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Comparison of Upper Arm Kinematics During a Volleyball Spike Between Players With and Without a History of Shoulder Injury

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Volleyball players are at high risk of overuse shoulder injuries, with spike biomechanics a perceived risk factor. This study compared spike kinematics between elite male volleyball players with and without a history of shoulder injuries. Height, mass, maximum jump height, passive shoulder rotation range of motion (ROM), and active trunk ROM were collected on elite players with (13) and without (11) shoulder injury history and were compared using independent samples *t* tests ($P < .05$). The average of spike kinematics at impact and range 0.1 s before and after impact during down-the-line and cross-court spike types were compared using linear mixed models in SPSS ($P < .01$). No differences were detected between the injured and uninjured groups. Thoracic rotation and shoulder abduction at impact and range of shoulder rotation velocity differed between spike types. The ability to tolerate the differing demands of the spike types could be used as return-to-play criteria for injured athletes.

Keywords: volleyball, spiking technique, shoulder overuse injuries

Volleyball enjoys worldwide popularity, with only soccer attracting more global participation.[1] Despite being a noncontact sport, volleyball still poses a definite risk of injury to its players,[2] with the reported injury incidence ranging from 1.7 to 3.8 injuries per 1000 hours of participation in practices and matches.[2–4] Of all the volleyball-related injuries, the shoulder is one of four most commonly injured locations, accounting for around 15% of all injuries.[1,3] These injuries are typically recurrent or overuse in nature (90% of all shoulder injuries),[1,3] which are known to have a long-term, debilitating effect on an athlete's performance and daily life. Therefore, developing successful prevention and management practices for shoulder injuries is important. However, to date there is little evidence supporting specific mechanisms that may be targeted to prevent and manage volleyball-related shoulder injuries.

A recent review summarized the following proposed shoulder injury risk factors for volleyball players: anatomy, biomechanics, conditioning/core stability, glenohumeral joint internal rotation deficit, previous shoulder injury, scapular dyskinesis, gender, load, and competitive situation.[1] However, there is a paucity of evidence directly linking any of these risk factors with shoulder injury in volleyball players. One persistently identified risk factor is the volleyball spike. The spike requires the athlete to move the upper arm through a large range of upper arm motion while airborne, which is believed to place the shoulder under significant load.[2,5,6] Anecdotally, spiking has been linked with the high number of overuse shoulder injuries with one study reporting 80% of all shoulder injuries could be linked to spiking.[3] Given that players have been reported to spike around 40,000 times per year, only small technique deficiencies may be associated with injury.[5]

Static shoulder range of motion (ROM) has also been linked with overuse shoulder injuries in the overhead athlete, although the extent to which this influences injury risk among volleyball players has been questioned.[1] It can be easily assessed and is therefore targeted clinically for intervention and management. There is evidence of reduced internal rotation range in athletes with a history of shoulder injury and volleyball players.[5,7] More recently, a study of baseball players reported reduced internal rotation range in the player's dominant shoulder compared with their nondominant, and this deficit was greater in those with a history of injury.[8] In light of these known differences, upper arm axial rotation should be recorded as a potential covariate when analyzing upper arm axial rotation during spike kinematics. Similarly, overall trunk ROM may directly relate to the amount of trunk movement during the spike and while there is no evidence that players with a history of shoulder injury have reduced trunk ROM, it is frequently assessed clinically. There is potential that spiking with a reduced trunk

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ROM could be compensated for by increased upper arm axial rotation.[9–11] Given the implications of trunk movement during the spike, trunk ROM should also be considered as a covariate.

To date, no study has measured the effect of a recent shoulder injury on spiking technique. Therefore, this study aimed to quantify differences in upper arm and trunk kinematics during the spike between elite volleyball players with and without a recent history of recurrent shoulder overuse injury. Further, given that players spike toward a number of different target regions, the consistency of upper limb and trunk kinematics when spiking at opposite sides of the volleyball court (down-the-line and cross-court) will also be determined. Differences in passive shoulder rotation and complete (three-dimensional) active trunk ROM between the injured and uninjured groups were also explored, as potential covariates.

Methods

Participants

Twenty-four elite male volleyball players were recruited from the Australian Institute of Sport and the West Australian National Volleyball League. Five of the players had competed at the International level, 10 had competed at the National level, and the remaining nine had played at the highest state level. Curtin University Human Research Ethics Committee approved this study and all volleyball players provided informed consent before participation. The players were divided into two groups. Those with a history of at least two episodes of shoulder pain in their spiking arm which resulted in injury diagnosis, treatment, training modification and missing a match in the 6 months before testing were included in the injured group. Players were included in the uninjured group if they had no history of any shoulder pain or injury within the last five years. Players were excluded if they had previously had any form of shoulder surgery or shoulder trauma, if they were currently not participating in full training/matches due to shoulder pain or injury, or if they had any other musculoskeletal injury that would prevent maximum skill execution at the time of testing. Thirteen players met the injured group criteria (mean (*SD*) age 23.5 (6.8), height 188.1 (7.6) and weight 83.1 (9.1)) and 11 the uninjured group criteria (mean (*SD*) age 25.5 (7.0), height 184.8 (9.2) and weight 78.5 (11.2). Statistical comparison of these demographics revealed no differences between groups (P value range 0.283–0.672).

Procedures

Testing was carried out at the Curtin University, School of Physiotherapy Motion Analysis laboratory, using a 10-camera Vicon MX motion analysis system (Oxford Metrics, inc.), operated at 250 Hz. The volleyball court boundaries (9 m × 9 m) were clearly marked and a game-certified net was set to match height (2.43 m). Two 3 m^2 target areas were defined to allow for down-the-line and cross-court spike simulations. Initially, each participant's height and mass was measured using a standardized stadiometer and an electronic scale respectively. The retro-reflective markers, necessary for Vicon motion tracking, were applied to specific anatomical landmarks on the player's pelvis, thorax, and spiking upper limb in accordance with a valid upper limb 3-dimensional mathematical model that used a cluster marker approach in compliance with International Society of Biomechanics recommendations (Figure 1).[12] Specifically, the pelvis markers were fixed to the skin surface over the right and left anterior superior iliac spines and right and left posterior superior iliac spines while the thorax markers were fixed over the 7th cervical and 12th thoracic vertebral processes, xyphoid process of the sternum and the manubrium notch. The shoulder joint center was calculated using a regression model[13] and previously described clusters of three markers on the acromion and distal upper arm were used to accurately replicated this position during dynamic trails.[14] A third cluster of three markers was placed on the distal upper arm to maximize the recording of upper arm rotation.[15] The medial and lateral elbow epicondyle positions were calculated during one static trial, such that their position could be replicated virtually during the dynamic trials. Three markers were also fixed to the volleyball and the hand to calculate ball velocity and the time of impact between the ball and the hand.

Following application of the marker set, participants performed a self-directed warm-up. The same assessor then measured each player's passive internal and external shoulder rotation ROM. A standard goniometer (Baseline, Inc.)[8] was used in accordance with previous protocols[16] that have demonstrated acceptable reliability.[16] The spiking trials were performed using a standardized ball placement, which has been demonstrated to facilitate reliable trial execution without compromising perceived spiking technique.[17] For this purpose, a standard volleyball ball (Mikasa) was secured to height adjustable rope "levers"

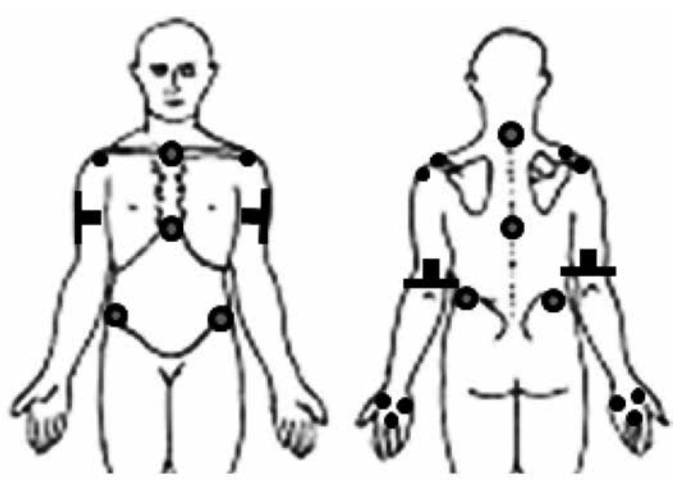

Figure 1 — Schematic of the upper arm and thorax marker set.

via Velcro. Each player's maximum jump height was then determined from the best of five jump height attempts, such that the ball height could be set to 65% of maximum jump height. Participants then performed ten familiarization spike trials toward both the down-the-line (DL) and cross-court (XC) target zones. A minimum of three successful DL and three XC spike actions with maximum voluntary effort were then recorded. Trials were deemed successful if the ball landed in the target zone and the player did not hit the net. Finally, trunk ROM in each plane (sagittal, transverse, and frontal) was recorded using the Vicon system.

Data Analysis

The Vicon data were analyzed using specialized Vicon motion analysis Software (Nexus; Oxford Metrics, Inc.). Each trajectory was checked for breaks that can occur when a marker is occluded during dynamic trials. Cubic spline interpolation and pattern fill procedures were used to fill breaks of less than 20 frames (0.08 s). If breaks larger than this were found the trial in question was discarded; however, this did not occur. The data were filtered using a quintic spline filter,[18] with a mean square error of 0.3 as indicated by a residual analysis performed on each trajectory of the raw spiking data.[19] The 3-dimensional mathematical model outlined above was then applied to each trial. The spike trial analysis included the visual inspection of the ball and hand, and the ball velocity graph to determine the instant of their impact. Kinematic data 0.4 s before and following this impact event were time normalized to 101 data points. Data could then be averaged across each subjects' trials, then for each group (injured and uninjured: DL and XC), and presented graphically. The minimum and maximum value of each kinematic variable was extracted and the total range calculated. The value of each kinematic variable at impact was also output.

The range and kinematics at impact were then compared using linear mixed model analyses in SPSS (SPSS 17, Chicago, IL, USA.). The differences between the injured and uninjured groups, as well as the two spike types were explored, with the significance level set at 0.01 to account for multiple comparisons. The interaction term between spike type and injured/uninjured was analyzed for each variable and was removed from the analysis if it was not significant. The upper arm rotation and complete active trunk ROM were compared between the injured and uninjured groups using independent sample *t* tests ($P < .05$).

Results

The statistical analysis indicated no significant difference in any of the ROM variables, spike ball velocity, and maximum jump height between groups (Table 1). Both groups had a much greater upper arm external rotation ROM compared with internal.

The statistical analysis indicated that there was no interaction between spike type and shoulder injury for any of the variables. Therefore both spike types were included in the analysis comparing the injured and uninjured groups; and both injured and uninjured groups were included in the spike type comparison.

The between-spike analysis revealed that during the cross-court spike, at the instant of impact between the ball and the hand, participants were significantly more

Table 1 Comparison of covariates between the uninjured and injured groups, including active trunk ROM, passive shoulder ROM, spike ball velocity maximum jump height and playing experience

	Uninjured	Injured	*P* Value
Active Trunk ROM, mean (*SD*) degrees			
Flexion	68.4 (11.3)	71.9 (19.2)	.364
Extension	–35.2 (13.5)	-44.2 (15.7)	.610
Right Lateral Flexion	46.0 (11.0)	51.7 (14.7)	.665
Left Lateral Flexion	–40.7 (10.3)	–43.1 (8.8)	.434
Right Rotation	–59.4 (7.8)	–62.6 (10.8)	.194
Left Rotation	53.1 (8.8)	55.5 (12.2)	.300
Passive Shoulder ROM, mean (*SD*) degrees			
External Rotation	85.3 (10.8)	90.1 (13.8)	.565
Internal Rotation	49.3 (12.4)	43.4 (6.8)	.149
Ball Velocity, mean (*SD*), m/s	19.0 (2.0)	19.4 (2.4)	.516
Max Jump Height, mean (*SD*), cm	68.2 (7.5)	69.9 (11.5)	.672

rotated through the trunk toward the cross-court target (mean difference 4.3°; 95% CI 0.9–7.7; P value .015) with their upper arm positioned further in front of their trunk (mean difference 4.2°, 95% CI –0.9 to 07.6; P value 0.016) (Table 2). The range of shoulder rotation velocity was also significantly greater when performing a cross court spike than down the line (mean difference 235.5°s,[1] 95% CI –60.7 to –410.2; P value .011) although there was no difference in shoulder acceleration or velocity at impact.

The analysis at the moment of impact showed no significant differences for any of the kinematics between the injured and uninjured groups (Table 2). The mean difference in ball velocity between groups was negligible (0.1 m·s^{-1}) as were the differences in shoulder flexion and abduction both throughout the spike and at impact (mean difference range 0.5–5.5°). There were slightly larger differences in shoulder rotation between groups, although they did not approach statistical significance. These results were consistent for the shoulder velocities and accelerations and are illustrated in figures (Figures 2–5). Although there were no differences detected in trunk kinematics at impact or throughout the spike between groups, the range of thoracic flexion between groups did approach statistical significance, with the injured group typically using a larger range of trunk flexion.

Discussion

This study was the first cross-sectional comparison of spike biomechanics of the shoulder and thoracic spine between uninjured volleyball players and those with a history of a recurrent shoulder injury. The comparison of the potential covariates revealed no difference in the maximum spike velocity between groups. The mean spike velocity achieved by both groups in this study (19 m·s^{-1}) is slightly lower to that reported in previous investigations (25–27 m·s^{-1}).[7] However, this is likely a result of using the fixed ball where some of the force created by the players was required to release the ball from the restraints. The comparison of the upper arm passive axial rotation between groups revealed no significant differences between the injured and uninjured groups. This supports results of recent research, suggesting this measure may not be related to shoulder injuries in volleyball populations.[20] Similar to previous research, both groups exhibited much greater upper arm external rotation than internal rotation ROM.[21]

The comparison of upper limb and spike kinematics between the two spike types demonstrated some adjustment to successfully spike toward the different target areas. The results indicate that players were more rotated through their trunk toward the cross-court target, with their arm further in front of the trunk at impact when spiking the ball cross-court are not surprising. However, the results suggesting an increased reliance on upper arm axial rotation during the cross-court spike was unexpected. Recent research found no significant differences between "cross-body" and "straight-ahead" spikes in maximum shoulder internal rotation torque and maximum shoulder force.[22] However, the sample sample size used in this study was larger (24 as compared with 14) and the previous research did not include measures of velocity.[22] Therefore, the current result might have implications for player rehabilitation/management following injury. For example, players returning following a shoulder injury provoked by shoulder axial rotation should be advised to prolong their return to spiking cross court during practice and games. The results revealed all players were very consistent in their upper-arm ROM in each plane, and axial rotation and vertical abduction at impact between spike types. This consistency might have clinical implications, with repetitive arm movements a known risk factor for shoulder injury.[23]

The comparison between the injured and uninjured groups revealed no statistical difference between any of the upper limb or trunk angles. While the upper arm flexion and abduction positions were remarkably similar between groups, the injured group were demonstrated to use an average of 13.6° greater upper arm axial rotation ROM and 11.3° increased trunk flexion ROM 0.1 s before and following impact. However, the wide confidence interval of both these differences (–10 to 37° and –21 to 1, respectively) highlights the variability in this data resulting in no statistical difference ($P < .01$). This suggests the possibility of a washout effect from grouping all the players with shoulder injuries together that could be clarified by case study analyses. In spite of this variability in the upper arm axial rotation and thorax flexion data, the remarkable consistency in the other upper arm planes (abduction and flexion) and trunk movements (rotation and lateral flexion), as well as all of the velocity and acceleration comparisons, between the uninjured and injured groups cannot be disregarded (Figures 2–5). Further, the previous comparison studies have reported motor control alterations between injured and control groups, such as adopting a reaching technique that places less load through the shoulder.[24–26] While a number of potential conclusions might be drawn from the current results, two favored are that (1) players do not adapt their technique in response to shoulder injury or (2) players' technique is only altered during the period of time they are injured and have symptoms such as pain during movement, returning to their more practiced method once these symptoms subside. While it is not within the scope of this study to delineate between these two possibilities, both have implications for current injury management/understanding, particularly in light of the frequency of reinjury within this population (between 2 and 6 episodes of injury symptoms including pain during volleyball performance).

The mean upper arm horizontal abduction position at impact was high for both groups, 130° for the uninjured group and 131° for the injured. Given that 90° shoulder abduction has been suggested as the optimal position for minimizing stress through the shoulder in baseball pitching,[27] this again highlights the potential risk volleyball players place their shoulders when spiking.

Table 2 Shoulder and thoracic spike kinematics comparison between injured and uninjured groups

		Uninjured Group	Injured Group	Mean Difference	95% Confidence Interval	*P* value
Shoulder flexion plane of elevation angle mean (*SD*) degrees	Impact	–137.0 (7.9)	–140.4 (13.5)	3.4	–5.6 to 12.4	.446
	Range	88.7 (1.7)	94.3 (1.5)	5.5	–7.4 to 18.5	.384
Shoulder abduction angle mean (*SD*) degrees	Impact	130.0 (14.3)	131.3 (8.4)	1.3	–10.9 to 8.4	.786
	Range	92.1 (19.8)	92.6 (15.9)	0.5	–13.5 to 14.4	.944
Shoulder rotation angle mean (*SD*) degrees	Impact	–73.9 (13.7)	–84.2 (22.9)	10.3	–5.9 to 26.5	.202
	Range	83.5 (27.8)	97.1 (28.7)	13.6	–10.1 to 37.4	.246
Thorax flexion angle mean (*SD*) degrees	Impact	–19.4 (18.4)	–25.5 (10.3)	8.0	–5.4 to 21.5	.228
	Range	33.6 (16.4)	44.7 (10.1)	11.3	–21.6 to –1.061	.032
Thorax lateral flex angle mean (*SD*) degrees	Impact	–27.8 (6.9)	–31.0 (6.8)	3.4	–2.5 to 9.4	.244
	Range	28.8 (8.6)	31.3 (7.9)	2.8	–10.2 to 4.6	.434
Thorax rotation angle mean (*SD*) degrees	Impact	–1.0 (13.0)	–3.8 (9.8)	1.4	–8.7 to 11.5	.776
	Range	23.7 (12.2)	30.6 (11.3)	6.2	–15.9 to 3.4	.195
Shoulder flexion angular velocity mean (*SD*) $deg \cdot s^{-1}$	Impact	39.4 (14.9)	38.7 (11.7)	0.7	–8.0 to 9.5	.864
	Range	463.8 (273.6)	397.6 (236.6)	66.6	–100.4 to 233.7	.417
Shoulder abduction angular velocity mean (*SD*) $deg \cdot s^{-1}$	Impact	838.7 (300.2)	866.4 (4112.0)	28.1	–264.6 to 320.8	.844
	Range	499.6 (327.4)	394.3 (268.1)	105.3	–76.3 to 289.9	.424
Shoulder rotation angular velocity mean (*SD*) $deg \cdot s^{-1}$	Impact	–703.9 (468.0)	–783.5 (318.4)	79.5	–231.1 to 390.2	.601
	Range	1040.7 (492.5)	908.4 (521.8)	132.330	–257.4 to 522.1	.489
Shoulder flexion angular acceleration mean (*SD*) $deg \cdot s^{-1}$	Impact	–29,604.2 (32,937.6)	–26,497.7 (30,718.0)	3,106.5	–28,324.8 to 22,111.702	.801
	Range	26,184.9 (18,833.9)	25,796.4 (18,314.9)	388.5	–14,018.7 to 13,241.7	.953
Shoulder abduction angular acceleration mean (*SD*) $deg \cdot s^{-2}$	Impact	–43,336.2 (25,619.5)	–37,543.8 (242,547.9)	5,792.4	–23,876.3 to 12,291.4	.513
	Range	41,518.2 (20,337.2)	30,935.3 (28,395.8)	10,582.9	–29,107.9 to 7,942.1	.49
Shoulder rotation angular acceleration mean (*SD*) $deg \cdot s^{-2}$	Impact	–34,351.8 (34,833.8)	–34,212.1 (34,833.8)	139.6	–26,854.2 to 26,574.9	.991
	Range	28,894.6 (19,307.9)	17,622.0 (17,399.4)	11,272.6	–24,476.1 to 1,930.9	.90

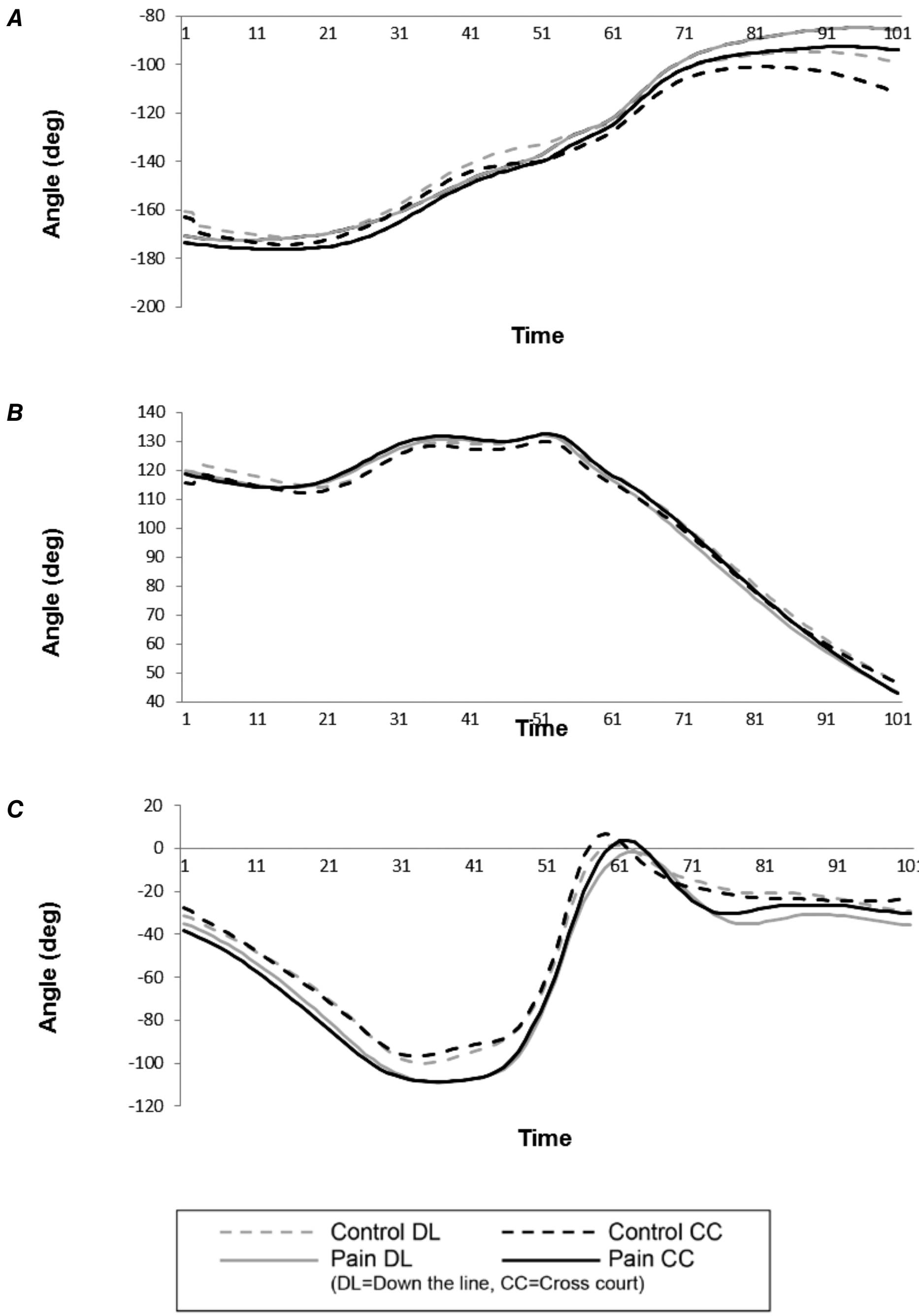

Figure 2 — Upper arm relative to thorax angle in all 3 anatomical planes: *(A)* Flexion-extension, *(B)* Abduction-adduction, *(C)* Internal-external rotation.

This study was limited to the 13 injured and 11 uninjured male participants used. The laboratory environment and fixed ball setup limited the ecological validity of this study, albeit a more controlled investigation. Given the variability in some of the results (upper arm axial rotation and trunk flexion) future research should consider case study analyses and/or further detailed classification of the nature of each shoulder injury. Future research should also consider statistical comparisons of the temporal characteristics of the kinematics (ie, time to peak), and recording the scapular motion, although current methods of scapular recording with surface based landmarks are known to be inaccurate during dynamic upper arm movements that achieve 120° of humeral elevation.[28] Finally, investigation of the effect of fatigue on kinematics and any potential relationship with shoulder injury history should be considered.

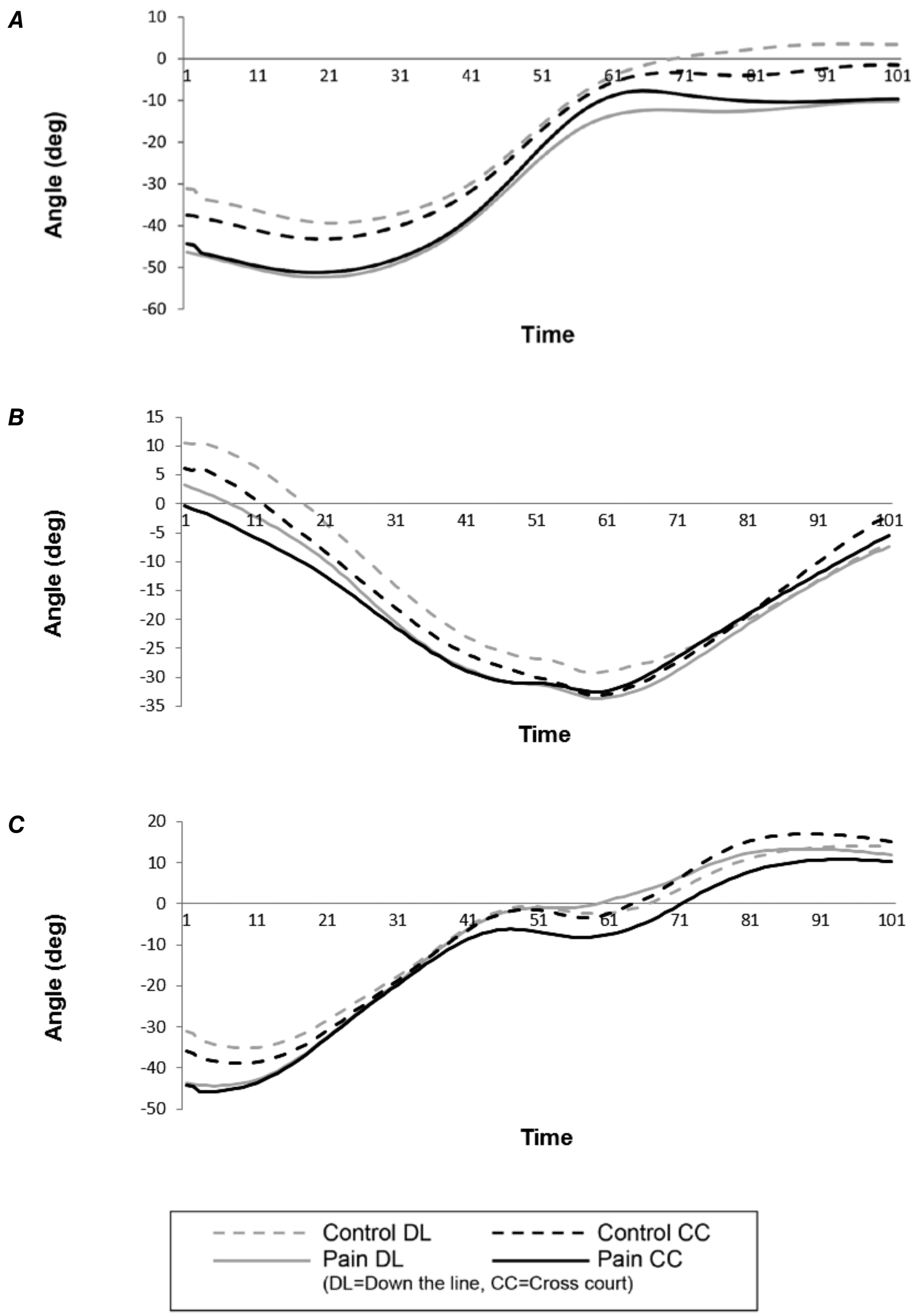

Figure 3 — Thorax relative to pelvis angle in all 3 anatomical planes: *(A)* Flexion-extension, *(B)* Right-left lateral flexion, *(C)* Right-left rotation.

In summary, this study found that volleyball players alter their trunk and upper arm positions at impact, and axial rotation velocity when striking the ball toward opposing ends of the court. This latter finding has implications for clinicians and coaches when monitoring players with a history of a recurrent shoulder injury. The consistency in the shoulder axial rotation and vertical abduction between spike types,[23] the position of large upper arm vertical abduction,[27] and large ranging upper arm axial rotation, all at high velocities/accelerations, highlight that volleyball players are at risk for repetitive overuse shoulder injuries. However, no differences were detected between the injured and uninjured groups in any of the kinematic variables. This suggests that either players do not adapt their technique in response to shoulder injury or that they modify their technique during

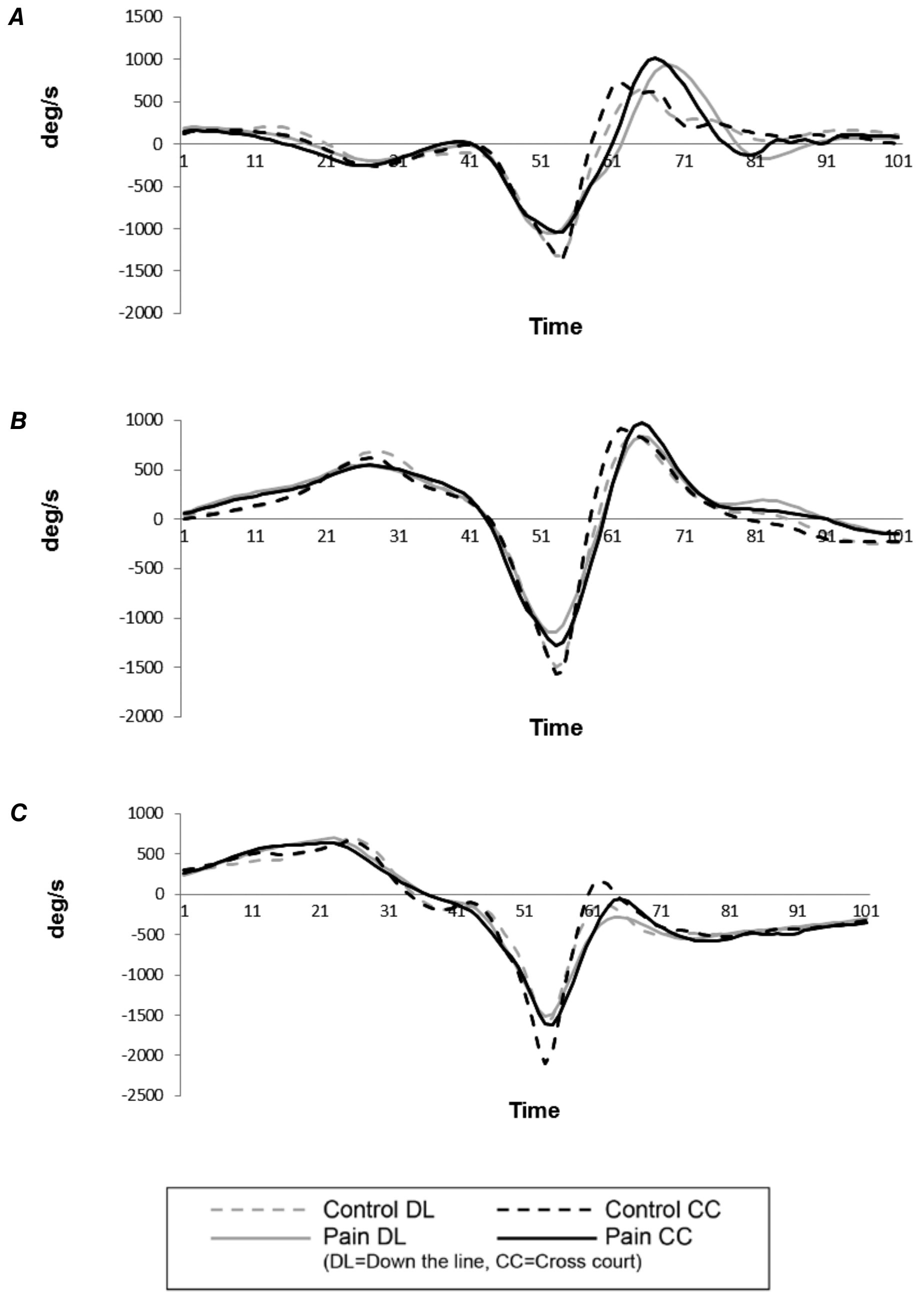

Figure 4 — Upper arm relative to thorax velocity in all 3 anatomical planes: *(A)* Flexion-extension, *(B)* Abduction-adduction, *(C)* Internal-external rotation.

the period of time they have painful symptoms of the injury, which then returns to their more practiced method once this pain subsides. Future research should endeavor to clarify differences between players with and without pain symptoms to confirm this supposition. Finally, some disparity between groups was evident in the upper arm axial rotation and trunk flexion data, which may reflect a washout effect within the injured group.[29] Future research, including a prospective study and case studies, is necessary to confirm the implications of this research.

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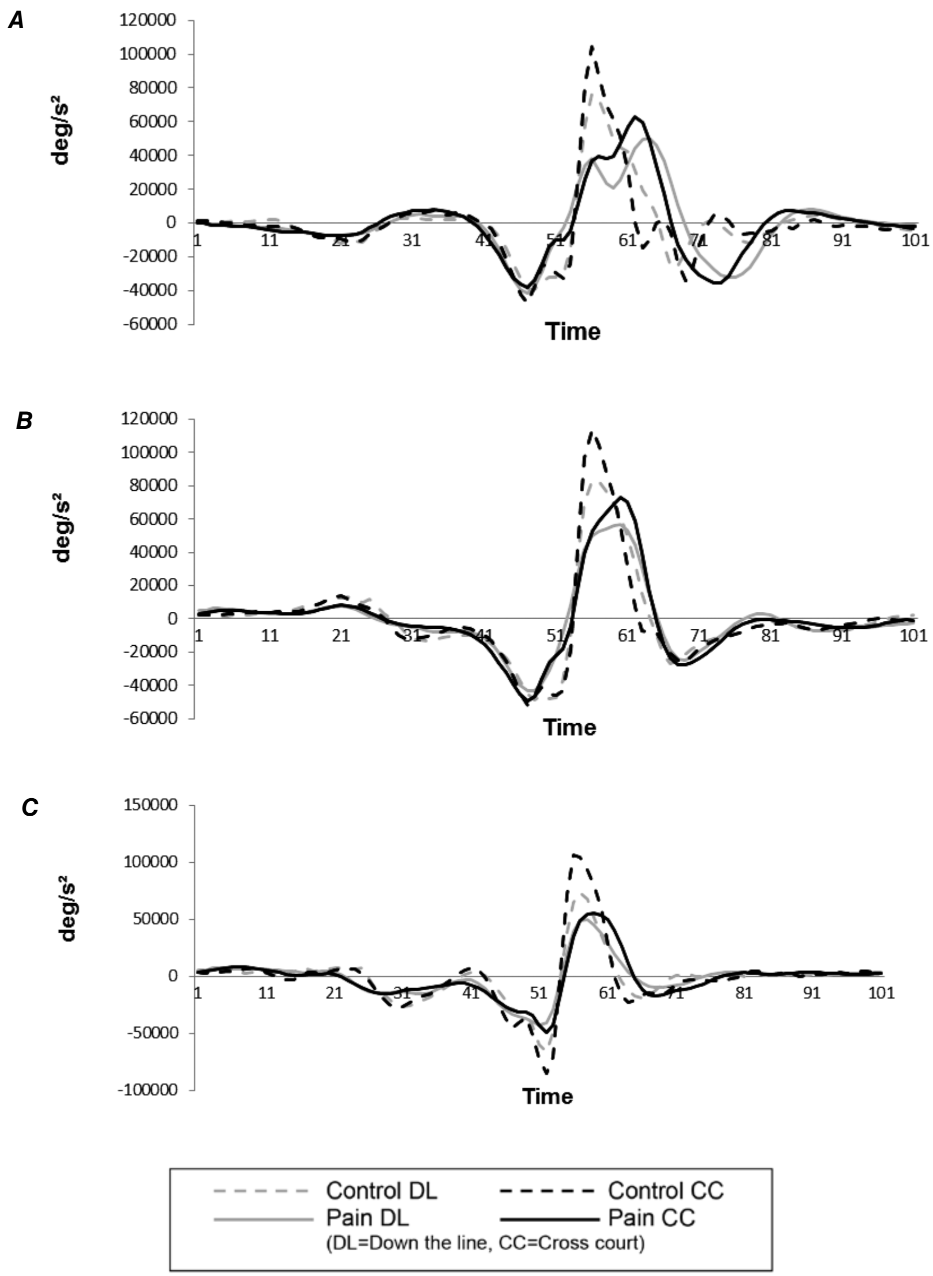

Figure 5 — Upper arm relative to thorax acceleration in all 3 anatomical planes: *(A)* Flexion-extension, *(B)* Abduction-adduction, *(C)* Internal-external rotation.

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