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Am. J. Sports Med. 2005; 33; 1513 originally published online Jul 11, 2005;
DOI: 10.1177/0363546505274935

Factors Correlated With Volleyball Spike Velocity

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Background: Spike effectiveness represents a determining element in volleyball. To compete at a high level, the player must, in particular, produce a spike characterized by a high ball velocity.

Hypothesis: Some muscular and physical features could influence ball velocity during the volleyball spike.

Study Design: Descriptive laboratory study.

Methods: A total of 19 male volleyball players from the 2 highest Belgian national divisions underwent an isokinetic assessment of the dominant shoulder and elbow. Ball velocity performance (radar gun) during a spike test, morphological feature, and jump capacity (ergo jump) of the player were measured. We tested the relationship between the isokinetic parameters or physical features and field performances represented by spike velocity. We also compared first-division and second-division player data.

Results: Spike velocity correlated significantly with strength performance of the dominant shoulder (internal rotators) and of the dominant elbow (flexors and extensors) in the concentric mode. Negative correlations were established with the concentric external rotator on internal rotator ratio at 400 deg/s and with the mixed ratio (external rotator at 60 deg/s in the eccentric mode on internal rotator at 240 deg/s in the concentric mode). Positive correlations appeared with both the volleyball players' jump capacity and body mass index. First-division players differed from second-division players by higher ball velocity and increased jump capacity.

Conclusion: Some specific strength and physical characteristics correlated significantly with spike performance in high-level volleyball practice.

Clinical Relevance: Our results could provide useful information for training management and propose some reflections on injury prevention.

Keywords: volleyball; muscle strength; spike velocity; isokinetic; shoulder; jump

Volleyball is a complex discipline with high technical, tactical, and athletic demands on the players.[17] Serving, passing, and setting the ball are accompanied with spiking or attacking actions.[7] To achieve success in volleyball, it is desirable to possess a strong offense, and the main form of attack in the modern game is the smash, or spike.[11] Starting with an approach followed by a vertical jump, one of the objectives of the volleyball spike is to hit the ball at the highest possible speed.[21] Unbelievably, a highly skilled attacker with 16 to 20 hours of weekly practice time spikes, for example, about 40 000 times a year.[17]

Considering the various spiking requirements, high-skilled volleyball player management justifies multidisciplinary assessments aimed to optimize performance and contribute to injury prevention. The purposes of this study were as follows: (1) to assess the isokinetic strength developed by the dominant shoulder and elbow of high-level volleyball players, (2) to establish possible relationships between the isokinetic parameters or physical features and field performances such as spike velocity, and (3) to compare volleyball players in the first division (N1) with volleyball players in the second division (N2). Possible implications of our findings for training optimization will obviously take into account shoulder injury prevention and treatment features.

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No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 33, No. 10
DOI: 10.1177/0363546505274935

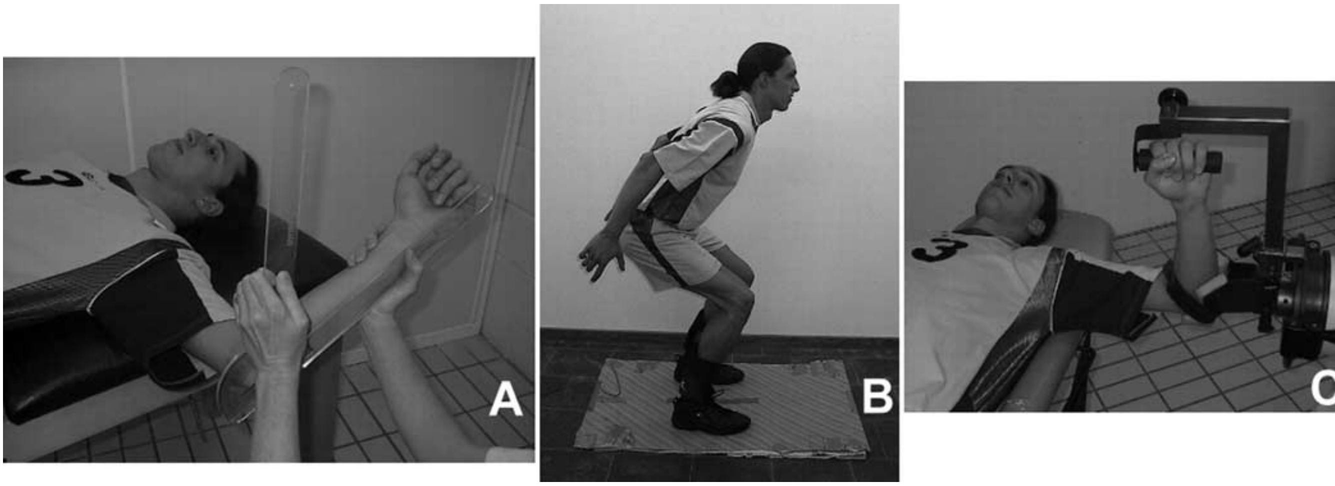

Figure 1. Representation of the passive shoulder rotation measurement (A), the counter-movement jump test (B), and the isokinetic assessment of the shoulder rotator muscles (C).

TABLE 1
Characteristics of Volleyball Players in First Division (N1) and Second Division (N2)[a]

Characteristic	N1	N2	*P*
Age, y	26 ± 5.4	21 ± 3.04	.03
Height, cm	193.9 ± 2.8	191.1 ± 5.6	.17
Body mass, kg	89.5 ± 6.3	85 ± 5.7	.44
Body mass index, kg/m²	23.8 ± 1.5	23.2 ± 3.6	.68
Muscular training per week, h	2.1 ± 1.5	0.25 ± 0.7	.003

[a]Values are presented as means ± SDs; significance level is $P < .05$.

MATERIALS AND METHODS

A total of 19 male frontline volleyball players involved in Belgian competitions participated in the study. Of these 19 players, 11 were N1 players and 8 were N2 players; 16 were right-handed. To be included in the study, all players signed informed consent forms and completed an enrollment questionnaire. The characteristics of the players are displayed in Table 1. Five players had suffered from dominant shoulder tendinosis, based on previous rotator cuff tests and ultrasound evaluation, but none of them experienced any pain during subsequent assessment and testing procedures. The goniometric measurements (Figure 1) of the dominant and nondominant shoulder motion in external and internal rotation were determined; the subject was lying in the supine position with the arm abducted at 90° in the frontal plane (the examiner passively mobilized the joint in a maximal position of rotation). The analysis of content and number of hours dedicated weekly to general muscle strength training was based on a retrospective questionnaire completed under the investigator's supervision.

A 15-minute warm-up included specific mobility and stretching exercises of the shoulders and submaximal spiking trials. Each player was instructed to perform 6 standardized spikes (an approach followed by a vertical jump) at maximal intensity with a 1-minute rest period between trials. The volleyball was controlled systematically with regard to type and inflation characteristics. Standardization was obtained through the participation of an experienced setter; the player had to hit balls toward a delimited target zone (diagonal). A radar gun (Timint Box, Radar Sports, Oceanside, NY) was placed 50 cm behind the opposite corner of the court. Filming analysis (Sony DCR Digital Hi8, Sony Corp, San Diego, Calif) during the spike test allowed us to measure the highest point of the player's hands when he jumped into the air and contacted the ball (Figure 2). The highest ball velocity (km/h) and the corresponding impact height (cm) were chosen among the successive spike trials for each subject.

The counter-movement jump, according to the Bosco method,[6] tested the highest vertical jump (jump height, in cm) and the longest flying time (jump time, in milliseconds) from 3 jump attempts. The apparatus consists of a digital timer (±1 millisecond) connected by a cable to a resistive (or capacitative) platform. The timer is triggered by the subject's feet at the moment of release from the platform and stops at the moment of touchdown.[6] The subject starts from an upright standing position on the platform, and the end of the eccentric phase corresponds to a semisquatting position, with arm assistance throughout the jump test[6] (Figure 1).

Afterward, isokinetic assessment of the dominant shoulder and elbow was conducted on a Cybex Norm dynamometer (Henley Healthcare, Sugarland, Tex). The internal rotators (IR) and external rotators (ER) of the dominant shoulder were assessed in the supine position, with the arm abducted at 90° in the frontal plane and the elbow flexed at 90° (Figure 1). The range of motion reached 50° in internal rotation and 70° in external rotation. The isokinetic speeds selected were 60 deg/s, 240 deg/s, and 400 deg/s in the concentric mode and 60 deg/s in the eccentric mode (3 repetitions at 60 deg/s and 5 repetitions at 240 deg/s and at 400 deg/s in the concentric mode; 4 repetitions at 60 deg/s in the eccentric mode). These testing sequences were preceded by familiarization at 120 deg/s and by 3

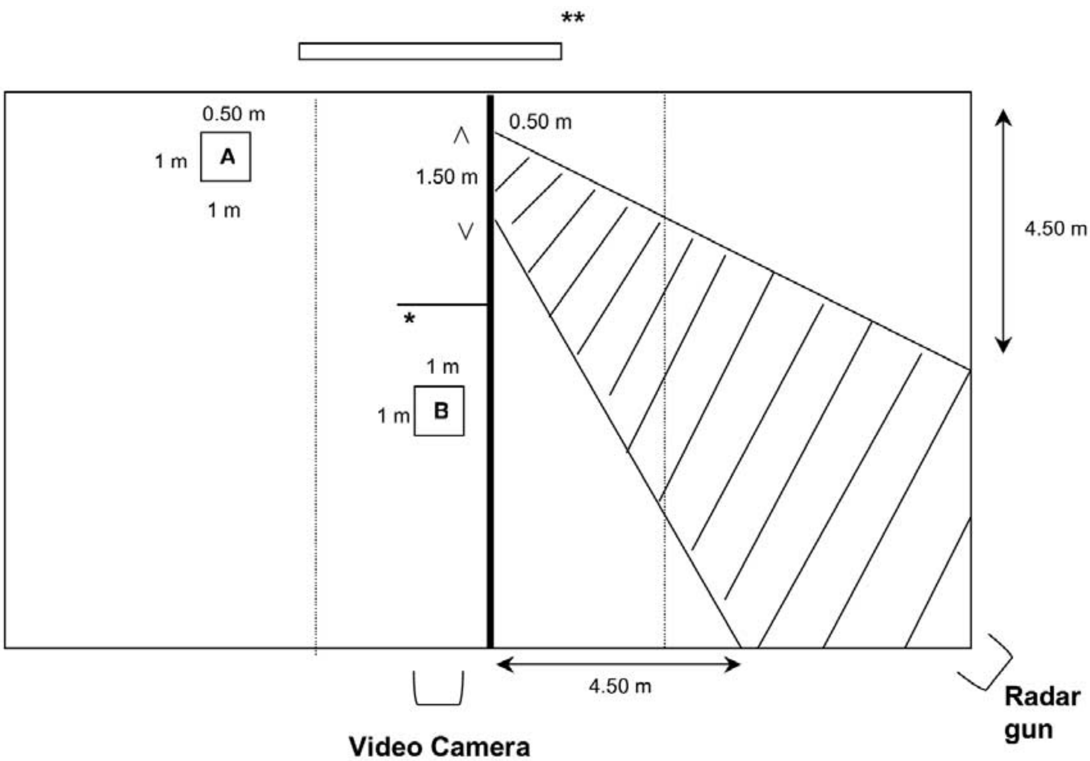

Figure 2. Standardized court organization for the spike test. A, starting zone of the spiker 0.50 m from the left side and 4.50 m from the central line; B, starting zone of the setter 5.25 m from the left side and 0.50 m from the central line; *4.50-m high bracket 3.25 m from the left sideline; **backdrop with a scale, allowing assessment of the height at which the ball was hit.

submaximal trials in the selected speed. Successive testing velocities were separated by 1 minute of rest. The flexors (FLEX) and extensors (EXT) of the dominant elbow were assessed in the supine position, with the arm at 45° of abduction in the frontal plane and the forearm in a neutral position. The range of motion corresponded to 140° of flexion from the full extension. Velocities were 60 deg/s and 180 deg/s in the concentric mode (3 and 5 exertions, respectively) and 60 deg/s in the eccentric mode (4 repetitions). As for the shoulder, the testing sequences were preceded by familiarization at 120 deg/s and 3 submaximal repetitions.

The isokinetic procedure allowed for measuring the absolute peak torque (PT, in N·m) and body mass relative peak torque (PT/kg, in N·m/kg). The ratios (ER/IR, FLEX/EXT) were calculated using the same speed and contraction mode for agonist and antagonist muscle groups. For the shoulder, a mixed ratio (combining ER in the eccentric mode at 60 deg/s and IR in the concentric mode at 240 deg/s) was designed to more accurately approach the relationship of shoulder muscles during the throwing task.[13]

Statistical Analysis

Results were expressed as means ± SDs. Mean values were compared by an unpaired Student *t* test (independent values). The association between 2 variables was measured by the Pearson product moment correlation coefficient. Results were considered to be significant at the 5% critical level ($P < .05$).

RESULTS

If considering the whole group of 19 volleyball players (N1 + N2), the external passive rotation of the dominant shoulder averaged 103° ± 12°, with no significant difference in comparison with the nondominant side (101.2° ± 8.7°). Conversely, the internal passive rotation of the dominant shoulder (65.8° ± 10.5°) was significantly ($P < .05$) lower than that of the nondominant side (71.3° ± 12°). Maximal ball velocity during the spike test reached 96.5 ± 8.9 km/h on average. Maximal height of the jump calculated with the counter-movement jump averaged 54.3 ± 4.6 cm, and maximal flying time of the jump reached 665.1 ± 28 milliseconds.

Isokinetic performances of the dominant shoulder and elbow are displayed in Tables 2 and 3. Classic isokinetic data were confirmed: the strength/velocity curve was compiled for the different shoulder and elbow muscles, and the eccentric mode allowed higher values in contrast to the concentric mode. The ER/IR and FLEX/EXT ratios were all less than 1, except the mixed ER/IR and eccentric FLEX/EXT ratios.

Tables 1 and 4 describe the significant ($P < .05$) differences in physical features, in field performances, and in

TABLE 2[a]
ER and IR Peak Torques of the Dominant Shoulder and ER/IR Ratios

	CONC 60	CONC 240	CONC 400	ECC 60	ECC 60/CONC 240
ER	36.4 ± 7.1[b]	30 ± 6.4[c]	22.3 ± 3.7[d]	45.7 ± 8.7[e]	
IR	52.5 ± 8.7[b]	43.8 ± 8.6[c]	33.9 ± 8.3[d]	60 ± 10.3[b]	
ER/IR	0.70 ± 0.14[b]	0.70 ± 0.15[b]	0.68 ± 0.14[b]	0.77 ± 0.14[b]	1.07 ± 0.23[c]

[a]Values are presented as means ± SDs in N·m. ER, external rotators; IR, internal rotators; CONC, concentric mode; ECC, eccentric mode. Numbers after CONC and ECC represent values in degress per second.
[b,c,d,e]Values represent significant differences ($P < .05$) between modalities of assessment for ER, IR, or ER/IR.

TABLE 3[a]
FLEX and EXT Peak Torques of the Dominant Elbow and FLEX/EXT Ratios

	CONC 60	CONC 180	ECC 60
FLEX	60.6 ± 8.6[b]	47.9 ± 8.3[c]	78.7 ± 15.5[d]
EXT	68.5 ± 15.9[b]	55.4 ± 9.3[c]	77.8 ± 19.6[b]
FLEX/EXT	0.91 ± 0.14[b,c]	0.87 ± 0.1[c]	1.05 ± 0.25[b]

[a]Values are presented as means ± SDs in N·m. FLEX, flexors; EXT, extensors; CONC, concentric mode; ECC, eccentric mode. Numbers after CONC and ECC represent values in degress per second.
[b,c,d]Values represent significant differences ($P < .05$) between modalities of assessment for FLEX, EXT, or FLEX/EXT.

isokinetic performances between the N1 and N2 league levels of the volleyball players. The N1 players were older, but there was no significant difference in the physical examination between the 2 groups. The goniometric passive motion of the dominant and the nondominant shoulders remained in the same range for both N1 and N2 divisions. The N1 players were significantly ($P < .05$) more efficient, providing the highest ball velocity during the strike test and the best jump capacity during both the spike test and the counter-movement jump tests. Compared to the N2 players, the N1 players benefit from longer muscular training per week (2.1 ± 1.5 hours vs 0.25 ± 0.7 hours), even if they have all played volleyball for the same number of years (10.8 ± 4.7 years). Conversely, there was no significant difference for either the absolute and body mass relative PT or the different ratios between N1 and N2 teams, even if the N1 players tended to be stronger in all testing conditions and had lower ratios (classical and mixed ratios).

Table 5 displays the significant ($P < .05$) correlations between the ball velocity during the spike and other measurements. Significant relationships were observed with the IR PT of the dominant shoulder and the FLEX or the EXT PT of the dominant elbow ($0.46 \leq r \leq 0.63$). The ER/IR conventional and the mixed ratios showed a negative correlation: the most efficient players in the spike velocity test had the lowest ER/IR ratios ($-0.52 = r = -0.62$). Jump capacity presented a positive correlation with the best results in the spike test, as did body mass index (kg/m^2)

TABLE 4
Differences in Physical, Field, and Isokinetic Performances Between First-Division (N1) and Second-Division (N2) Players[a]

	N1	N2	*P*
Spike velocity, km/h	100.9 ± 6	90.4 ± 8.3	.005
Impact height, cm	321.8 ± 10.8	305 ± 7.6	.001
Jump time, ms	678.9 ± 27.8	646.1 ± 14.8	.008
Jump height, cm	56.5 ± 4.6	51.2 ± 2.3	.008
Dominant passive shoulder range of motion, deg			
External rotation	103.3 ± 8.7	102.6 ± 16.3	.91
Internal rotation	67.9 ± 9	62.9 ± 12.2	.31
Dominant shoulder			
ER PT CONC 60	37.4 ± 5.8	35 ± 8.9	.47
IR PT CONC 60	54 ± 9.1	50.4 ± 8.2	.39
ER/IR CONC 60 ratio	0.71 ± 0.13	0.70 ± 0.17	.94
ER PT CONC 240	31.1 ± 4.7	28.5 ± 8.3	.40
IR PT CONC 240	45.7 ± 6.3	41.2 ± 10.5	.27
ER/IR CONC 240 ratio	0.69 ± 0.14	0.70 ± 0.17	.93
ER PT CONC 400	22.3 ± 2.3	22.2 ± 5.2	.87
IR PT CONC 400	36.1 ± 7.5	30.9 ± 8.9	.18
ER/IR CONC 400 ratio	0.64 ± 0.12	0.74 ± 0.14	.10
ER PT ECC 60	45.6 ± 7.3	45.9 ± 10.9	.95
IR PT ECC 60	62.1 ± 11.4	57.1 ± 8.2	.31
ER/IR ECC 60 ratio	0.74 ± 0.13	0.80 ± 0.15	.38
ER ECC 60/ IR CONC 240 ratio	1.02 ± 0.24	1.14 ± 0.22	.29
Dominant elbow			
FLEX PT CONC 60	62.6 ± 8.5	57.9 ± 8.4	.24
EXT PT CONC 60	69.4 ± 16.5	67.4 ± 16	.80
FLEX/EXT CONC 60 ratio	0.93 ± 0.14	0.88 ± 0.13	.50
FLEX PT CONC 180	49.7 ± 7.5	45.4 ± 9	.27
EXT PT CONC 180	56.4 ± 5.9	64.1 ± 13.2	.48
FLEX/EXT CONC 180 ratio	0.88 ± 0.1	0.85 ± 0.12	.59
FLEX PT ECC 60	81.8 ± 18.3	74.4 ± 10.1	.31
EXT PT ECC 60	80 ± 17.7	74.8 ± 22.3	.65
FLEX/EXT ECC 60 ratio	1.04 ± 0.20	1.07 ± 0.32	.82

[a]Values are presented as means ± SDs; significance level $P < .05$. ER, external rotators; IR, internal rotators; FLEX, flexors; EXT, extensors; PT, peak torque in N·m; CONC, concentric mode; ECC, eccentric mode. Numbers after CONC and ECC represent values in degress per second.

TABLE 5
Summary of Pearson Coefficients of Correlation Relating Ball Velocity to Relevant Assessment Factors[a]

	r	*P*
IR PT CONC 60, N·m	0.63	.004
IR PT CONC 240, N·m	0.54	.017
IR PT CONC 400, N·m	0.47	.044
ER/IR CONC 400 ratio	–0.62	.005
ER ECC 60/IR CONC 240 ratio	–0.52	.022
FLEX PT CONC 60, N·m	0.59	.008
FLEX PT CONC 180, N·m	0.46	.045
EXT PT CONC 180, N·m	0.52	.023
Impact height, cm	0.51	.026
Jump time, ms	0.44	.056
Body mass index, kg/m²	0.47	.040
Body mass, kg	0.44	.055
Muscular training per week, h	0.46	.046

[a] r = coefficient of correlation; significance level $P < .05$. IR, internal rotators; ER, external rotators; FLEX, flexors; EXT, extensors; PT, peak torque in N·m; CONC, concentric mode; ECC, eccentric mode. Numbers after CONC and ECC represent values in degress per second.

and the number of hours of muscular training per week ($0.44 \le r \le 0.51$).

For the 5 players with a history of shoulder tendinosis compared with the other players, we observed a trend of lower ER/IR ratios (eg, 0.57 ± 0.13 vs 0.75 ± 0.12 at 60 deg/s in the concentric mode and 0.91 ± 0.14 vs 1.13 ± 0.24 for the mixed ratio) and a passive internal rotation impairment (60° ± 13.5° vs 67.9° ± 8.9°). Nevertheless, such a small sample does not permit a relevant statistical analysis.

DISCUSSION

The spike's effectiveness undoubtedly represents a determining element in volleyball.[9,11,21] To compete at a high level, the player must produce a spike characterized by a high ball velocity. The volleyball spike is a complex skill that requires many components of movement, technical, and muscular qualities.[1,9,27] Effectiveness of tennis serves or baseball pitches has been attributed to an energy transfer in a kinetic chain concept from the lower limb to the upper extremity, depending on flexibility, strength, and coordination.[16,19,25] Although these aspects would affect the volleyball spike, some differences must be noted: the spiking action is characterized by a running approach followed by a vertical jump.[1,11,20,21] The approach enables the spiker to gain horizontal momentum, which then must be converted to vertical momentum through subsequent flight.[11]

In the present study, we aimed at determining, in frontline players, the physical and muscular features that could be correlated with ball velocity during a spiking test. Legitimately, one could suspect a relationship between ball velocity and the strength developed by the throwing arm, but no study to date devoted to volleyball has looked for such a link. With that in mind, each volleyball player tested in the present study underwent an isokinetic assessment of his dominant shoulder and elbow and a specific field test (the spike).[2,17,27] The PT of the IR in all concentric conditions showed a satisfactory relationship with ball velocity performance, particularly at the lowest isokinetic speed ($r = 0.63$). This finding leads us to postulate that improvement of IR strength could increase ball velocity during the spike, even if the study can only show associations, not prove cause and effect between some correlated factors and spike velocity.

Reviewing other sports activity described in the literature, the relation between isokinetic results and field performances seems varied. Focusing on handball players, Bayios et al[4] found that PT of the shoulder IR and ER was not a good indicator of throwing velocity, except for the jump shot correlated with IR PT. Bartlett et al[3] reported, in baseball, a significant correlation between shoulder adductors and throwing speed but no relationship with the rotators. In a recent study,[13] we demonstrated strong correlations between javelin throws and ER-IR isokinetic PT. Ellenbecker[12] did not observe any significant link between strength assessment and maximal speed tennis serves. To date, we have not found any study dedicated to volleyball players highlighting correlations that could provide useful information for training management of the player.

Interestingly, spike velocity showed a significant but negative relationship with the ER/IR ratio at 400 deg/s or with the mixed ratio: once again, IR strength appears to be correlated with increased spike velocity. Cohen et al[10] showed a similar relationship between ER/IR ratio and ball velocity during the tennis serve. Nevertheless, even if ER strength is not critical for optimizing spike velocity, several authors[12,17,23,24,25,26] recommend correcting ER weakness and ER/IR imbalances. According to Wang and Cochrane,[23] muscle imbalance may play a key role in the cause of shoulder injuries. Although strengthening the IR seems to be relevant in volleyball performance optimization, we advise against an agonist/antagonist imbalance revealed by a decreased ER/IR ratio. In our study, the 5 players reporting a history of shoulder tendinosis showed a trend of weakened ER/IR ratios. An adapted ER strengthening for those players would provide a correct balance, probably without any harmful influence on the IR strength potential. For Noffal,[18] throwers exhibited significantly lower mixed ratios (eccentric ER on concentric IR at 300 deg/s) in their dominant limb than did nonthrowers. For both rehabilitation and injury prevention, he proposed regimens that include exercises for improving eccentric external rotation strength.[18]

Regarding the elbow isokinetic data, a significant relation existed between ball velocity and maximal strength developed by the FLEX and EXT, highlighting the main role played by that joint in the throwing motion.[1,2,19,20] The findings of Cohen et al[10] similarly exhibited a relation between tennis serve velocity and elbow extension torque production. For Zheng and Barrentine,[27] producing the optimal hand speed results from producing the proper combination of optimal elbow extension and shoulder internal rotation. Alfredson et al[2] found a higher concentric and eccentric strength in the rotator muscles of the shoulder and in the extensor muscles of the elbow among female volleyball players compared with untrained controls.

Interestingly, we observed a significant relationship (r = 0.46) between ball velocity and the time specifically dedicated to a general muscle strength training program estimated through a retrospective questionnaire. N1 players benefited from more hours per week of such training than did N2 players. Obviously, a retrospective calculation of training hours according to the players' recollection by memory would be interpreted with caution.

The vertical jump ability allows the volleyball player to contact the ball overhead at the highest point of the jump, attempting to strike it down onto the court on the opposite side of the net.[7] As a result of a lower contact point, the spiker has to stretch to hit the ball over the net.[20] This movement hinders his spiking action and generally results in his hitting the ball with his fingers rather than with the heel of his hand. Furthermore, an attack over a block is most likely impossible.[20] We found a significant correlation between ball velocity and impact height (r = 0.51), determined by the filming analysis, and a correlation close to the statistical level with the jump flying time measured by the counter-movement jump test (r = 0.44). The best league level, N1, showed significant superiority in the jump tests (jump flying time and height) in comparison with N2. For Smith et al,[22] the team players who reached a significantly higher block and spike jump possessed more desirable characteristics because of years of physical conditioning and playing, in addition to innate genetic endowment. Training thus has a significant role in the preparation of international caliber volleyball players.[22] Moreover, a superior technique in N1 players places them on advanced teams that tend to have greater training requirements.[8] Ciccarone et al[8] did not observe a statistical difference in all jumping tests among young (<20 years) volleyball and basketball players, even though senior (>20 years) volleyball players showed better jumping performances in comparison with senior basketball players. For those authors, the difference might be because jumping capacities are improved more specifically and continuously during volleyball training.[8]

Among the morphological characteristics, a significant correlation was shown between spike velocity and body mass index of the player. A relationship close to the significance level (P = .055) also existed with body mass. This finding implies that the heavier the player is in proportion to height, the more efficient he is in spike activity. Such a finding is rather surprising. One might assume that increased body mass would decrease the vertical height jump. Indeed, our study did not reveal any correlation between the vertical height jump and the body mass of the player. For Abendroth-Smith and Kras,[1] the pre-execution phase, namely the running approach, gives the player horizontal velocity so as to be able to transfer that momentum into a high vertical jump during the takeoff phase of the spike. Obviously, we might also consider the transfer of energy to the upper extremity in a kinetic chain concept for increased spike velocity.[1,16,19,21] The components of momentum rest on the velocity of approach and the mass of the player,[1] giving importance to the body mass of the volleyball player.

Conversely, the passive flexibility of the dominant shoulder did not influence ball velocity data. The significant decrease in the internal passive rotation we measured, in comparison with the nondominant side, is classically reported.[5,14,15,24,25] For Bigliani et al,[5] such a specific arc of motion in the shoulder could lead to selective stretching of the anterior capsule and tightening of the posterior capsule. Wilk et al[25] recommended specific stretching session exercises aimed to improve posterior shoulder flexibility for preventing shoulder injury. For these authors, the significant loss of internal rotation resulted, in particular, from repetitive eccentric forces during arm deceleration and might lead to increased anterior translation of the humeral head. In our study, the 5 players who had suffered from tendinosis had very low mobility in internal rotation. Even if speculative, we emphasize the possible relevance of restoring a normal mobility pattern to prevent reinjury, as suggested above.[25] In the literature, most overhand sports show a significant anteroinferior laxity of the glenohumeral joint, which permits excessive range of motion for external rotation in the dominant shoulder.[25] In contrast, our study did not reveal any significant difference of passive external rotation between dominant and nondominant sides. Our players exhibited a bilateral increased external rotation, reaching more than 100° of range of motion on both sides. Wang and Cochrane[23] published the same shoulder mobility profile in elite volleyball players, with internal rotation mobility impairment in the dominant side and no significant difference between both sides in external rotation. Such a different profile in comparison with baseball pitchers could result from the very specific action in volleyball. During the spike, the player hits the ball into the air, associating a trunk rotation and hyperextension,[1] which could require a less extensive range of external rotation of the shoulder. Interestingly, javelin throwers[13] have bilaterally larger passive possibilities in external rotation than does the sedentary population, but no statistical link was found between that passive dominant shoulder mobilization and javelin throwing distance.

CONCLUSION

The aim of this study was to describe the correlation between postimpact ball velocity in volleyball spiking action and physical, morphological, and muscular performances.

Spike velocity significantly correlated with the following:

- the maximal isokinetic torque developed by the IR of the dominant shoulder in the concentric mode at all speeds (mainly at 60 deg/s),
- the ER/IR ratio at 400 deg/s and the mixed ratio (negative correlation),
- the FLEX and EXT concentric PT of the dominant elbow at 60 deg/s and/or 180 deg/s,
- the height at which the volleyball player contacted

the ball during the spike test,
- the muscular training hours performed weekly, and
- the player's body mass index.

These observations pertaining to the frontline players could provide useful guidelines for training to optimize field performance.

Interestingly, jump performances influencing ball velocity performance were among the main capacities that distinguished N1 volleyball players from N2 volleyball players, emphasizing the qualities required for accessing high skill level. Players with a history of tendinosis showed a trend of weakened ER/IR ratios and reduced internal rotation mobility.

ACKNOWLEDGMENT

The authors thank Miss Muriel Barsin for her contribution to the study, Mrs Annie Depaifve for her kind technical assistance, Professor Adelin Albert's department for statistical analysis, and the firm Wilson's Belgium for the loan of the radar gun for the experimental part.

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