JSES International 7 (2023) 662–667

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Preseason shoulder screening in volleyball players: is there any change during season?

Camille Tooth, PT, PhD[a,b,*], Cédric Schwartz, PhD[a], Amandine Gofflot, PT[b], Stephen Bornheim, PT, PhD[b], Jean-Louis Croisier, PT, PhD[a,b], Bénédicte Forthomme, PT, PhD[a,b]

[a]Laboratory of Human Motion Analysis, University of Liège, Liège, Belgium
[b]Department of Physical Medicine and Rehabilitation, University of Liège, Liège, Belgium

ARTICLE INFO

Keywords:
Shoulder
Overhead athlete
Assessment
Volleyball
Sport
Performance

Level of evidence: Basic Science Study; Kinesiology

Background: Volleyball players sollicit their shoulder with high velocity and high ranges of motion. Musculoskeletal adaptations have been described after some years of practice but have not been explored after some months of practice. The objective of this study was to analyze the short-term evolution of shoulder clinical measures and functional performance in youth competitive volleyball players.
Methods: Sixty-one volleyball players were assessed twice, at preseason and at midseason. Shoulder internal and external rotation range of motion as well as forward shoulder posture and scapular upward rotation were measured in all players. Two functional tests were also performed: the upper quarter Y-balance test and the Single-arm medicine ball throw. The results obtained at midseason were compared to those measured at preseason.
Results: Compared to preseason, an increase in absolute value of shoulder external rotation, total rotation range of motion and forward shoulder posture were observed at midseason ($P < .001$). An increase in side-to-side difference for shoulder internal rotation range of motion was also observed during the season. As for scapular kinematics, scapular upward rotation was significantly decreased at 45° and increased at 120° of abduction at midseason. Concerning functional tests, an increase in throwing distance in the single-arm medicine ball throw was observed at midseason while no change was noted for the upper quarter Y-balance test.
Conclusion: Significant changes in clinical measures and functional performance were observed after some months of practice. Since some variables have been suggested to be correlated to a higher risk of shoulder injuries, the current study emphasizes the importance of regular screening in order to highlight injury risk profiles throughout the season.

Volleyball players hit the ball with high velocity and high range of motion. Both in training sessions and matches, their shoulder is highly solicited, particularly during serves and spikes.[5,19,56] In high-level players, the total number of spikes can exceed 100 for a team per match, with outside hitters and middle blockers hitting most of them.[58] All of these solicitations can influence musculoskeletal structures and biomechanics at shoulder part in the medium-to-long term.

Different adaptations have been described in overhead athletes following years of practice. The capsule undergoes adaptations, with an increase in mobility for the anterior capsule and a decrease in mobility for the posterior capsule.[8,48] A decrease in internal rotation as well as an increase in external rotation range of motion was also reported in athletes practicing overhead sports.[4,8,17,31,40,46] The decrease of internal rotation range of motion seems to be associated with posterior shoulder stiffness, caused by repetitive eccentric contractions of the posterior shoulder muscles in the follow-through phase of serves and spikes.[4,20,46] A decrease of total rotation[46] and of horizontal adduction[43] is also observed for the dominant arm of overhead athletes after some years of practice. Another main change that occurs in overhead athletes following practice concerns scapular kinematics. Indeed, it has been observed a few years ago that scapular dyskinesis was present in 61% of overhead athletes.[10] Moreover, Myers et al[37] observed an increase of scapular upward rotation and scapular retraction during shoulder elevation in asymptomatic throwers. Thomas et al[46] found the

The University Hospital of Liège Medical Ethics Committee approved this study File number: 218-242 B707201837397.

*Corresponding author: Camille Tooth, PT, PhD, Allée des Sports, 1, Liège 4000, Belgium.

E-mail address: ctooth@uliege.be (C. Tooth).

https://doi.org/10.1016/j.jseint.2023.03.022

same results for baseball players. As for Hosseinimehr et al,[29] they found a decrease in scapular upward rotation in a resting position but an increase of this rotation at 90° and 135° of abduction. Concerning scapular anterior tilt (and forward shoulder posture), an increase has been reported in swimmers and tennis players,[28,52] mainly due to pectoralis minor retraction.[9,17,32] Finally, adaptations have also been reported in the maximal strength developed by the dominant arm of volleyball players, with an increase of internal rotators maximal strength at the expense of external rotators strength.[11,24,39]

Although the relationship between those adaptations and the occurrence of shoulder injuries has not been clearly defined in the scientific literature for all the variables considered,[49] it seems important to understand the evolution of them, not only after years of practice but also during a mere season or after a few weeks of practice (especially in an objective of prevention). In baseball, Thomas et al[47] observed changes in glenohumeral range of motion as well as scapular kinematics after a season but the evolution of the previously described variables over the short-term has not yet been explored in volleyball. Moreover, functional testing has become more and more popular over the last years.[15,50] However, the impact of sport practice on the results of those tests has not been explored yet.

Since the evolution of strength has been more documented in literature,[18,34] the objective of this study was to explore the evolution of clinical measures and functional tests values between preseason and midseason in competitive young volleyball players.

Material and methods

Participants

Sixty-one young players (16 males and 45 females) were included in the study. They were 14.84 ± 2.09 years old, weighted 60.58 ± 10.55 kg, and measured 172.48 ± 8.90 centimeters. Fifty-eight of them were right-handed and the 3 other ones were left-handed. They had to practice volleyball at least 8 hours a week (3 training sessions and 1 match), for at least 3 years, at national and/or at provincial levels in the Belgian Volleyball Championship. Some of them practiced shoulder prevention exercises during the training sessions, which mainly consisted in rotator and scapular exercises with an elastic band but stopped these exercises throughout the duration of the study to avoid influencing the results. Moreover, they were asked to keep their normal training schedule but not to perform any lifting or strengthening work on their own to limit the influence on the results on the study. Players with current or history of shoulder pain/injury in the last 6 months or a history of shoulder surgery were not included (or excluded) in the sample.

The entire protocol was approved by the Medical Ethics Committee of the Liège University Hospital (process number: B707201837397). Participants were informed about the different tests before the study and signed a written consent.

A first session of tests was organized at the beginning of September, before the beginning of competition (about 3 weeks after their return to training). A second one was organized at midseason (at the end of January).

All the measurements were done on the field and divided into 3 main parts: clinical assessment (aimed at assessing shoulder range of motion and appreciating scapular upward rotation), upper quarter Y-balance test (UQYBT) (aimed at assessing shoulder stability in a closed kinetic chain) and single-arm medicine ball throw (SAMBT) (aimed at assessing shoulder strength and power).[50]

Each part was evaluated by a different assessor, who was always the same for the first and the second sessions in order to limit potential biases. The order of the different evaluations was randomized between subjects but was kept between the first and the second sessions. Warm-up consisted in 2 series of 10 repetitions of internal and external rotation, with a resistive elastic band, at 0° and 90° of abduction as well as 2 series of 10 overhead medicine ball throws. Warm-up was always performed before the measurements (mobility as well as functional performance testing).

Clinical assessment

Internal (IR) and external rotation (ER) range of motion were measured with a goniometer. The subject was lying on a table (supine), arm at 90° of abduction in the frontal plane, and elbow at 90° of flexion. The glenohumeral joint was passively moved into the maximal range of motion for rotations, without compensation of the scapula (for internal rotation), of the humeral head or the back (for external rotation). Good intrarater reproducibility has been reported for these measures (intra-class correlation coefficient [ICC] = 0.94-0.97; standard error of measurement [SEM] = 2.11-3.44; minimal detectable change 90 = 4.93-8.03).[14]

Then, in a supine position, the distance between the posterior border of the acromion and the table was measured (with a tape measure) to estimate forward shoulder posture (PM) (ICC = 0.92-0.93).[24,33]

Finally, in a seated position, scapular upward rotation was measured at 0°, 45°, 90°, and 120° of abduction (frontal plane) with an inclinometer with the same method as Johnson et al.[30] A good reproductibility has been demonstrated on 20 nonoverhead sportspeople (mean age 22.1 ± 2.8) by the experimenter of the study for this method (ICC = 0.653 (0.053-0.871)) (nonpublished data).[51]

All the measurements were done on both the dominant and nondominant sides in a randomized order. Only dominant and bilateral differences were considered for analysis since they seem to be the most relevant values to consider when screening athletes in an objective of prevention.

Upper quarter Y-balance test (UQYBT)

The UQYBT[25,45,57] is a closed kinetic chain functional test. This test consists of, in a push-up position, pushing a plastic indicator using their hand as far as possible in 3 directions (medial, superolateral and inferolateral). A very good intrarater and inter-rater reliability has been reported for this test (0.80> ICC >0.99) in literature,[6,25,57] with a SEM about 1.41-1.77 and a minimal detectable change 95 about 3.91-4.91.[7] In order to get accommodated with this test, players underwent 2 familiarization trials. They then attempted the UQYBT 3 times on each side and only the best score (in centimeters) was retained for analysis. Between the 3 repetitions, participants had 1 minute of rest. The average score of the 3 directions was calculated to obtain the composite score. All the scores obtained were normalized by the length of the upper limb (distance between C7 and the extremity of the middle finger in centimeters) to make comparisons between subjects. The test was performed on both dominant and nondominant sides in a randomized order.

Single-arm medicine ball throw (SAMBT)

The single-arm medicine ball throw test was only performed on the dominant side. In a lunge position, participants had to throw a 0.8-kg medicine ball as far as possible from a cocking position (90° of abduction and 90° of external rotation).[23] A significant correlation has been found between this test and maximum peak torque of internal rotators at 60° and 240°/s.[23] Three familiarization trials

Table I
Clinical assessment at the beginning of the season (preseason) and at the midseason.

	Preseason	Midseason	*P* value Wilcoxon
IR D (°)	50.0 (45.0; 55.0)	48.0 (45.0; 52.0)	.627
Diff IR (°)	10.0 (5.0; 15.0)	12.0 (8.0; 20.0)	.018*
ER D (°)	105.0 (98.0; 114.0)	111.0 (102.0; 121.0)	.0001*
Diff ER (°)	7.0 (2.0; 13.0)	6.0 (3.0; 11.0)	.565
Tot rot D (°)	154.0 (147.0; 154.0)	160.0 (150.0; 172.0)	.001*
Diff tot rot (°)	12.0 (6.0; 17.0)	13.0 (7.0; 19.0)	.519
PM D (cm)	5.0 (4.0; 6.5)	6.0 (5.0; 7.0)	.001*
Diff PM (cm)	1.0 (0.0; 2.0)	1.5 (0.5; 2.0)	.156
UpwardR 0 D (°)	−2.5 (−5.0; 0.0)	−2.50 (−5.0;-0.5)	.630
Diff UpwardR 0 D (°)	2.0 (1.0; 5.0)	2.0 (0.5; 3.5)	.082
UpwardR 45 D (°)	1.5 (0.0; 3.5)	−0.5 (−2.5; 0.0)	.0001*
Diff UpwardR 45 D (°)	2.5 (0.5; 4.0)	1.5 (0.5; 2.5)	.032*
UpwardR 90 D (°)	14.0 (12.5; 16.0)	14.0 (12.5; 15.0)	.717
Diff UpwardR 90 D (°)	1.0 (0.5; 2.0)	0.5 (0.5; 1.5)	.004*
UpwardR 120 D (°)	33.5 (30.5; 35.5)	36.0 (34.0; 38.5)	.0001*
Diff UpwardR 120 D (°)	1.5 (0.5; 2.0)	1.0 (0.5; 1.5)	.0001*

IR, internal rotation; *ER*, external rotation; *Tot Rot*, total rotation; *PM*, forward shoulder posture; *UpwardR*, scapular upward rotation; *D*, dominant; *Diff*, bilateral difference [median value (Q1; Q3); *P* value Wilcoxon test].
*Significant result (P < .05).

were performed to get used to the movement. Then, the test was performed 3 times, with a rest 2 time of 2 minutes between repetitions. Only the best distance (in meters) among the 3 trials was considered for analysis.

Statistical analysis

Statistical analysis was performed using SPSS Statistics (IBM Corp., Armonk, NY, USA). Dominant side values as well as bilateral differences were considered for analysis. The normality of the variables was assessed with a Shapiro–Wilk test. Since the variables were not distributed in a normal way, descriptive data were expressed with the median value as well as the 1st and the 3rd quartile. Differences between preseason and midseason values were assessed with a Wilcoxon signed-rank test. The level of significance was set at $P < .05$ for all the tests.

Results

Comparison between preseason and mid-season

Results of clinical measures are presented in Table I. In comparison to preseason, a significant increase of shoulder external rotation ($P = .0001$) and total rotation range of motion ($P = .001$) were observed on the dominant side of players. This increase was about 6° for both variables considered. However, no significant changes were observed during the season for bilateral difference for both variables ($P > .05$). The opposite was observed for shoulder internal rotation range of motion. No significant difference was observed in absolute value ($P > .05$) but a significant increase of 2° was observed in bilateral difference at midseason in comparison to preseason ($P = .018$) (explained by a decrease in internal rotation on the dominant side). For forward posture, a significant increase of 1 centimeter was observed for absolute value at midseason on the dominant side ($P = .001$) but no change was observed when considering bilateral difference. Finally, concerning scapular upward rotation, significant changes were observed between midseason and preseason for all the ranges of motion considered, except for 0°. Indeed, a decrease of 2° at 45° of abduction ($P = .0001$) as well as an increase of 2.5° at 120° of abduction ($P = .0001$) were observed at midseason on the dominant side. However, bilateral differences concerning scapular motion tended to significantly decrease between 0.5° and 1° for all range of motion considered, except for 0° ($P = .0001$-.032).

Unlike clinical measures, the upper quarter Y-balance test values were not significantly changed between preseason and midseason ($P > .05$) (Table II).

Finally, the maximal distance reached in the single-arm medicine ball throw was significantly increased during season ($P = .003$). Indeed, the median score reached 9.20 meters at the beginning of the season and was about 11.20 at midseason (Table III).

Discussion

The shoulder is a frequently injured body part in volleyball (12%-18%),[2,13,16] mainly due to overuse mechanisms. In prospective studies, it has been reported that 15%-23% of volleyball players were subject to shoulder injuries or shoulder complaints during a season.[13,16,24] The relationship between musculoskeletal adaptations (such as gleno-humeral internal rotation deficit, rotator cuff weakness or scapular dyskinesis) and the occurrence of injuries in overhead athletes has been widely explored throughout the last years in order to be able to detect the injury risk profiles and to implement specific prevention measures.[12,24,42] Nowadays, players often undergo tests during the preseason but few of them are regularly screened during the year. Therefore, the evolution of musculoskeletal adaptations over a mere season is often misunderstood and it remains unclear if an athlete without an injury risk profile at the beginning of the season might be considered as having an increased risk of injury after some months of practice. That is why the objective of this study was to explore the evolution of shoulder range of motion, scapular kinematics, and functional performance between preseason and midseason in young competitive volleyball players.

At the beginning of the season, a decrease in glenohumeral internal rotation as well as an increase in external rotation was observed on the dominant side, in comparison to the nondominant side. An increase of forward posture was also found on the dominant side. Then, scapular upward rotation was decreased at 0° and 45° but increased above 90° on the dominant side in comparison to the nondominant side. The adaptations measured in the current study are in accordance with the adaptations reported in overhead athletes in literature.[12,22,44] However, the standard deviations for all the variables considered are quite high, which means that there is

Table II
Upper quarter Y-balance test values (normalized according to upper limb length) at the beginning of the season (preseason) and at the midseason.

	Preseason	Midseason	*P* value
Medial D	0.96 (0.88; 1.00)	0.95 (0.89; 0.98)	.827
Diff medial	0.05 (0.03; 0.07)	0.03 (0.02; 0.06)	.085
Superolateral D	0.71 (0.62; 0.79)	0.72 (0.62; 0.80)	.124
Diff superolateral	0.05 (0.03; 0.08)	0.05 (0.02; 0.07)	.534
Inferolateral D	0.87 (0.80; 0.95)	0.87 (0.78; 0.95)	.877
Diff inferolateral	0.05 (0.03; 0.09)	0.05 (0.03; 0.10)	.749
Composite D	0.85 (0.79; 0.90)	0.83 (0.79; 0.88)	.462
Diff composite	0.04 (0.02; 0.06)	0.04 (0.02; 0.06)	.695

D, dominant; *Diff*, bilateral difference [median-value (Q1; Q3); *P* value Wilcoxon test].

Table III
Results of single-arm medicine ball throw at the beginning of the season (preseason) and at the midseason [median value (Q1; Q3); *P* value Wilcoxon test].

	Preseason	Midseason	*P* value
Score (in meters)	9.20 (10.30; 11.70)	11.20 (10.20; 13.10)	.003

an important individual variability between the players and strengthens the importance of individual screening.[53]

A decrease in internal rotation as well as an increase in external rotation and total rotation range of motion have been reported in volleyball players after some years practice.[21,40,41] Thomas et al[47] even observed changes in a single season. The current study showed that similar adaptations were observed over the short term (4 months). These changes have been shown to be related to the spike, which requires extreme external rotation range of motion before ball contact and intense eccentric contraction of external rotators during follow-through.[19,54]

The current study shows a significant increase in shoulder external rotation range of motion during the season on dominant side. Since having values of external rotation above 100°[55] or an ER gain superior to 7.5°[1] have been respectively described as a risk factor in swimmers and handball players, this adaptation further increases the risk of being injured in volleyball players too. As for internal rotation, only bilateral differences were significantly influenced during the season, which means that internal rotation is more decreased on the dominant than on the non-dominant side, which could predispose the players to an increased risk of shoulder injuries.[36] However, this difference appears to be inferior to SEM values for this variable and can, therefore, not be considered as clinically relevant.[14]

A significant increase of forward posture was also observed during season. However, no change in bilateral difference was reported between preseason and midseason. An association between asymmetric pectoral shortening and shoulder injuries have been demonstrated in volleyball players.[40] From a biomechanical point of view, an increase in forward shoulder posture results in an increase of scapular anterior tilting, thus decreasing the subacromial space and enhancing the risk of shoulder pain.[32] However, since the difference is quite minor (about 1 centimeter), further explorations will be necessary to understand the evolution of this variable over time.

As for scapular kinematics, as reported by Thomas et al[47] in baseball during a season, the current study reported changes in upward rotation between preseason and midseason. Unlike these authors, no changes were observed at 0° of abduction. Since this position is quite far from any sport gesture, the results seem consistent. But a decrease of upward rotation was observed at 45° of abduction on the dominant side of our population. Nowadays, the influence of scapular dyskinesis on shoulder injuries in overhead athletes is still discussed. Some authors like McKenna et al[35] in swimming or Clarsen et al[12] in handball found an association between scapular dyskinesis and the occurrence of shoulder injuries. Contrariwise, Myers et al[38] in baseball or Asker et al[3] in handball found no correlation between scapular dysfunction and shoulder injuries. As for Struyf et al,[44] they demonstrated, in a 2-year prospective study, that a decrease of scapular upward rotation at 45° and 90° of abduction increased the risk of shoulder injuries in recreational overhead athletes.

The current study also observed a decrease of scapular upward rotation at 45° as well as an increase at 120° of abduction during the season. This observation can be correlated with the results of Hosseinimehr et al[29] who found an increase of upward rotation at 90° and 135° of elevation in the dominant arm of overhead athletes, in comparison with the nondominant arm, after some years of practice. This increase in upward rotation was considered by Myers et al[37] to be a beneficial adaptation to help clear the acromion from the subacromial structures, thus decreasing the risk of shoulder impingement and injuries. Then, the current study observed that side-to-side differences for scapular upward rotation tended to slightly decrease at 45°, 90°, and 120° of elevation during season (from 0.5 to 1°). This observation could be explained by undergoing bilateral movements during practice or by the exercises performed during the strength and conditioning sessions. Although prevention exercises were not done throughout the duration of the study, the players still performed some strength and conditioning exercises with their trainers. However, this decrease in bilateral difference is not clinically relevant and might not have any consequences in practice.

Considering functional performance, no significant difference was found between preseason and midseason for the upper quarter Y-balance test results. However, despite becoming more and more popular over the last years, the relationship between this test and the occurrence of shoulder injuries has not been clearly defined yet.[50] Borms et al[7] observed a correlation between scores in the superolateral direction and isokinetic external rotators strength while Westrick et al[57] found a significant relationship between this test and trunk endurance. This test involves shoulder stability, mobility, proprioception but also core stability, which makes the results sometimes difficult to interpret.[25,57] Volleyball gestures are always performed in open-chain position while the upper quarter Y-balance test is performed in a closed-chain position. This may be the reason why no difference was found between preseason and midseason evaluations, despite a high intensity of practice during the season. However, this test could have been interesting to use in order to assess if a decrease in "shoulder stability" occurred on the dominant side during the season.[50] And, according to the results of the current study, this is probably not the case even if future studies will be necessary to confirm this hypothesis.

Finally, the score of the single-arm medicine ball throw was significantly increased during the season. This functional test is closer to volleyball gesture but is more correlated to performance than to the occurrence of shoulder injuries. Indeed, this test has been correlated with both ball velocity during field performance test and absolute peak torque of internal rotators strength in concentric mode.[21,23] The increase observed in the current study can be explained by the important number of spikes and strokes performed and/or by the strength and conditioning sessions performed by the players on a regular basis. This observation can be considered as a positive adaptation designed to increase performance.

In practice, these results show us that significant changes in range of motion, scapular kinematics, and functional performance do not only occur after some years of practice but that those variables can even evolve in some months of practice. Therefore, a single preseason assessment appears to be insufficient in the management of competitive athletes since a player that is not considered as having an atypical profile (or a risk pattern) could be in a different situation at another moment of the season, or the opposite, based on practice and the evolution of training load. External rotation range of motion, scapular dyskinesis and functional performance are recommended to be screened on a regular basis in order to prescribe appropriated exercises, if needed, and to adapt them at different moments of the season according to the athlete's requirements.

This study still presents some limitations. The first one is the variability of the level of practice, with some players performing at national and others at provincial level. The second one is the variability of the age of the players (between 11 and 18 years), including both prepubescent, pubescent, and postpubescent players. In adolescents players, growth and puberty have an important impact on strength, flexibility and, motor control, and changes can be observed in a short period, especially around growth spurts.[26,27] This factor may also have influenced the results obtained.

Conclusion

This study highlighted that changes in shoulder range of motion, scapular upward rotation, and functional performance can occur after some months of practice in young competitive volleyball players.

Firstly, significant changes in clinical shoulder measures were observed between preseason and midseason ($P < .001$). A significant increase in bilateral shoulder internal rotation difference as well as a significant increase in shoulder external rotation and total rotation range of motion has been reported at midseason. An increase in forward shoulder posture was also observed.

Secondly, concerning scapular kinematics, in comparison to preseason, scapular upward rotation was significantly decreased at 45° and increased at 120° of abduction at midseason. Since all of these factors (except scapular upward rotation at 120°) have been described as risk factors of shoulder injuries,[12,44] they have to be seriously considered and regularly assessed in the follow-up of athletes.

Finally, for the functional tests, a significant increase was observed at midseason for the single-arm medicine ball throw, in comparison to preseason. This increase can be considered as a positive adaptation aimed at increasing ball velocity and performance. No change was noted for the upper quarter Y-balance test values during the season. The usefulness of this test in volleyball players should maybe be reconsidered.

The current study emphasizes the importance, in an individual approach, of a regular screening of the athlete to determine atypical profiles and risk patterns (for which training should be adapted or exercises could be prescribed), which can be modified during the season. In the future, prospective studies will be necessary to determine at which frequency the evaluations would have to be done.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Achenbach L, Laver L, Walter SS, Zeman F, Kuhr M, Krutsch W. Decreased external rotation strength is a risk factor for overuse shoulder injury in youth elite handball athletes. Knee Surg Sports Traumatol Arthrosc 2020;28:1202-11. https://doi.org/10.1007/S00167-019-05493-4.
2. Agel J, Palmieri-Smith RM, Dick R, Wojtys EM, Marshall SW. Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association injury surveillance system, 1988-1989 through 2003-2004. J Athl Train 2007;42:295-302.
3. Asker M, Waldén M, Källberg H, Holm LW, Skillgate E. Preseason clinical shoulder test results and shoulder injury rate in adolescent elite handball players: a prospective study. J Orthop Sports Phys Ther 2020;50:67-74. https://doi.org/10.2519/jospt.2020.9044.
4. Astolfi MM, Struminger AH, Royer TD, Kaminski TW, Swanik CB. Adaptations of the shoulder to overhead throwing in youth athletes. J Athl Train 2015;50:726-32. https://doi.org/10.4085/1062-6040-50.1.14.
5. Bere T, Kruczynski J, Veintimilla N, Hamu Y, Bahr R. Injury risk is low among world-class volleyball players: 4-year data from the FIVB injury surveillance system. Br J Sports Med 2015;49:1132-7. https://doi.org/10.1136/bjsports-2015-094959.
6. Borms D, Cools A. Upper-extremity functional performance tests: reference values for overhead athletes. Int J Sports Med 2018;39:433-41. https://doi.org/10.1055/a-0573-1388.
7. Borms D, Maenhout A, Cools AM. Upper quadrant field tests and isokinetic upper limb strength in overhead athletes. J Athl Train 2016;51:789-96. https://doi.org/10.4085/1062-6050-51.12.06.
8. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete. Sport Med 2008;38:17-36. https://doi.org/10.2165/00007256-200838010-00003.
9. Borstad JD, Ludewig PM. The Effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sport Phys Ther 2005;35:227-38. https://doi.org/10.2519/jospt.2005.35.4.227.
10. Burn MB, McCulloch PC, Lintner DM, Liberman SR, Harris JD. Prevalence of scapular dyskinesis in overhead and nonoverhead athletes: a systematic review. Orthop J Sport Med 2016;4:2325967115627608. https://doi.org/10.1177/2325967115627608.
11. van Cingel R, Kleinrensink G, Stoeckart R, Aufdemkampe G, de Bie R, Kuipers H. Strength values of shoulder internal and external rotators in elite volleyball players. J Sport Rehabil 2006;15:236-45. https://doi.org/10.1123/jsr.15.3.236.
12. Clarsen B, Bahr R, Andersson SH, Munk R. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. Br J Sport Med 2014;48:1327-33.
13. Clarsen B, Bahr R, Heymans MW, Engedahl M, Midtsundstad G, Rosenlund L, et al. The prevalence and impact of overuse injuries in five Norwegian sports: application of a new surveillance method. Scand J Med Sci Sports 2015;25:323-30.
14. Cools AM, De Wilde L, van Tongel A, Ceyssens C, Ryckewaert R, Cambier DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. J Shoulder Elbow Surg 2014;23:1454-61. https://doi.org/10.1016/j.jse.2014.01.006.
15. Cools AM, Maenhout AG, Vanderstukken F, Declève P, Johansson FR, Borms D. The challenge of the sporting shoulder: from injury prevention through sport-specific rehabilitation toward return to play. Ann Phys Rehabil Med 2021;64:101384. https://doi.org/10.1016/j.rehab.2020.03.009.
16. Cuñado-González Á, Martín-Pintado-Zugasti A, Rodríguez-Fernández ÁL. Prevalence and factors associated with injuries in elite Spanish volleyball. J Sport Rehabil 2019;28:796-802. https://doi.org/10.1123/jsr.2018-0044.
17. Downar JM, Sauers EL. Clinical measures of shoulder mobility in the professional baseball player. J Athl Train 2005;40:23-9.
18. Ellenbecker T, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. J Sci Med Sport 2003;6:63-70. https://doi.org/10.1016/S1440-2440(03)80009-9.
19. Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. Sports Med 2009;39:569-90. https://doi.org/10.2165/00007256-200939070-00004.
20. Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. Sport Med 1996;21:421-37.
21. Forthomme B. Exploration musculaire isocinétique de l'épaule. Université de Liége: Liége; 2005.
22. Forthomme B, Crielaard JM, Croisier JL. Scapular positioning in athlete's shoulder: Particularities, clinical measurements and implications. Sport Med 2008;38:369-86. https://doi.org/10.2165/00007256-200838050-00002.
23. Forthomme B, Crielaard JM, Forthomme L, Croisier JL. Field performance of javelin throwers: relationship with isokinetic findings. Isokinet Exerc Sci 2007;15:195-202. https://doi.org/10.3233/IES-2007-0273.
24. Forthomme B, Wieczorek V, Frisch A, Crielaard J-M, Croisier J-L. Shoulder pain among high-level volleyball players and preseason features. Med Sci Sport Exerc 2013;45:1852-60. https://doi.org/10.1249/MSS.0b013e318296128d.
25. Gorman PP, Butler RJ, Plisky PJ, Kiesel KB. Upper quarter Y balance test. J. Strength Cond Res 2012;26:3043-8. https://doi.org/10.1519/JSC.0b013e3182472fdb.
26. Granados A, Gebremariam A, Lee JM. Relationship between timing of peak height velocity and pubertal staging in boys and girls. J Clin Res Pediatr Endocrinol 2015;7:235. https://doi.org/10.4274/JCRPE.2007.
27. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocr Rev 2018;39:803-29. https://doi.org/10.1210/er.2018-00020.

28. Hibberd EE, Laudner KG, Kucera KL, Berkoff DJ, Yu B, Myers JB. Effect of swim training on the physical characteristics of competitive adolescent swimmers. Am J Sports Med 2016;44:2813-9. https://doi.org/10.1177/0363546516669506.
29. Hossein Hosseinimehr S, Anbarian M, Asghar Norasteh A, Fardmal J, Taghi Khosravi M. The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. Man Ther 2015;20:758-62. https://doi.org/10.1016/j.math.2015.02.010.
30. Johnson VL, Halaki M, Ginn KA. The use of surface electrodes to record infraspinatus activity is not valid at low infraspinatus activation levels. J Electromyogr Kinesiol 2011;21:112-8. https://doi.org/10.1016/j.jelekin.2010.08.007.
31. Kibler WB, Chandler TJ, Livingston BP, Roetert EP. Shoulder range of motion in elite tennis players. Effect of age and years of tournament play. Am J Sports Med 1996;24:279-85.
32. Kibler BW, Sciascia A, Wilkes T. Scapular dyskinesis and its relation to shoulder injury. J Am Acad Orthop Surg 2012;20:364-72. https://doi.org/10.5435/JAAOS-20-06-364.
33. Lewis JS, Green A, Wright C. Subacromial impingement syndrome: the role of posture and muscle imbalance. J Shoulder Elbow Surg 2005;14:385-92. https://doi.org/10.1016/j.jse.2004.08.007.
34. Liaghat B, Bencke J, Zebis MK, Sørensen H, Myklebust G, Wedderkopp N, et al. Shoulder rotation strength changes from preseason to Midseason: a cohort study of 292 youth elite handball players without shoulder problems. J Orthop Sport Phys Ther 2020;50:381-7. https://doi.org/10.2519/JOSPT.2020.9183.
35. McKenna L, Straker L, Smith A. Can scapular and humeral head position predict shoulder pain in adolescent swimmers and non-swimmers? J Sports Sci 2012;30:1767-76. https://doi.org/10.1080/02640414.2012.718092.
36. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. Clin J Sport Med 2007;17:215-9. https://doi.org/10.1097/JSM.0b013e3180592a48.
37. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. Am J Sports Med 2005;33:263-71. https://doi.org/10.1177/0363546504268138.
38. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. J Shoulder Elbow Surg 2013;22:1154-9. https://doi.org/10.1016/j.jse.2012.12.029.
39. Pluim BM, Staal JB, Windler GE, Jayanthi N. Tennis injuries: occurrence, aetiology, and prevention. Br J Sports Med 2006;40:415-23. https://doi.org/10.1136/bjsm.2005.023184.
40. Reeser JC, Joy EA, Porucznik CA, Berg RL, Colliver EB, Willick SE. Risk factors for volleyball-related shoulder pain and dysfunction. PM R 2010;2:27-36. https://doi.org/10.1016/j.pmrj.2009.11.010.
41. Schleichardt A, Erber C, Wolfarth B, Beyer CN, Ueberschär O. Physiological adaptations in the dominant and non-dominant shoulder in male competitive junior volleyball players. Sport Orthop Traumatol 2019;35:22-30. https://doi.org/10.1016/j.orthtr.2019.01.007.
42. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. J Shoulder Elbow Surg 2015;24:1005-13. https://doi.org/10.1016/j.jse.2015.03.012.
43. Shanley E, Thigpen CA, Clark JC, Wyland DJ, Hawkins RJ, Noonan TJ, et al. Changes in passive range of motion and development of glenohumeral internal rotation deficit (GIRD) in the professional pitching shoulder between spring training in two consecutive years. J Shoulder Elbow Surg 2012;21:1605-12. https://doi.org/10.1016/j.jse.2011.11.035.
44. Struyf F, Nijs J, Meeus M, Roussel N, Mottram S, Truijen S, et al. Does scapular positioning predict shoulder pain in recreational overhead athletes? Int J Sports Med 2013;35:75-82. https://doi.org/10.1055/s-0033-1343409.
45. Taylor JB, Wright AA, Smoliga JM, DePew JT, Hegedus EJ. Upper-extremity physical-performance tests in college athletes. J Sport Rehabil 2016;25:146-54. https://doi.org/10.1123/jsr.2014-0296.
46. Thomas SJ, Swanik KA, Swanik CB, Huxel KC, Iv JDK. Change in glenohumeral rotation and scapular position after competitive high school baseball. J Sport Rehabil 2010;19:125-35. https://doi.org/10.1123/jsr.19.2.125.
47. Thomas SJ, Swanik CB, Swanik K, Kelly JD. Change in glenohumeral rotation and scapular position after a Division I collegiate baseball season. J Sport Rehabil 2013;22:115-21.
48. Tonin K, Stražar K, Burger H, Vidmar G. Adaptive changes in the dominant shoulders of female professional overhead athletes. Int J Rehabil Res 2013;36:228-35. https://doi.org/10.1097/MRR.0b013e32835d0b87.
49. Tooth C, Gofflot A, Schwartz C, Croisier JL, Beaudart C, Bruyère O, et al. Risk factors of overuse shoulder injuries in overhead athletes: a systematic review. Sports Health 2020;12:478-87. https://doi.org/10.1177/1941738120931764.
50. Tooth C, Schwartz C, Ann C, Croisier J-L, Gofflot A, Stephen B, et al. Upper limb functional testing in athletes: a Delphi study. Shoulder Elb 2022;175857322211018. https://doi.org/10.1177/17585732221101880.
51. Tooth C, Schwartz C, Colman D, Croisier J-L, Bornheim S, Brüls O, et al. Kinesiotaping for scapular dyskinesis: the influence on scapular kinematics and on the activity of scapular stabilizing muscles. J Electromyogr Kinesiol 2020;51:102400. https://doi.org/10.1016/j.jelekin.2020.102400.
52. Turgut E, Colakoglu FF, Baltaci G. Scapular motion adaptations in junior overhead athletes: a three-dimensional kinematic analysis in tennis players and non-overhead athletes. Sport Biomech 2019;18:308-16. https://doi.org/10.1080/14763141.2017.1409256.
53. Verhagen E, Van Dyk N, Clark N, Shrier I. Do not throw the baby out with the bathwater; screening can identify meaningful risk factors for sports injuries. Br J Sport Med 2018;52:1223-4. https://doi.org/10.1136/bjsports-2017-098547.
54. Wagner H, Tilp M, Von Duvillard SPV, Mueller E. Kinematic analysis of volleyball spike jump. Int J Sports Med 2009;30:760-5. https://doi.org/10.1055/s-0029-1224177.
55. Walker H, Gabbe B, Wajswelner H, Blanch P, Bennell K. Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. Phys Ther Sport 2012;13:243-9. https://doi.org/10.1016/j.ptsp.2012.01.001.
56. Watkins J, Green Msc BN. Volleyball injuries: a survey of injuries of Scottish National League male players. Br J Sports Med 1992;26:135-7.
57. Westrick RB, Miller JM, Carow SD, Gerber JP. Exploration of the y-balance test for assessment of upper quarter closed kinetic chain performance. Int J Sports Phys Ther 2012;7:139-47.
58. Wolfe H, Poole K, Tezanos AGV, English R, Uhl TL. Volleyball overhead swing volume and injury frequency over the course of a season. Int J Sports Phys Ther 2019;14:88-96. https://doi.org/10.26603/ijspt20190088.