 0.031$).

Conclusion

The results of this study demonstrated that young volleyball athletes presented lower IR and TRM of the shoulder in the dominant upper limb. Age and BMI were directly

a **Corresponding Author:**
Rafael Telles
Email: telles.rf@gmail.com
Phone: +5511997630833

associated with ball velocities when serving. Passive rotation ROM did not have a relationship with this performance measurement.

Level of Evidence

3b

INTRODUCTION

BACKGROUND

Throwing athletes have important morphological alterations of the shoulder as a result of the mechanical stimuli of sports movements. First observed in baseball pitchers, the main adaptations described affect the rotation range of motion (ROM) of the dominant shoulder, leading to greater ROM of external rotation (ER) and a concurrent internal rotation (IR) deficit, also known as glenohumeral internal rotation deficit (GIRD).[1]

In throwing sports, these alterations are due to both soft tissue and bony adaptations. Retraction of the posterior articular capsule and rotator cuff muscles restrict humeral internal rotation and occur because of the eccentric stress that these structures receive during the deceleration phase of the arm during throwing.[2] The ER gain can be due to loosening of the anterior capsule, related to the high amplitudes in the late cocking phase[2] and due to the increased arm retroversion, which results from throwing torsional stress. This coincides with GIRD once the humeral axis is changed. In this way, total rotation motion (TRM, sum of internal and external rotation) is not altered.[3]

Volleyball practitioners, who continuously repeat intense and fast movements of the dominant limb during actions such as the serve and spike, also experience ROM changes;[4,5] asymmetries in rotator muscle strength,[4] and postural differences compared to the nondominant side.[5] In a recent literature review dealing with the volleyball population, seven out of nine studies verified the presence of GIRD, and five out of seven found an association between shoulder adaptations and injury or pain.[6] However, the literature that addresses the possible relationship of these findings to volleyball performance measurements is still scarce. Some authors have investigated the ball speed during spike and the morphological aspects of the shoulder,[5,7] but the serve and its association with ROM values has not yet been explored.

Therefore, the purpose of this study was to compare the passive ranges of motion of IR, ER, and TRM of the shoulder in dominant and nondominant limbs of young volleyball athletes, and to investigate their relationship with ball speed during serves with and without precision (inside and outside court, respectively). Possible association of anthropometric data and competitive practice time with these velocities was also investigated.

METHODS

STUDY DESIGN

This was a cross-sectional study, in agreement with the STROBE statement for observational studies. Shoulder rotation passive ROM and maximum serve speed of adolescent male volleyball athletes were measured to investigate associations. Dominant and nondominant rotation passive ROM measurements were also compared. Recruitment took place between 2015 and 2016 during two seasons in a training center in Sao Paulo, Brazil. The study was approved by the Research Ethics Committee of Federal University of São Paulo.

PARTICIPANTS

Participants were selected from an initial interview to match the eligibility criteria, which included volleyball athletes aged between 15 to 23 years. They must have trained for competition for at least one year; could not present any pain that could interfere with the assessment; could not have had previous surgery in the dominant shoulder; and could not be in physical therapy treatment for a complaint related to the shoulder. All participants and legally responsible guardians signed written forms consenting to their participation in the study.

VARIABLES

Variables that characterized the population were age, weight, height, BMI, competitive practice time, weekly training load, position on court, presence of previous injuries in dominant shoulder, IR and ER range of motion, TRM of dominant and nondominant upper limbs, and maximal serving speed with and without precision (inside and outside court, respectively).

PROCEDURES

The included athletes underwent a single assessment, which consisted of an initial interview followed by bilateral measurement of shoulder rotation ROM and serve speed in the order presented below.

Initial interview: Participants gave personal, demographic, and sports data, as well as reporting any shoulder injuries or pain.

Rotation ROM: Two trained physiotherapists conducted bilateral assessment to obtain passive glenohumeral IR and ER values. TRM was calculated by adding IR and ER values. The physiotherapists practiced the assessment methods for two months before the testing started, mentored by another physiotherapist with expertise in shoulder assessment. One therapist was responsible for stabilizing the shoulder anteriorly and taking it to the maximum range of rotation, while the other positioned a 12-in manual bubble goniometer (Prestige Medical®, Los Angeles, CA, USA) for measurement. Measurement was performed with each participant in the supine position with knees flexed, feet supported on the table, with shoulder to be evaluated placed at 90° of abduc-

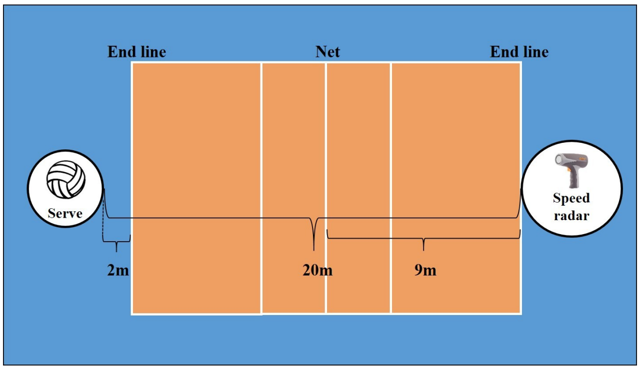

Figure 1: Experimental setup

tion, with forearm in the neutral position.[8] The reliability of these measures was assessed in a pilot study, with a confidence index of 0.9.

Serve speed: Serve speed was measured using a speed radar gun (Bushnell Velocity ™) with an accuracy of ± 2 km/h and a speed range of 16-177 km/h at 27 m. The athletes were positioned 2 m behind the end line of the court for the execution of the serves. The evaluator was positioned beyond the opposite end line, 20 m away from the athlete, and aimed the radar toward the participant (Figure 1). To obtain maximum serve speeds involving precision, the participants were informed that they should serve with the maximum force possible, seeking to reach the interior of the opposite court. Then, in order to obtain maximum speeds without precision, they were asked to serve with as much force as possible, seeking to hit off-court. For both conditions, the serve was executed without jumping, in view of its influence on speed.[9] The ball could not touch the net; the participants repeated the execution until three values with variation of up to 10% between the attempts were obtained, and an interval of 10 seconds between them was given. A submaximal test for each condition was performed as a procedure for familiarization. The reliability of this measurement was assessed in a pilot study whose confidence index was 0.9.

BIAS

It was opted to evaluate ROM first, followed by measurement of serve speed, while considering the possible acute effects of the movement in the amplitude measurements.[10]

STUDY SAMPLE SIZE

The number of participants was achieved by initial calculus of the sample size, which was calculated using standard deviation values of 8.53 for IR, 7.81 for ER, and 9.04 for TRM obtained in a previous study.[11] With a power of 80% and significance of 5%, the minimum number of athletes required for the present study were 30, 5, and 3, according to the standard deviations of IR, ER and TRM, respectively.

STATISTICAL METHODS

Data were analyzed using the Statistical Package for Social Sciences (SPSS) software for Windows version 18.0 (SPSS, Inc., Chicago, Illinois). The anthropometric and sports characteristics, measures of shoulder ROM and maximum serve speed were described by mean and standard deviation for the total sample. The number of athletes who reported previous injuries in the dominant shoulder, and the number of athletes per position, were given in absolute values and percentage. After checking for normality, differences between dominant and nondominant upper limb ranges of motion and between on-and off-court ball velocities were investigated through paired *t*-tests. Associations between the explanatory variables (age, height, BMI, competitive practice time, dominant IR, and dominant ER) and serve velocities were verified using a simple linear regression model. This model was later adjusted to the multiple approach using the stepwise method of variable selection,[12] in accordance with a previous study with similar methodology.[5] The results were presented as an estimated coefficient and standard error, and a significance level of 0.05 was adopted for all analysis.

RESULTS

PARTICIPANTS

The study included 57 young male volleyball players. The descriptive data characterizing the sample, including ROM data and serve speed, are presented in Table 1.

RANGE OF MOTION

Passive ROM comparisons between the dominant and nondominant limbs are shown in Table 2. IR and TRM were significantly lower for the dominant limbs, whereas ER did not differ between the sides.

SERVE SPEED

Table 2 also shows the comparison of the velocities of the ball in the two serve situations. The speed was 10.3 km/h higher when the athletes were asked to purposely hit out of the court.

ASSOCIATIONS WITH SERVE SPEED

The results of the simple linear regression are presented in Table 3. An indirect association between the range of the dominant ER and the maximum speed of the ball outside court was found, so that the increase of one degree in ER represented a decrease of 0.11 km/h in velocity ($p = 0.004$).

Evidence of a direct association with ball velocities was found for age in both inside and outside court conditions ($p < 0.001$), for BMI within the court ($p = 0.009$) and outside it ($p = 0.008$), and for competitive practice time both within the court ($p = 0.008$) and outside it ($p = 0.003$).

Table 4 presents the results of the multiple linear regression. After adjustment of the models, the variables age and BMI were selected because they explained 34.2% of the

Table 1: Descriptive data of volleyball athletes (n=57)

Anthropometrics and sporting data	Mean (SD)
Age (years)	17.1 (1.9)
Weight (kg)	74.7 (9.7)
Height (m)	1.87 (0.09)
BMI (kg/m²)	21.4 (1.9)
Competitive practice time (months)	46.2 (23.5)
Weekly training load (h/week)	13.5 (5.1)
Position on court	**(Absolute/%)**
Middle blocker	9 (15.8)
Setter	9 (15.8)
Libero	8 (14.0)
Opposite	12 (21.1)
Outside hitter	19 (33.3)
Previous injury in dominant shoulder	**(Absolute/%)**
No	41 (71.9)
Yes	16 (28.1)
Rotation ROM (degrees)	**Mean (SD)**
DIR	59.1 (16.7)
NDIR	66.4 (16.9)
DER	114.3 (19.1)
NDER	112.7 (16.2)
DTROM	173.5 (31.8)
NDTROM	179.1 (29.9)
Maximum ball speed in serve (km/h)	**Mean (SD)**
Ball inside court	62.8 (4.4)
Ball outside court	73.1 (5.5)

DIR =dominant internal rotation, NDIR = non-dominant internal rotation, DER = dominant external rotation, NDER = non dominant external, DTROM = dominant total rotation motion, NDTROM = non-dominant total rotation motion

Table 2: Comparisons between dominant and non-dominant ROM and ball speed in two serve situations

Measurement	Mean (CI 95%)	p-value*
DIR - NDIR	-7.2 (-9.5; -4.9)	<0.001
DER – NDER	1.6 (1; 4.2)	0.219
DTRROM – NDTRROM	-5.6 (-8.5; -2.7)	<0.001
Ball speed inside court – Ball speed outside court	-10.3 (-11.6; -9.1)	<0.001

CI = confidence interval; DIR = dominant internal rotation; NDIR = non-dominant internal rotation, DER = dominant external rotation; NDER = non-dominant external rotation; DTRROM = dominant total rotation range of motion; NDTRROM = non-dominant total rotation range of motion
*statistically significant difference at p <0.05

variability of the velocity measurements within the court, and 39.2% of the variability of the velocity measurements outside the court.

DISCUSSION

The purpose of the present study was to compare the shoulder rotation passive ROM of the dominant and nondominant sides of young male volleyball players and to investigate the relationship between these measurements and ball speed when serving. The association of this performance measure with anthropometrics and competitive practice time was also investigated.

There were no significant differences in ER measures thus, the smaller TRM on the dominant side was due to lower IR. Other studies also verified the presence of GIRD in volleyball athletes.[11,13,14] On the other hand, several authors[15-17] have verified the presence of GIRD associated with higher ER values on the dominant side. Other authors have also found similar ROM between sides for both internal and external rotation.[18,19] Inconsistency among the findings may be due to variations in the ROM assessment

Table 3: Results of simple linear regression: association between demographics and dominant ROM and ball speed in two serve situations.

	Ball speed inside court (km/h)		Ball speed outside court (km/h)	
Variables	Coefficient (SE)	p-value	Coefficient (SE)	p-value
Age (years)	1.26 (0.27)	<0.001*	1.71 (0.32)	<0.001*
BMI (kg/m^2)	0.81 (0.30)	0.009*	1.02 (0.37)	0.008*
Competitive practice time (years)	0.07 (0.02)	0.008*	0.09 (0.03)	0.003*
DIR (degrees)	-0.02 (0.04)	0.609	-0.06 (0.04)	0.144
DER (degrees)	-0.03 (0.03)	0.283	-0.11 (0.04)	0.004*

SE = standard error of mean, BMI= body mass index, DIR = dominant internal rotation, DER = dominant external rotation, *statistically significant difference at p <0.05

Table 4: Results of linear regression in multiple analysis

	Ball speed inside court (km/h)		Ball speed outside court (km/h)	
Variables	Coefficient (SE)	p-value	Coefficient (SE)	p-value
Age (years)	1.14 (0.27)	<0.001*	1.56 (0.32)	<0.001*
BMI (kg/m^2)	0.58 (0.27)	0.034*	0.71 (0.32)	0.031*

SE = standard error of mean, BMI= body mass index *statistically significant difference at p <0.05

methods, differences in the populations studied, sports practice level, gender, and the fact that some studies were carried out with beach volleyball athletes.[11,17]

The results of the current study identified a significant IR deficit, reinforcing the presence of specific musculoskeletal adaptations of the shoulder of the volleyball athlete, which have already been described in other throwing sports.[1,20] When an isolated IR deficit is present without gain in ER, compared to nondominant side, this deficit may be related to changes within the posterior soft tissues of the shoulder, such as the articular capsule and rotator cuff muscles. This is due to the high eccentric loads that these structures are subjected to during the deceleration phase of the arm in throwing athletes.[2] When IR deficit is comorbid with ER gain, bony adaptations can be present because of changes in the humeral axis. The findings of the present study suggest that, in general, this population of young volleyball male players did not have enough repeated chronic strain to lead to bony alteration, although bony alteration was not directly measured. However, it could be present later, in more experienced players who have taken part in volleyball training programs over more years.

Serve velocities on and off the court differed significantly. According to Fitts' Law, the accuracy of movement toward a target decreases as the velocity of motion increases, and this relationship has already been verified under various conditions.[21] It was expected and confirmed that in the outside court serve condition, the athletes would attain higher serving velocities, as it is a condition in which less precision is demanded. This difference was important because in the multiple regression model, the coefficient of determination for age and BMI (39.2%) explained the variability of off-court velocities most clearly. Despite the differences found in velocities during serves with and without precision, there is no consensus on how to better assess the speed of a serve in volleyball. Two studies have used radar speed to evaluate the spike.[5,7] Among studies that have evaluated serve speed, one does not describe the methodology used,[18] and another did so with the use of a radar device on a tripod during a professional tournament.[9]

Simple regression analysis showed an indirect association between serve speed and ER on the dominant side when athletes were asked to hit the ball out of court; that is, there was a tendency that the higher the ER, the lower the velocity of the ball. These results are opposite from those observed in baseball pitchers: those with the highest ball speeds present higher degrees of ER.[2] These associations had not been investigated in volleyball athletes until the present study. Forthomme et al.[7] investigated factors correlated with volleyball spike velocity and assessed shoulder rotation ROM, but they did not investigate correlational factors. Shoulder rotation ROM was assessed only to describe the sample and verify differences between sides. Challoumas et al.[5] investigated some shoulder morphological measurements, such as scapular lateralization and dorsal and inferior capsule laxity and verified their correlation with spike speed, but shoulder rotation ROM was not investigated.

One possible explanation for the association found in the simple regression between ER and serve speed is that in young athletes undergoing shoulder adaptations, higher ER angles could represent less control over the joint, negatively impacting the kinetic chain energy transfer and power production when serving. Authors that have verified increased dominant shoulder ER in volleyball athletes have not investigated its association with serve or spike speed;[4,15-17] therefore, the association found in the present study is still difficult to compare to existing literature. Additionally, correlation between ER and serve speed was not confirmed in the multiple regression model. It is possible that higher shoulder ER could be present in younger athletes with lower BMIs. This may negatively impact serve speed, as seen in the multiple regression analysis. Although the relationship of shoulder morphology and physical performance data with velocity measures in volleyball has been investigated before, ROM and serve speed have not been explored. It has already been verified that spike speed is positively correlated with the peak torque of the internal rotators of the dominant shoulder, jumping capacity, and BMI,[7] and that there is a positive relationship between the spike speed and the shoulder posterior capsule's state of contracture as measured by a horizontal adduction test.[5] Differently from the present study results, Schwab et al.[18] did not find correlative relationship between shoulder measurements and serve speed in the simple regression. But they observed elite volleyball players and the shoulder measurement was humeral torsion. In addition, the methods to assess serve speed were not explained and took place months before shoulder assessment.

Age, BMI, and competitive practice time were the variables positively associated with ball velocity according to the simple regression analysis. In the multiple regression model, only age and BMI were associated with serve speed, which means they explained the variability of speeds most clearly. Nevertheless, the determination coefficients were weak, which means the interpretation of the results (considering only what was kept in the final model) may be subject to significant errors.

Muscle mass and strength, coordination, and refinement of serving technique could be among the factors that could explain the results, but none of these were measured in this research design. These questions need to be tested in future randomized clinical trials to investigate the use of isokinetic machines for strength training and their effects on serve speed. Furthermore, we suggest investigating the effects of specific serve skills training protocols to improve serve speed.

In the present study, only young male volleyball players were observed; therefore, the results cannot be generalized to all volleyball athletes. The measurements obtained for shoulder ROM do not necessarily represent the amplitudes that may be reached during the serve movement in a more functional context. Additionally, while a radar gun was used, there is no consensus on how to best assess serve speed.

Future studies should evaluate athletes who practiced volleyball longer and in whom musculoskeletal adaptations are more evident. These studies should also evaluate the relationship between ROM adaptations, such as diminished IR, and specific measures of sport performance. To better understand the function of the shoulder in this population, studies involving kinematics should investigate whether the active rotation motion reached during the execution of the serve relates to serve speed and whether these amplitudes are at all similar to the passive measures. In addition, studies should investigate the function of other joints in the transfer of mechanical energy within the kinetic chain of the serve motion and their relationship with this performance measure.

CONCLUSION

The results of this study indicate that young male volleyball athletes present with decreased internal rotation and total rotation motion of the shoulder in the dominant upper limb as compared to the non-dominant limb. Age and BMI were the variables directly associated with ball velocities in serving and further justified its variability, explaining 34.2% of the velocities within the court and 39.2% outside the court. Passive rotation ROM does not seem to have a relationship with serving speed.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

FUNDING

No funding was provided for this study.

Submitted: September 18, 2017 CDT, Accepted: October 10, 2020 CDT

REFERENCES

1. Kibler WB, Kuhn JE, Wilk K, et al. The disabled throwing shoulder: Spectrum of pathology—10-Year update. *Arthrosc*. 2013;29(1):141-161. e26. doi:10.1016/j.arthro.2012.10.009

2. Kinsella SD, Thomas SJ, Huffman GR, Kelly JDT. The thrower's shoulder. *Orthop Clin North Am*. 2014;45(3):387-401. doi:10.1016/j.ocl.2014.04.003

3. Chant CB, Litchfield R, Griffin S, Thain LM. Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. *J Orthop Sports Phys Ther*. 2007;37(9):514-520. doi:10.2519/jospt.2007.2449

4. Harput G, Guney H, Toprak U, Kaya T, Colakoglu FF, Baltaci G. Shoulder-rotator strength, range of motion, and acromiohumeral distance in asymptomatic adolescent volleyball attackers. *J Athl Train*. 2016;51(9):733-738. doi:10.4085/1062-6050-51.12.04

5. Challoumas D, Artemiou A, Dimitrakakis G. Dominant vs. non-dominant shoulder morphology in volleyball players and associations with shoulder pain and spike speed. *J Sports Sci*. 2017;35(1):65-73. doi:10.1080/02640414.2016.1155730

6. Challoumas D, Stavrou A, Dimitrakakis G. The volleyball athlete's shoulder: biomechanical adaptations and injury associations. *Sports Biomech*. 2017;16(2):220-237. doi:10.1080/14763141.2016.1222629

7. Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. *Am J Sports Med*. 2005;33(10):1513-1519. doi:10.1177/0363546505274935

8. Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med*. 2011;39(2):329-335. doi:10.1177/0363546510384223

9. Moras G, Busca B, Pena J, et al. A comparative study between serve mode and speed and its effectiveness in a high-level volleyball tournament. *J Sports Med Phys Fit*. 2008;48(1):31-36.

10. Case JM, Mannava S, Fallin JH, Stone AV, Freehill MT. Acute changes in glenohumeral range-of-motion following in-season minor league pitching starts. *Phys Sportsmed*. 2015;43(4):360-365. doi:10.1080/00913847.2015.1059249

11. Saccol MF, Almeida GP, de Souza VL. Anatomical glenohumeral internal rotation deficit and symmetric rotational strength in male and female young beach volleyball players. *J Electromyogr Kinesiol*. 2016;29:121-125. doi:10.1016/j.jelekin.2015.08.003

12. Olkin I, Sampson AR. Multivariate analysis: Overview. In: Smelser NJ, Baltes PB, eds. *International Encyclopedia of the Social & Behavioral Sciences*. Pergamon; 2001:10240-10247.

13. Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fit*. 2001;41(3):403-410.

14. Reeser JC, Joy EA, Porucznik CA, Berg RL, Colliver EB, Willick SE. Risk factors for volleyball-related shoulder pain and dysfunction. *PM R*. 2010;2(1):27-36. doi:10.1016/j.pmrj.2009.11.010

15. Schwab LM, Blanch P. Humeral torsion and passive shoulder range in elite volleyball players. *Phys Ther Sport*. 2009;10(2):51-56. doi:10.1016/j.ptsp.2008.11.006

16. Kugler A, Kruger-Franke M, Reininger S, Trouillier HH, Rosemeyer B. Muscular imbalance and shoulder pain in volleyball attackers. *Br J Sports Med*. 1996;30(3):256-259. doi:10.1136/bjsm.30.3.256

17. Lajtai G, Pfirrmann CW, Aitzetmuller G, Pirkl C, Gerber C, Jost B. The shoulders of professional beach volleyball players: High prevalence of infraspinatus muscle atrophy. *Am J Sports Med*. 2009;37(7):1375-1383. doi:10.1177/0363546509333850

18. Almeida GP, Silveira PF, Rosseto NP, Barbosa G, Ejnisman B, Cohen M. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J Shoulder Elbow Surg*. 2013;22(5):602-607. doi:10.1016/j.jse.2012.08.027

19. Etnyre BR. Accuracy characteristics of throwing as a result of maximum force effort. *Percept Mot Skills*. 1998;86(3 Pt 2):1211-1217. doi:10.2466/pms.1998.86.3c.1211

20. Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. *Am J Sports Med*. 2005;33(10):1513-1519. doi:10.1177/0363546505274935

21. Forthomme B, Wieczorek V, Frisch A, Crielaard JM, Croisier JL. Shoulder pain among high-level volleyball players and preseason features. *Med Sci Sports Exerc*. 2013;45(10):1852-1860. doi:10.1249/MSS.0b013e318296128d