INVESTIGATION OF SHOULDER KINEMATICS IN VOLLEYBALL SPIKES

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This study investigated the shoulder kinematics of volleyball spikes, performed during European League Games. For the kinematic description of the shoulder movement quaternions and the axis-angle approach was used to avoid the gimbal lock. The orientation of the resulting axis of rotation in the shoulder joint and the rotational angle were calculated. Additionally, the 3D coordinates of the elbow movement around the shoulder and the internal and external rotation were investigated. The results show that specific movement strategies for the humerus could be detected using these methods. Interdependencies of internal and external rotation with abduction and adduction were found for shoulder movements during volleyball spikes.

KEY WORDS: shoulder kinematics, quaternions, axis angle, volleyball spike

INTRODUCTION:

The description of the complex shoulder movement during a volleyball spike leads to the problem of gimbal lock (GL). Investigating movements where the upper arm passes all body planes using Euler angles lead to discontinuities in time histories of the results. Depending on the rotation sequence this problem of GL occurs for angles close to 0° or 180° with respect to certain body planes (Senk & Cheze 2006). The ISB shoulder group proposed standardization for describing shoulder kinematics (Wu et al. 2005). Therein a specific definition of joint coordinate systems and the use of Y-X-Y rotation sequence are recommended. But in dependency of the observed range of motion other rotation sequences can be found in the literature to avoid the GL (Levasseur et al. 2007, Senk & Cheze 2006). In addition, Karduna et al. 2000 found that altering the rotational sequence influences of their results significantly. In this study, the huge range of motion within the shoulder joint for the whole volleyball spike was expected to lead to GL. To solve this problem, quaternions will be used to represent the rotation of the humerus with respect to the thorax and to calculate the orientation of the resulting rotational axis as well as the angle around this axis. The goal of this study was to define parameters for the investigation of shoulder movement in volleyball spikes performed by elite athletes during international competition. The focus was set on the correlation between the trajectories of the elbow joint with respect to the shoulder joint coordinate system and the orientation of the resulting axis of rotation.

METHODS:

16 diagonally performed volleyball spikes were analyzed. The subjects were European top level outside hitters of the national teams of Croatia, Estonia, Germany, and Netherlands. The spikes were captured during European League games. Therefore, motion analysis was executed using four high speed Basler cameras (100Hz) and the software Simi Motion. The 3D coordinates were digitized manually and the movements were reproduced with high accuracy using the man model DYNAMICUS (Roemer et al. 2007). For the inter-individual comparison of the shoulder kinematics for these movements, the data were time normalized with respect to take-off and ball-impact. Only the phase between strike out position and ball impact was taken into account for this study. The position and orientation of the coordinate systems fixed to the thorax, and the humerus, respectively, were defined as recommended by Wu et al. 2005. To quantify the shoulder kinematics quaternions were calculated out of the rotation matrix of the humerus coordinate system relative to the shoulder joint coordinate system.

$$q = a + bi + cj + dk \qquad with \ \ a,b,c,d \in R$$

Based on the unit quaternion, the orientation of the resulting axis of rotation (RA) between upper arm and thorax as well as the angle around this axis can be determined (Liu & Prakash 2003).

$$q = (s, v) = \left[\cos\left(\frac{1}{2}\theta\right),\ \hat{n}\sin\left(\frac{1}{2}\theta\right) \right]$$

Using this approach the 3-dimensional vector of unit length can be determined referring to the shoulder joint coordinate system for description of RA. To investigate the shoulder kinematics in more detail, also the trajectory of the elbow joint with respect to the shoulder coordinate system was analyzed. In addition the angle representing the internal and external rotation around the longitudinal axis of the humerus was defined based on the ISB recommendations.

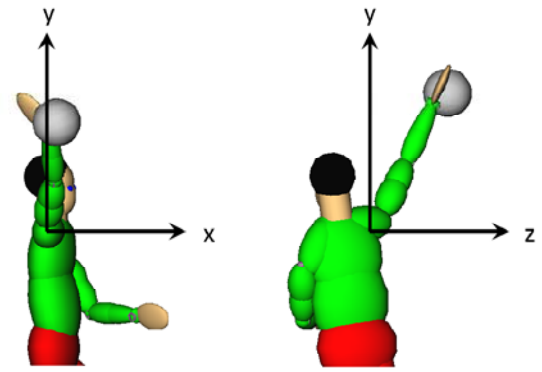

Figure 1: Definition of shoulder coordinate system (ISB standard)

To investigate the relationship between the upper arm movements and the orientation of the RA the Pearson correlation coefficient was calculated. The following assumptions were tested:

- Arm movements within the frontal plane correlate with the x-coordinate of the RA
- Arm movements within the sagittal plane correlate with the z-coordinate of the RA
- Arm movements within the transversal plane correlate with the y-coordinate of RA

Concerning the volleyball spike technique it was assumed that the internal and external rotation is mainly performed in combination with an abduction/adduction movement. Therefore, the correlation between the upper arm movement in the frontal plane with the internal and external rotation was tested. All correlations were calculated for each spike.

RESULTS AND DISCUSSION:

The results concerning the arm movement with respect to the body planes and their correlation to the orientation of the RA are shown in Table 1.

These results confirm the assumption, that the movements in the sagittal plane (ellb x-coord. and ellb y-coord.) and in the transversal plane influence the orientation of RA. High negative correlations can be found for the x-coordinate and the z-coordinate of RA and high positive correlations for the y-coordinate of RA. Furthermore, the movements in the frontal plane (ellb z-coord.) show an influence only for few trials. Eight trials out of 16 show no significant correlation. The other trials indicate significant positive correlation as well as significant negative correlation for the same coordinate. For example trial13 shows a negative correlation with the x-coordinate of RA while trial 14 shows a positive one. Figure 2 show the normalized trajectories of hand and elbow with respect to the shoulder joint (origin of the sphere).

The trajectories show two different movement techniques for the spike. For trial 13 the range of motion (ROM) for the internal/external rotation was 142°, from 87° of internal rotation to 55° of external rotation. This is also shown by the large movement of the hand in different directions in Figure 2. The trials with negative correlations shown in Tab.1 also showed high correlation between the rotational angles (ISB standard) and the z-coordinate of the elbow:

trial 2 (*r=-0.89*), 5 (*r=-0.8*), and 13 (*r=-0.8*). In trial 14 the ROM was only 67°, from 29° of internal rotation to 38° of external rotation. All trials with negative correlation shown in Tab.1 revealed weak dependency to the rotational angles: trial 4 (*r=0.45*), 8 (*r=0.6*), 14 (*r=-0.45*), and 15 (*r=0.31*). The significance p-value was p<0.01 for all results. For trial one a correlation with the elbow was detected but only weak correlation with the rotational angle was found. For this trial the ROM was 90°. These results indicate a dependency of the orientation of RA from the combination of abduction/adduction and rotation in the shoulder joint. No dependency between the arm movements in the sagittal and transversal plane with internal and external rotation in the shoulder joint was found for volleyball spikes. Brown et al. 1988 found for baseball pitchers an increased ROM for external rotation only within 90° abduction and suggested this finding to be a specific adaptation to throwing mechanics. The interdependency between abduction and rotation for diagonally performed volleyball spikes found in this study indicate specific spiking techniques. Further studies have to be done to understand the differences of these techniques.

Table 1: Pearson correlation coefficient (p<0.01) concerning the relationship between elbow trajectories and orientation of RA

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10	Trial 11	Trial 12	Trial 13	Trial 14	Trial 15	Trial 16
ellb y-coord./ axis x-coord.	-0.94	-0.99	-0.99	-0.97	-0.98	-0.99	-1.00	-0.97	-0.95	-1.00	-0.96	-0.99	-0.97	-0.90	-0.94	-0.98
ellb z-coord./ axis x-coord.	-0.92	-0.92	-0.92	-0.90	-0.98	-0.98	-0.98	-0.85	-0.71	-0.90	-0.68	-0.95	-0.67	-0.98	-0.99	-0.93
ellb x-coord./ axis y-coord.	0.85	0.93	*0.48*	-0.75	0.69	*0.37*	*0.55*	-0.70	*-0.57*	0.76	*-0.21*	*0.10*	0.94	-0.67	-0.76	*0.45*
ellb z-coord./ axis y-coord.	0.99	0.95	0.98	0.99	0.92	0.86	0.90	0.94	0.91	0.98	0.98	0.98	0.87	0.96	0.96	0.88
ellb x-coord./ axis z-coord.	-0.95	-0.70	*-0.20*	0.79	*0.05*	*0.16*	*0.24*	0.98	0.94	*-0.48*	*-0.47*	*0.12*	-0.71	0.95	0.97	*0.05*
ellb y-coord./ axis z-coord.	-0.94	-0.98	-0.99	-0.95	-0.80	-0.79	-0.81	-0.78	-0.70	-0.98	-0.85	-0.97	-0.84	-0.99	-0.95	-0.94

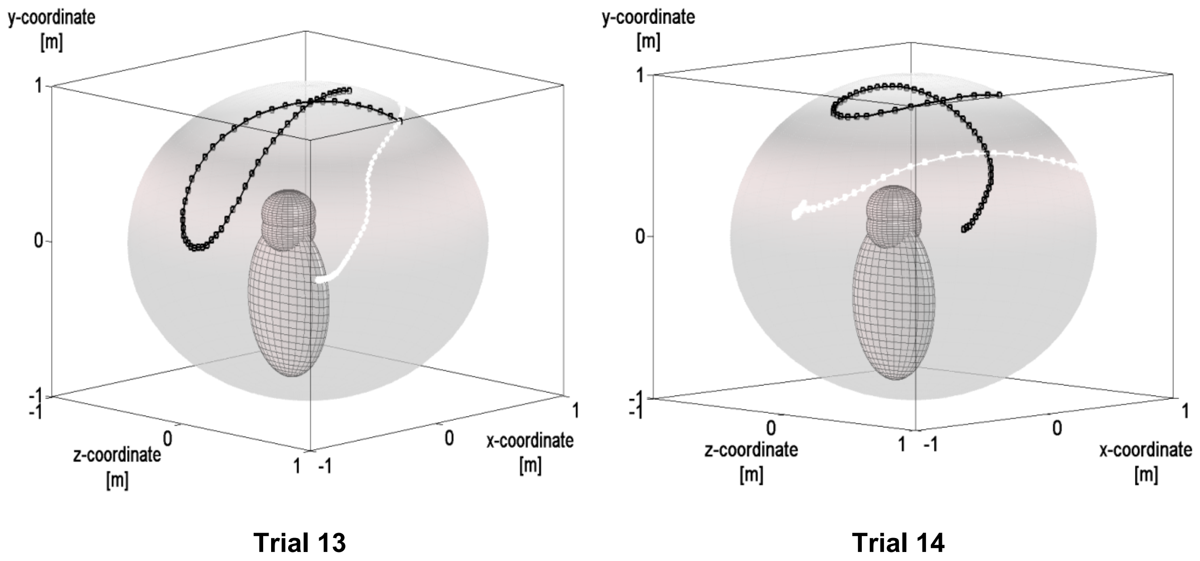

Figure 2: Trajectories of hand (black) and elbow (white) with respect to the shoulder joint, normalized and projected to a sphere

CONCLUSION:

The shoulder joint kinematics for volleyball spike movements was described using quaternions. The resulting joint axis as well as the angle was calculated. The advantage of this method is to avoid the problem of gimbal lock. The comparison of elbow trajectories with those of the RA revealed high correlation of upper arm movement in the sagittal and transversal plane with the orientation of RA. For movements in the frontal plane an additional dependency of internal and external rotation was found. That leads to the conclusion that concerning shoulder kinematics in volleyball spikes the abduction and adduction angles and the internal and external rotation are interdependent and may indicate different spike techniques.

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