Journal of Athletic Training 2014;49(3):338–344
doi: 10.4085/1062-6050-49.2.05

www.natajournals.org

original research

Strength Asymmetry of the Shoulders in Elite Volleyball Players

Vedran Hadzic, MD*; Tine Sattler, PhD*; Matjaž Veselko, PhD, MD†; Goran Markovic, PhD‡; Edvin Dervisevic, PhD, MD*

*Faculty of Sport, University of Ljubljana, Slovenia; †Department of Traumatology, University Clinical Centre Ljubljana, Slovenia; ‡School of Kinesiology, Motor Control, and Human Performance Laboratory, University of Zagreb, Croatia

Context: Volleyball players are reported to have shoulder strength imbalances. Previous authors have primarily investigated small samples of male players at a single skill level, without considering playing position, and with inconsistent findings.

Objective: To evaluate shoulder strength asymmetry and a history of shoulder injury in a large sample of professional volleyball players of both sexes across different playing positions and skill levels.

Design: Descriptive laboratory study.

Patients or Other Participants: A sample of 183 volleyball players (99 men, 84 women).

Main Outcome Measure(s): We assessed shoulder internal-rotator and external-rotator concentric strength at 60°/s using an isokinetic dynamometer and dominant-nondominant differences in shoulder strength and strength ratios using repeated-measures analyses of variance. Peak torque was normalized for body mass and external-rotation/internal-rotation concentric strength.

Results: Internal-rotation strength was asymmetric in favor of the dominant side in both sexes, regardless of previous shoulder injury status. Male volleyball players had a lower shoulder strength ratio on the dominant side, regardless of previous shoulder injury status. However, this finding was valid only when hand dominance was taken into account. Female volleyball players playing at a higher level (ie, first versus second division) were 3.43 times more likely to have an abnormal strength ratio. Playing position was not associated with an abnormal shoulder strength ratio or strength asymmetry.

Conclusions: In male volleyball players, the external-rotation/internal-rotation strength ratio of the dominant shoulder was lower, regardless of playing position, skill level, or a previous shoulder injury. In female players, the ratio was less only in those at a higher skill level. Although speculative, these findings generally suggest that female volleyball players could have a lower risk of developing shoulder-related problems than male volleyball players. Isokinetic shoulder testing may reveal important information about the possible risk factors for shoulder injuries, so we recommend including it in the functional screening of volleyball players.

Key Words: isokinetic testing, muscle imbalances, injury prevention, muscle strength

Key Points

- Male volleyball players had a lower external-rotation/internal-rotation strength ratio of the dominant shoulder.
- Female volleyball players at a higher skill level were 2.5 times more likely to have abnormal strength ratios.
- When analyzing shoulder strength findings, we must consider hand dominance.
- Functional screening of volleyball players could include isokinetic testing.

Isokinetic strength testing can play an important part in the comprehensive evaluation and rehabilitation of a patient with a shoulder injury.[1] Of all the muscle groups of the shoulder, evaluation of the shoulder external rotators (ERs) and internal rotators (IRs) is most informative because those muscle groups are responsible for dynamic stabilization of the glenohumeral joint.[2] One possible mechanism leading to shoulder injury may be a strength imbalance between those muscles,[3] which is easily assessed using isokinetic strength testing. Differences in IR and ER strength ratios appear to be related to injury in almost all players whose sports involve overhead throwing activities, such as baseball,[4] water polo,[5] tennis,[6] handball,[7] and volleyball.[8] In volleyball, strength of the ERs and IRs is related to either serving or spiking performance, which are both important elements of success in volleyball; IR concentric strength correlates well with volleyball spike velocity.[9]

Considering the asymmetric nature of shoulder movements in volleyball, one would expect that volleyball practice itself causes strength imbalances that present in the form of strength asymmetries between the dominant (D) and nondominant (ND) shoulders and abnormal strength ratios between the ERs and IRs. An asymptomatic overhead athlete should have IRs that are 3% to 9% stronger in the D shoulder than in the ND shoulder, whereas ER strength may be weaker, in the range of 0% to 14%, compared with the ND side.[10] Shoulder strength asymmetry above this threshold can be an injury risk factor and is characteristic of volleyball players with shoulder problems.[11,12] Our literature search revealed several groups that have evaluated the ER and IR strength of both shoulders in volleyball players[11–17] (Table 1). Most of these authors investigated

Table 1. Isokinetic Strength of the Internal and External Shoulder Rotators of Male and Female Volleyball Players With Strength Ratios Measured at 60°/s

Authors, Year	Country, Playing Level	Sex	No.	Age, y	Body Mass, kg	Internal Rotation, Nm			External Rotation, Nm			Strength Ratio, External Rotators/ Internal Rotators	
						D	ND	Difference, %[a]	D	ND	Difference, %	D	ND
Alfredson et al,[13,14] 1998	Sweden	F	11	22	68.8	40	38	5.7[b]	29	30	−2.8	0.72[b]	0.79
Wang et al,[17] 2000[c]	England national team	M	10	20	85.9	194	168	13.4[b]	128	158	−23.4[b]	0.67[b]	0.98
Gozlan et al,[15] 2006	NA	M	9	29	NA	58	61	−5.5	29	32	−10.1	0.50	0.52
Witvrouw et al,[11] 2000	Belgian male volleyball team	M	12	26	89.0	85	77	9.4	57	52	8.8	0.67	0.68
Michael et al,[16] 2003	German state league	M	16	29	78.5	48	41	14.6[b]	40	39	2.5	0.83	0.95
		F	13	26	60.7	22	21	4.6	26	21	19.2[b]	1.18	1.00
Wang and Cochrane,[12] 2001[c]	England elite volleyball players	M	16	NA	86.4	208	175	15.9[b]	150	183	−22.0[b]	0.73	1.06
Current study, 2014	Slovenian first and second divisions	M	99	24	85.2	74.2	69	7.0[b]	45	43	2.9	0.61[b]	0.63
		F	84	22	68.0	39.4	37	6.8[b]	29	26	9.9[b]	0.74	0.71

Abbreviations: D, dominant; F, female; M, male; NA, not available; ND, nondominant.

[a] Bilateral strength difference with negative value reflecting a stronger ND side.

[b] Difference between D and ND.

[c] Strength ratio was reported in the article. Strength values were reported in newtons and extracted from the article.

male players,[11,12,15–17] and only 3 of them[13,14,16] also provided data for female players. Notably, the samples of volleyball players in those studies were relatively small (range, 9–29 players) and involved athletes at a single skill level without distinguishing among different playing positions. Thus, their findings may not apply to all volleyball players. Further, the findings of previous studies are inconsistent, as some researchers[11,15] did not report strength asymmetry and others[12–14,16,17] concluded that IR strength on the D side was stronger than that on the ND side. Disagreement also exists with regard to ER strength, as greater values have been reported on the ND side[12,17] and the D side.[16] Methodologic concerns, including the type of dynamometer used, glenohumeral joint positioning, and data-processing software, could be responsible for these inconsistencies in the literature.[18,19]

The main aim of our study was to evaluate the existence of strength asymmetry of the ERs and IRs in a large sample of professional volleyball players of both sexes. Unlike previous authors, we investigated both the absolute difference (ie, left-to-right difference, regardless of hand dominance) and the relative difference (ie, the difference based on limb dominance) in the strength of the ERs and IRs. We also evaluated the strength asymmetry of the ERs and IRs across different skill levels and playing positions. Because shoulder muscle imbalances as represented by a low ER/IR strength ratio are related to shoulder injury prevalence,[8] we also evaluated the associations between the abnormal strength ratio and different playing positions and skill levels. Our results obtained on a representative sample of volleyball players of both sexes could be of interest to clinicians, coaches, physical conditioning specialists, and health care professionals as reference values for shoulder ER and IR strength for rehabilitation, training, and selection purposes in volleyball.

METHODS

Participants

A sample of 183 volleyball players (99 men and 84 women) from the Slovenian first and second national divisions without a history of shoulder pain in the previous 3 months volunteered for the research. Before testing, each volunteer signed a consent form for participation in research and was informed about the purpose of the research. The study was approved by the Board of Ethics of the Faculty of Sport, University of Ljubljana. Each player completed an enrollment questionnaire concerning previous shoulder injuries, hand dominance, playing position, level of play, and hours of training. The *D hand* was defined as the hand used to serve or spike.

Design

In this cross-sectional descriptive laboratory study, we performed isokinetic strength testing of ER and IR rotation on healthy volleyball players.

Procedures

The measurements were performed on an isokinetic dynamometer (model REV 9000; Technogym, Forli, Italy) at the Faculty of Sport, University of Ljubljana, by the same experienced examiner. Using this dynamometer, the examiner's mean intraclass correlation coefficient for reproducibility of shoulder strength testing ranged from 0.80 to 0.94, and the standard error of measurement ranged from 6.0% to 9.9%.[20] Testing was performed over a period of 4 weeks toward the end of the competitive season, and players from the same club were tested on the same day. No practice was allowed 1 day before the testing. Before players were tested each day, the examiner calibrated the

Figure. Illustration of the general posture of the participant during the test.

dynamometer using the isometric contraction mode with a standard calibration weight. The examiner used a standard shoulder attachment and calibrated the system before each test session to fit the allowable limits for the right or left arm. The ERs and IRs of the D and ND shoulders were assessed in sitting position, with the arm abducted to 90° and in the scapular plane with the elbow flexed to 90° (Figure). For the measurements, the range of motion was set to 60° (90°–30°) of external rotation. The selected isokinetic speed was 60°/s in the concentric mode of contraction. The test was initiated at 90° of external rotation; internal rotation was the first movement tested for the 5 repetitions. This testing sequence was preceded by familiarization at 60°/s and by 3 submaximal trials in the selected speed, followed by a 1-minute rest before trials. Previous authors[11,12,14–16] tested volleyball players at 2 testing velocities (60°/s and 180°/s), with differences most often found at the lower testing velocity. Our decision to test using a single velocity was based on those findings as well as on the number of participants and possible feasibility issues, because testing at 2 velocities would have doubled the testing time. After a 5-minute break that allowed a change of sides, the testing was repeated on the other shoulder using the same testing protocol. The participant was allowed to see the torque curve on the display during the measurements and was given consistent verbal encouragement throughout the testing protocol.

We assessed body height and body mass using a stadiometer and scale (models 222 and 762, respectively; Seca Instruments Ltd, Hamburg, Germany) and skinfolds using Harpenden skinfold calipers (Holtain Ltd, Crosswell, Crymych, United Kingdom). From 7 skinfold measures, we calculated the body fat percentage.[21]

Statistical Analyses

We obtained data from the dynamometer evaluation report for the D and ND limbs. A contraction with the highest peak torque value (Nm) was used in the later analyses. Torque was normalized for body weight (Nm/kg).[22] We calculated the concentric strength ratio (ER/IR) for the D and ND limbs, as well as the ER/IR strength asymmetry between the D and ND sides. Strength asymmetry was calculated using the formula $1 - (ND_{strength}/D_{strength})$ and expressed as a percentage. For absolute strength, we rearranged the asymmetry data according to laterality (left or right side), regardless of the hand dominance reported by the player, and repeated the calculations.

We used 2 repeated-measures analyses of variance to evaluate (1) the difference in muscle strength of the ERs and IRs and the strength ratio (ER/IR) between the D and ND sides and (2) the absolute difference between the right and left sides, regardless of hand dominance. To explore possible differences among participants with regard to the level of play (first or second division) and playing position (libero, opposite, blocker, receiver, setter), we used these between-subjects factors in a model with a Bonferroni correction for multiple comparisons (the analysis-of-variance model was set as 2 [dominance: D or ND] × 2 [level of play: first or second division] × 5 [playing position: libero, opposite, blocker, receiver, or setter]). The association between the abnormal strength ratio of the D and ND shoulders and different levels of play and playing positions was evaluated using a χ^2 test. A strength ratio was defined as abnormal if it was below 0.60 or above 0.75, based on the general recommendations proposed by Ellenbecker and Davies[1]; strength asymmetry was defined as abnormal when the difference between the shoulder ER or IR in the 2 arms exceeded 15%.[10,12] All calculations were performed using SPSS for Windows (version 17.0; SPSS Inc, Chicago, IL). A significance level of .05 was used for all tests.

RESULTS

The main characteristics of the players are presented in Table 2. Note that the players of both sexes were proportionally distributed according to the different levels of play and playing positions. The prevalence of a previous shoulder injury was 9.1% in the male and 7.1% in the female volleyball players.

The results of strength testing of IR and ER (normalized for body mass) along with the strength ratios (ER/IR) are shown in Table 3. We observed differences between the D and ND shoulders for IR (in favor of the D side) in male and female players, regardless of any previous shoulder injury. However, this significant strength asymmetry of the IRs was associated with concomitant strength asymmetry of

Table 2. Main Characteristics of the Volleyball Players

Variable	Males (n = 99)	Females (n = 84)
Playing level, No. (%)		
First division	55 (55.6)	52 (61.9)
Second division	44 (44.4)	32 (38.2)
Playing position, No. (%)		
Libero	8 (8.1)	12 (14.3)
Opposite	17 (17.2)	17 (20.2)
Blocker	26 (26.3)	20 (23.8)
Receiver	28 (28.3)	22 (26.2)
Setter	20 (20.2)	13 (15.5)
Age, y	23.7 ± 5.2	22.2 ± 4.0
Height, cm	188.9 ± 7.0	175.1 ± 6.8
Weight, kg	85.2 ± 10.0	68.0 ± 8.2
Body fat, %	10.8 ± 2.8	21.5 ± 3.7
Training, h/d	1.7 ± 0.6	1.3 ± 0.6
Hand dominance, No.		
Left	6	6
Right	93	78
Previous shoulder injury, No.		
First division	5	4
Second division	4	2

the ERs only in female players without a history of shoulder injury. None of the male players or the female players with a history of shoulder injury demonstrated differences in ER strength of the D versus ND shoulder ($P > .05$). This resulted in a lower strength ratio of the D shoulder in comparison with the ND shoulder in male players, both those without a history of shoulder injury (0.61 versus 0.63; $F = 5.73$, $P < .05$) and those with a history of shoulder injury (0.57 versus 0.65; $F = 8.99$, $P < .05$), whereas in female players, the strength ratio was not different between the D and ND sides, regardless of any history of shoulder injury. We noted no interaction effect with the covariates (ie, level of play or playing position).

When we disregarded hand dominance, we found a difference in ER strength only between the left and right sides in male volleyball players without a previous shoulder injury ($F = 5.05$, $P < .05$) and, consequently, no difference in the strength ratio between the left and right shoulders ($F = 2.90$, $P = .09$). This finding is directly opposite to what we observed when we considered dominance (see the previous paragraph), suggesting that hand dominance is an important factor when analyzing shoulder strength in volleyball players.

An abnormal strength ratio of the D shoulder and level of play were associated only in female volleyball players without a previous shoulder injury ($\chi^2_1 = 6.68$, $P = .01$). Based on the odds ratio, this seems to reflect the fact that female volleyball players from the first division and without a previous shoulder injury were 3.43 times (95% confidence interval = 1.32, 8.89) more likely to have an abnormal ER/IR strength ratio in the D shoulder than their counterparts from the second division. The likelihood of an abnormal strength ratio was not associated with playing position among male or female volleyball players, regardless of previous shoulder injury status, although the frequency of an abnormal strength ratio was highest among the blockers, opposites, and receivers in both sexes. The likelihood of strength asymmetry of either the ERs or IRs was not associated with playing position or level of play, regardless of sex and previous shoulder injury status.

DISCUSSION

The main finding of our study is a strength asymmetry of the IRs in favor of the D side in both male and female volleyball players, regardless of a previous shoulder injury. When such asymmetry in IR strength is not associated with the concomitant strength asymmetry of the ERs, the ER/IR strength ratio of the D shoulder will be less than for the ND shoulder. Put differently, a low ER/IR strength ratio of the D shoulder can result from a strength deficit in external rotation, but both decreased ER and increased IR will influence the ER/IR ratio. Indeed, our results show that among male volleyball players with or without a previous shoulder injury and also among female players with a previous shoulder injury, we found no concomitant strength asymmetry of the ERs. Consequently, the ER/IR strength ratio of the D shoulder was lower only in men when compared with the ND shoulder. However, this was not the case in female players without a previous shoulder injury, in whom the ERs of the D shoulder were stronger than those of the ND shoulder and the ER/IR strength ratio of the D shoulder was not lower. Importantly, this finding was

Table 3. External-Rotator and Internal-Rotator Strength and Strength Ratios of the Dominant (D) and Nondominant (ND) Shoulders (60°/s) in Volleyball Players by Sex and History of Previous Shoulder Injury, Mean ± SD

			Previous Shoulder Injury?			
			Men		Women	
Variable	Side	Strength	Yes	No	Yes	No
Internal rotation	D	PT, Nm	82 ± 9	74 ± 13	42 ± 10	39 ± 8
		PT/BW, Nm/kg	0.94 ± 0.11[a]	0.87 ± 0.13[b]	0.62 ± 0.12[a]	0.58 ± 0.11[b]
	ND	PT, Nm	74 ± 7	69 ± 11	39 ± 7	37 ± 7
		PT/BW, Nm/kg	0.84 ± 0.08	0.81 ± 0.12	0.57 ± 0.09	0.54 ± 0.10
External rotation	D	PT, Nm	47 ± 13	44 ± 10	26 ± 5	29 ± 6
		PT/BW, Nm/kg	0.53 ± 0.13	0.53 ± 0.11	0.39 ± 0.08	0.42 ± 0.08[b]
	ND	PT, Nm	49 ± 8	43 ± 7	25 ± 4	26 ± 5
		PT/BW, Nm/kg	0.55 ± 0.09	0.51 ± 0.08	0.37 ± 0.05	0.38 ± 0.07
Strength ratio	D		0.57 ± 0.11[a]	0.61 ± 0.14[a]	0.63 ± 0.15	0.75 ± 0.15
	ND		0.65 ± 0.08	0.63 ± 0.11	0.65 ± 0.04	0.72 ± 0.15

Abbreviations: BW, body weight; PT, peak torque.

[a] $P < .05$.

[b] $P < .0001$.

valid only when we accounted for hand dominance, suggesting that when analyzing the shoulder strength in volleyball players, we must consider such information as being highly relevant. We also found that female volleyball players without a previous shoulder injury who were playing at a higher skill level (ie, first division) were 3.4 times more likely to have an abnormal strength ratio than their counterparts playing at a lower skill level. Finally, our results suggest that playing position was not associated with an abnormal strength ratio or abnormal strength asymmetry of the ERs or IRs in volleyball players, regardless of sex or a previous shoulder injury.

Compared with data from the literature (Table 1), we conclude that our results agree with previous findings that the IR strength of the D shoulder is higher than that of the ND shoulder in male[12,16,17] and female volleyball players.[13,14] Significant differences between the D and ND internal-rotation strength were reported by Wang and Cochrane[12] and Wang et al,[17] who tested England's elite male volleyball players on 2 occasions and reported that the mean strength values of the IR concentric (and eccentric) contractions on the D side were greater than those on the ND side. Michael et al[16] also observed greater IR strength on the D side only among male volleyball players. However, contrary to Alfredson et al,[13,14] who investigated ER and IR peak torque in 11 female players from the first Swedish division and concluded that the concentric IR peak torque at 60°/s was higher in the D shoulder, Michael et al[16] did not find differences in IR strength in female players. Apart from that study, our results also oppose the findings of Gozlan et al[15] and Witvrouw et al,[11] who reported no differences in ER or IR strength of the D and ND shoulders at 60°/s and 180°/s in male volleyball players. Aside from the previously mentioned methodologic differences related to the type of dynamometer and software used and participant positioning, the observed discrepancies in the results may also be attributed to interstudy differences in sample size, experimental setup, and time of testing during an annual cycle.

With regard to strength asymmetry of the ERs, only Wang and Cochrane,[12] Wang et al,[17] and Michael et al[16] reported differences between the D and ND shoulders. Investigating male volleyball players, Wang and Cochrane[12] and Wang et al[17] demonstrated differences in favor of the ND shoulder, whereas Michael et al,[16] like us, reported stronger ERs of the D shoulder only in female volleyball players. Our results suggest an important sex-related difference with regard to the ER strength asymmetry that seems to be a characteristic of female volleyball players without a previous shoulder injury. Unlike Wang and Cochrane,[12] we did not find statistically important differences in ER strength in men, and 63% of male players without a history of shoulder injury had normal strength asymmetry of the ERs (ie, strength difference within 15%), as proposed by Reinold and Gill[10] and Wang and Cochrane.[12] Female players differed considerably from male players in that more than half of the female players without a previous shoulder injury (56%) had abnormal strength asymmetry. Further, similar to Michael et al,[16] we have shown that among female volleyball players without a previous shoulder injury, the ER strength on the D side was higher than on the ND side. This asymmetry results in a normal ER/IR strength ratio of the D shoulder, which is very important because a study[23] of overhead athletes showed an association between an abnormal ER/IR strength ratio and the incidence of shoulder injury. We can only speculate if this finding could result in a lower shoulder injury rate among female volleyball players; no data are available to identify sex as an independent risk factor for shoulder problems.[24] Unfortunately, at this point, we do not have evidence to explain our observational findings, but possibilities deserving further research are (1) the number of arm swings during rallies in women, (2) the amount and specificity of resistance training, and (3) possible sex-related differences in the spike technique. For example, during maximal external rotation, potential energy is stored by twisting the torso[25]; women may rely more on their shoulder rotatory strength to execute a spike.

Further, we believe that the difference between the statistical and clinical significance of findings should also be raised in relation to our results. The mean differences in IR strength between the D and ND sides in our study were 9.19% ± 13.5% ($P < .05$) and 9.19% ± 19.8% ($P < .05$) for men and women, respectively, without a previous shoulder injury. The mean difference in ER strength between the D and ND sides in players without a previous shoulder injury was almost negligible in men (4.2% ± 17.8%, $P > .05$), whereas in women that difference was 13.3% ± 20.9% ($P < .05$). In spite of some statistically significant differences in the bilateral ER and IR strength (Table 3), all values were below the threshold level of 15% suggested by other authors.[10,12] Thus, although statistically significant, those differences were not large enough to indicate a risk of shoulder injury and become clinically significant.

The ER/IR strength ratio for male volleyball players, regardless of a previous shoulder injury, was lower on the D side (Table 3) and was at the lower border of the general recommendations (0.60–0.75) proposed by Ellenbecker and Davies.[1] In addition, these results clearly highlight the ER weakness of the D (and also ND) shoulder of the studied male volleyball players, as the same authors[1] suggest that ER strength should be increased from approximately two-thirds of the IR to about three-fourths of the IR for overhead athletes. However, a prospective follow-up of male volleyball players is needed to confirm the association between this low ER/IR strength ratio and possible shoulder injury or pain occurrence (or both). Yet the incidence of shoulder injuries alone (ie, without pain) based on the time-loss injury definition may mask the true magnitude of shoulder problems in volleyball players because players may experience shoulder pain and discomfort but continue the training and competition process without reporting an injury. To sum up, our findings support the recommendations of previous authors[12,17] that additional resistance training for concentric and eccentric ER strength of the D shoulder must be emphasized, especially in male and female volleyball players with a history of shoulder injury.

In female players without a previous shoulder injury, the mean strength ratios were in line with general and specific recommendations (D versus ND side: 0.75 versus 0.72, $P >$ .05). However, the likelihood of an improper strength ratio on the D side was higher in the players from the first division (abnormal versus normal strength ratio: 75% versus 25%) than in the players from the second division (abnormal versus normal strength ratio: 47% versus 53%), meaning that female players at higher skill levels and without a history of shoulder injury should be given special attention with regard to the possibility of an abnormal strength ratio.

A final point is that in the current study, playing position was not associated with an abnormal shoulder strength ratio or strength asymmetry. If we assume that the amount of spiking is a risk factor for shoulder problems,[26] then the position-related difference in the number of spikes during a volleyball game[27] would suggest differently. This is particularly evident for setters, who perform considerably fewer attack jumps than other volleyball players.[27] Although the proportion of players at each position was not uniform in our study (Table 2), this seems unlikely to be a major reason for the relatively unexpected result. Variability among players in the timing of position specialization during one's career could be a confounding factor. Further investigation is needed to clarify this important issue.

Our study also has limitations, including a lack of eccentric strength testing. The eccentric strength of the IRs is important in shoulder stabilization during the arm-cocking phase of a volleyball spike, whereas the eccentric strength of the ERs is crucial during the arm-deceleration phase.[8] However, shoulder strength testing in the eccentric mode of contraction has documented reproducibility concerns: some authors[28] report low intraclass correlation coefficients (0.44–0.68) for eccentric testing of the ERs. Apart from this factor, which can be controlled by a proper testing protocol and familiarization, the main reason we omitted eccentric strength testing in our study was related to the number of participants; an additional testing contraction mode or speed would have doubled or tripled the testing time and thereby negatively influenced the feasibility of the study.

In conclusion, our findings highlight some sex-related differences in the isokinetic strength profile of the D versus ND shoulder in volleyball players. The male volleyball players presented with an ER strength deficit that resulted in a lower ER/IR strength ratio of the D shoulder, and this phenomenon was not associated with playing position or skill level. In contrast, among the female players, a smaller ER/IR strength ratio characterized only players at the higher skill level, although in female players in general, a strong IR was associated with a proportional increase in ER strength and normal strength ratio of the D shoulder. This was valid only for female volleyball players without a previous shoulder injury; among their previously injured counterparts, the strength findings were similar to those for the male volleyball players. These results suggest that female volleyball players could have a smaller risk of developing shoulder-related problems than male players, but we believe that prospective epidemiologic studies are needed to confirm such a hypothesis. Finally, isokinetic testing could reveal important information about the possible risk factors for shoulder injuries and could be a part of functional screening of volleyball players. Based on currently available data, the isokinetic evaluation of the shoulder in volleyball players would be best performed bilaterally, at 1 or 2 testing velocities (60°/s and 180°/s), in the concentric mode of contraction, and with hand dominance taken into consideration. The choice of number of testing velocities and contraction modes should depend on the time available for testing. As noted earlier, most previous significant findings occurred at lower concentric velocities, and significant findings in the concentric mode of contraction were always correlated and followed by identical findings in the eccentric mode of contraction. Therefore, we believe that testing at a single low concentric velocity (eg, 60°/s) is sufficient for preliminary screening, and testing at additional velocities or in the eccentric mode of contraction (or both) should be reserved for those participants with abnormal findings during initial testing.

REFERENCES

1. Ellenbecker TS, Davies GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. *J Athl Train*. 2000;35(3):338–350.
2. Hamill J, Knutzen KM. *Biomechanical Basis of Human Movement*. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2003.
3. Noffal GJ. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. *Am J Sports Med*. 2003;31(4):537–541.
4. Ellenbecker TS, Mattalino AJ. Concentric isokinetic shoulder internal and external rotation strength in professional baseball pitchers. *J Orthop Sports Phys Ther*. 1997;25(5):323–328.
5. McMaster WC, Long SC, Caiozzo VJ. Isokinetic torque imbalances in the rotator cuff of the elite water polo player. *Am J Sports Med*. 1991;19(1):72–75.
6. Saccol MF, Gracitelli GC, da Silva RT, et al. Shoulder functional ratio in elite junior tennis players. *Phys Ther Sport*. 2010;11(1):8–11.
7. Andrade Mdos S, Fleury AM, de Lira CA, Dubas JP, da Silva AC. Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *J Sports Sci*. 2010;28(7):743–749.
8. Stickley CD, Hetzler RK, Freemyer BG, Kimura IF. Isokinetic peak torque ratios and shoulder injury history in adolescent female volleyball athletes. *J Athl Train*. 2008;43(6):571–577.
9. 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.
10. Reinold MM, Gill TJ. Current concepts in the evaluation and treatment of the shoulder in overhead-throwing athletes, part 1: physical characteristics and clinical examination. *Sports Health*. 2010;2(1):39–50.
11. Witvrouw E, Cools A, Lysens R, et al. Suprascapular neuropathy in volleyball players. *Br J Sports Med*. 2000;34(3):174–180.
12. Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fitness*. 2001;41(3):403–410.
13. Alfredson H, Nordstrom P, Pietila T, Lorentzon R. Long-term loading and regional bone mass of the arm in female volleyball players. *Calcif Tissue Int*. 1998;62(4):303–308.
14. Alfredson H, Pietila T, Lorentzon R. Concentric and eccentric shoulder and elbow muscle strength in female volleyball players and non-active females. *Scand J Med Sci Sports*. 1998;8(5 pt 1):265–270.
15. Gozlan G, Bensoussan L, Coudreuse JM, et al. Isokinetic dynamometer measurement of shoulder rotational strength in healthy elite athletes (swimming, volley-ball, tennis): comparison between dominant and nondominant shoulder [in French]. *Ann Readapt Med Phys*. 2006;49(1):8–15.
16. Michael J, Konig D, Hessling U, Popken F, Eysel P. Results of shoulder isokinetic testing in volleyball players [in German]. *Sportverletz Sportschaden*. 2003;17(2):71–74.
17. Wang H, Macfarlane A, Cochrane T. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med*. 2000;34(1):39–43.

18. Hupli M, Sainio P, Hurri H, Alaranta H. Comparison of trunk strength measurements between two different isokinetic devices used at clinical settings. *J Spinal Disord*. 1997;10(5):391–397.
19. Schonle C, Kling P, Baumer C, Carstensen S, Kuss A, Lepthin HJ. Software and system-induced errors in isokinetic force measurements [in German]. *Z Orthop Ihre Grenzgeb*. 1995;133(1):84–91.
20. Hadzic V, Ursej E, Kalc M, Dervisevic E. Reproducibility of shoulder short range of motion isokinetic and isometric strength testing. *J Exerc Sci Fitness*. 2012;10(2):83–89.
21. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. *Med Sci Sports Exerc*. 1980; 12(3):175–181.
22. Jaric S, Mirkov D, Markovic G. Normalizing physical performance tests for body size: a proposal for standardization. *J Strength Cond Res*. 2005;19(2):467–474.
23. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375–1382.
24. Krogsgaard MR, Safran MR, Rheinlænder P, Cheung E. Preventing shoulder injuries. In: Bahr R, Engebretsen L, eds. *Sports Injury Prevention*. West Sussex, UK: Blackwell Publishing; 2009:134–152.
25. Reeser JC, Fleisig GS, Bolt B, Ruan M. Upper limb biomechanics during the volleyball serve and spike. *Sports Health*. 2010;2(5):368–374.
26. Reeser JC, Fleisig GS, Cools AM, Yount D, Magnes SA. Biomechanical insights into the aetiology of infraspinatus syndrome. *Br J Sports Med*. 2013;47(4):239–244.
27. Sheppard JM, Gabbett TJ, Stanganelli LC. An analysis of playing positions in elite men's volleyball: considerations for competition demands and physiologic characteristics. *J Strength Cond Res*. 2009; 23(6):1858–1866.
28. Malerba JL, Adam ML, Harris BA, Krebs DE. Reliability of dynamic and isometric testing of shoulder external and internal rotators. *J Orthop Sports Phys Ther*. 1993;18(4):543–552.

Address correspondence to Vedran Hadzic, MD, Faculty of Sport, University of Ljubljana, Gortanova 22, Ljubljana, Ljubljana 1000, Slovenia. Address e-mail to vedran.hadzic@guest.arnes.si.