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Shoulder Joint Angle Errors Caused by Marker Offset

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Abstract

The International Society of Biomechanics (ISB) has recommended a standardization of the definition of the joint coordinate system (JCS) and use of a sequential rotation to describe human shoulder joint rotation. Markers attached to the surface of the body may move during the process of motion data capture, resulting in an offset from their initial location. This leads to a change of the JCS and therefore affects the calculated shoulder joint angles. In this research study, we presented a simple marker offset model to quantify the shoulder joint errors for both static poses and dynamic activities. Specific conditions of different offsets and elbow flexion angles were studied. Results showed that the errors should not be neglected when the shoulder elevation angle was near -90° and 90°, or elbow flexion was very small. Attention should be paid to these errors for such activities especially walking and throwing.

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Keywords: errors; ISB; marker offset; shoulder.

1. Introduction

Human shoulder movement has been frequently reported in different research studies [1-4] to study the kinematic or kinetic characteristics of activities, or related movement abnormalities and injury risk factors. The human shoulder has a complicated structure made up of three bones (clavicle, scapula and humerus) and a combination of a complex of 30 muscles, five joints and many tendons and ligaments. Consequently, in a wide range of biomechanical studies, human shoulder joint movement is simplified as the movement of the humerus with respect to the thorax, without lower segmentation of the acromioclavicular and sternoclavicular joints.

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One of the most common ways to describe shoulder joint motion is using the recommendation of the International Society of Biomechanics (ISB) [5]. According to this recommendation, shoulder motions are defined as three rotations of the humerus joint coordinate system (JCS) relative to thorax coordinate system in Cardan sequences Y-X-Y order. Note that the three rotations, the order of which must be maintained, define plane of elevation θ_{S1}, elevation θ_{S2} and axial rotation θ_{S3}. The definition of the thorax coordinate system is based on bony landmarks which is unambiguous: the *y*-axis is determined by the line linking the midpoint of incisura jugularis (IJ) and the 7th cervical vertebrae (C7), and the midpoint of precessus xiphoideus (PX) and the 8th thoracic vertebrae (T8); the *z*-axis is determined by the line perpendicular to the plane made up of IJ, C7, and the midpoint between PX and T8; the *x*-axis is determined by the cross product of the *y*- and *z*- axes. However, the ISB provides two alternative definitions of the humerus JCS as described in Fig. 1.

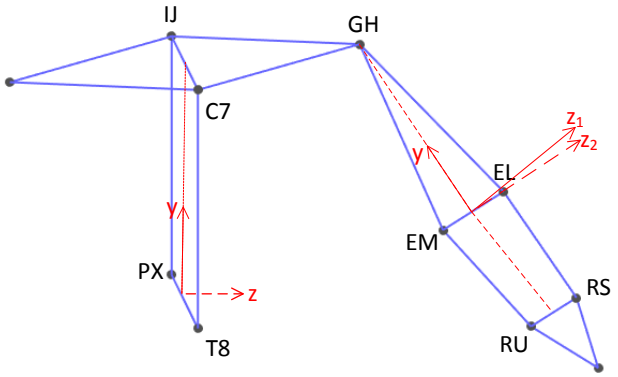


Fig. 1. Shoulder joint coordinate system determination alternatives

Both of these two methods define the *y*-axis by the vector linking the midpoint of the line between the lateral (EL) and medial (EM) epicondyles of the humerus to the glenohumeral joint (GH). In both cases, the *x*-axis is determined by cross product of the *y*- and *z*- axes as long as the *z*-axis is defined. Definition of the *z*-axis in each case is, however, different. The first method simply uses the line linking EM and EL, while the second method uses the vector normal to the plane made up of GH, the midpoint of the line between EL and EM and the midpoint of the line between the radial (RS) and ulnar (US) styloids. The second method is motivated by the high error sensitivity of direction connecting EL and EM of the first method, due to the relatively short distance between EL and EM. For example, any skin movement will result in an offset of the marker at EM (Fig. 2), which may lead to a direct shoulder joint axial rotation error when using the first method. The ISB, therefore, recommends the second method [5].

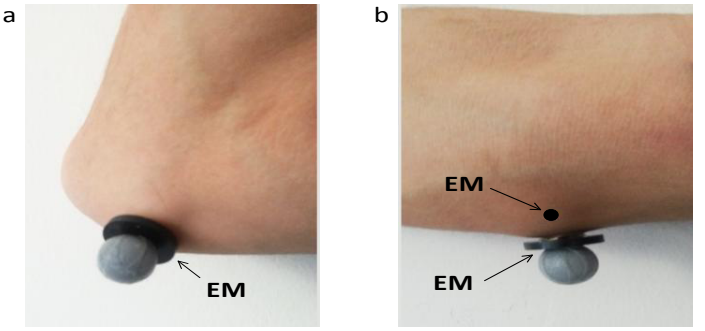


Fig. 2. Offset of marker EM to EM' due to skin movement: (a) elbow bended; (b) elbow straightened.

Although the second method avoids the distinct errors produces by the first method, it may still include an error caused by marker offset. For example, if there is an offset of the marker located at EM, then the middle point of the line EM-EL may also change. As a result, it will cause the change of the orientation of the plane formed by GH, the midpoint of EL-EM, and the midpoint of RS-RU, with the calculated joint angles affected to a different extent. In addition, if there is already an offset of the middle point of EL-EM (in the case the middle point no longer stays in the original plane), any change of the middle point of RS-RU will also affect the plane. In another words, the elbow flexion angle may also lead to errors.

Considering these possibilities for uncertainty in the determination of the shoulder joint rotation angles, the purpose of this study, therefore, is to investigate the shoulder joint angle errors caused by different marker position offsets under different elbow extension angles for the second calculation method of the ISB.

2. Methods

A model was used to create a virtual offset for the marker at EM as shown Fig. 3. The marker was shifted to a new location denoted by EM'. A simple ellipse was used to represent the elbow cross-section for convenience; the major and minor radii being the elbow width, a, and depth, b, respectively (Fig. 3). The amount of marker offset was quantified by the angle, α, between EM and EM' with respect to the centre of the ellipse. A single subject was used to estimate the dimensions for this model in the present study. The selected elbow width and depth were 80 mm and 55 mm, respectively. The length of the upper arm was 260 mm. The angle α was given a value of 5° and 10° for a small and a larger offset respectively for the purposes of the study.

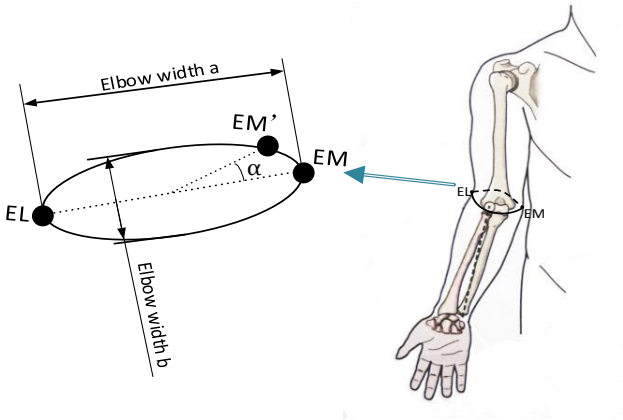


Fig. 3. Elbow marker offset model definition

Two strategies were used to study the shoulder joint angle errors under the effects of different offsets and different elbow flexion angles. Firstly, the marker position data of *static poses* were generated from a human model. Secondly, the marker position data of *dynamic activities* were collected during an experiment. In both cases an offset, in accordance with the model (Fig. 3), will be applied in order to simulate the inevitable marker offset errors.

2.1. Static poses

A model of a human trunk and arm, as shown in Fig. 1, was created for virtual marker generation based on the elbow marker offset model (Fig. 3). Virtual marker positions were determined by joint angle inputs with shoulder joint angle errors calculated with the EM marker offset to the alternative location EM'.

Specific angle inputs were chosen for the simulations, including those poses with the upper arm either vertical, horizontal or at 45° or 135° flexion. In addition, a better exhaustion of infinite combinations of inputs was also calculated from this model, which was hard to achieve through the physical experiment. Results of both are presented and analysed in the Results and Discussion section.

2.2. Dynamic activities

Marker positions during dynamic continuous movements were collected using a motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) at a sample rate of 100 Hz (Fig. 4). The volunteer was asked to do basic movements such as walking, jogging, running, throwing, lifting and a racket sport forehand and backhand. Specifically, the participant undertook a simulated action of javelin throwing for the throwing activity, lifting a box from the ground to over shoulder height for the lifting activity, and table tennis strokes for the racket sport activity. Markers were attached to the participant's body in positions similar to those shown in Fig. 1. Data collection was conducted at Nanyang Technological University (NTU) in accordance with a protocol that was approved by the NTU Institutional Review Board.

Collected data were processed with a Butterworth low-pass filter of 6-9 Hz depending upon the specific activity. Data were then reduced to a full cycle or full cycles of movement. Virtual marker offset was introduced (Fig. 3) for calculating shoulder joint angle errors, which was similar to that performed in the previous sub-section.



Fig. 4. Continuous movement running experiment

3. Results and Discussion

Results for the static poses simulations are shown in Table 1 and Fig. 5 while results for the dynamic activities experiments are shown in Table 2. In Table 1, shoulder joint angle errors of several specific static poses are listed under two different elbow flexion angles (θ_{E1}= 1°/45°) and two offset angles (α= 5°/10°). The angles, the units of which are degrees, of the inputs (first column) and outputs (other columns) are written as three-angle groups i.e. the three shoulder rotation angles in the previously specified sequential order: θ_{S1}, θ_{S2}, θ_{S3}.

Table 1. Shoulder joint angle errors of specific static poses.

Pose (input angles (°): θ_{S1}, θ_{S2}, θ_{S3})	Errors (°) under 5° offset		Errors (°) under 10° offset	
	Elbow flexion=1°	Elbow flexion=45°	Elbow flexion=1°	Elbow flexion=45°
Upper arm vertical (0, -1, 0)	14.6, -0.1, -10.9	14.6, -0.1, -14.5	26.3, -0.2, -117.2	26.3, -0.2, -26.1
Upper arm horizontal (0, -90, 0)	0.3, -0.0, 3.6	0.3, -0.0, 0.0	0.5, -0.1, -91.0	0.5, -0.1, 0.2
Upper arm forward 45° (45, -45, 0)	0.4, -0.0, 3.4	0.4, -0.0, -0.2	0.7, -0.1, -91.5	0.7, -0.1, -0.4
Upper arm up 45° (0, -135, 0)	0.4, -0.0, 3.9	0.4, -0.0, 0.3	0.7, -0.1, -90.4	0.7, -0.1, 0.7

In Fig. 5, a group of 3D colour map figures are plotted under the same conditions of two different elbow flexion angles (θ_{E1}=1°/45°) and two offset angles (α= 5°/10°). Unlike in Table 1, here the calculated errors for all the poses under inputs of the elevation of plane angle varying from -90° to 90°, and the elevation angle varying from -165° to -15° are shown. For convenience, the input of axial rotation angle was assumed as zero and only the root mean

square (RMS) of the output, rather than each of the three rotation angles, is presented. In the figure, different colours are used to represent the different magnitudes of the RMS errors according to the colour bar scale, while the input was plotted as a range of movement in space, which were half-spheres. In other words, when a person stands with his shoulder aligned with the centre of each sphere, the colours of the sphere surface follow a distribution of errors with respect to upper arm spatial orientation.

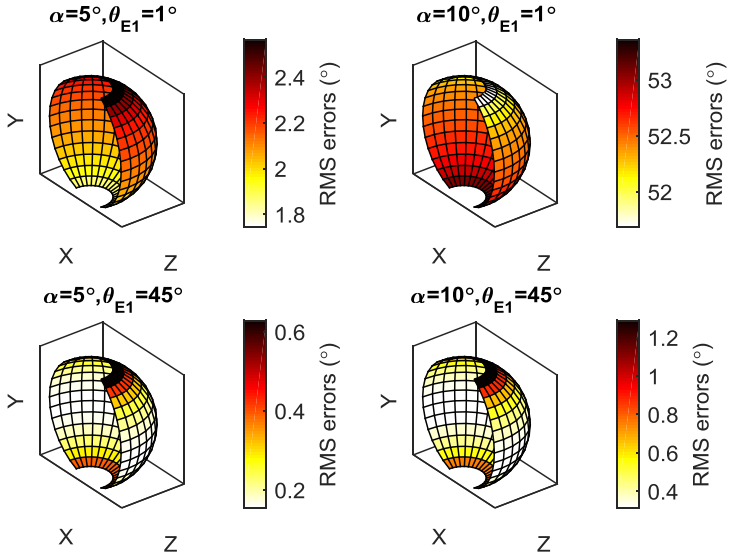


Fig. 5. Shoulder joint RMS errors of static poses (°)

In Table 2, the errors of the dynamic activities under the two offset angles (α= 5°/10°) are shown. Both the RMS and max errors are presented in three-angle groups, which is the same as in Table 1. Besides, the elbow flexion range during the activities was also calculated so as to examine the correlation between the errors and the elbow extension angles.

Table 2. Shoulder joint errors of dynamic activities

Activity	Errors (°) under 5° offset		Errors (°) under 10° offset		Elbow flexion range (°)
	RMS	Max	RMS	Max	
walking	1.6, 0.3, 3.9	3.1, 0.5, 7.0	3.1, 0.6, 7.4	6.1, 0.9, 13.2	8.3 ~ 32.4
jogging	0.8, 0.4, 0.8	1.3, 0.5, 1.3	1.6, 0.8, 1.7	2.5, 0.9, 2.6	76.5 ~ 87.3
running	0.7, 0.4, 0.7	1.4, 0.5, 1.4	1.4, 0.9, 1.5	2.7, 1.0, 2.7	81.6 ~ 108.6
throwing	1.0, 0.3, 1.5	2.6, 0.5, 4.1	1.9, 0.6, 2.8	5.1, 1.0, 7.7	12.4 ~ 134.5
lifting	0.5, 0.3, 0.9	1.8, 0.3, 2.9	1.1, 0.5, 1.7	3.6, 0.6, 5.7	22.3 ~ 72.6
forehand	0.9, 0.2, 1.8	2.5, 0.4, 5.3	1.7, 0.5, 3.5	4.9, 0.8, 10.3	13.4 ~ 90.5
backhand	0.9, 0.2, 1.1	1.6, 0.4, 2.2	1.9, 0.4, 2.2	3.1, 0.8, 4.0	16.5 ~ 80.6

As can be seen from Table 1, the errors are extremely large when the upper arm is vertical. Larger marker offset α results in larger errors for all of the angles. Very small elbow flexion angle (1°) may also lead to larger errors. When there are both a large marker offset and a small elbow flexion angle, the errors may be much bigger, especially the shoulder axial rotation.

Similar results are also shown in Fig. 5. Errors are extremely large when shoulder joint has an elevation close to -90° and 90° (the poles of the spheres are not shown for this reason). The plane of elevation has little impact on the errors, which can be seen since the colour has minor change along the longitudinal lines of the sphere. Another interesting result from the coloured distribution is that the error is smaller when the arm points downward as opposed to upward, except when both α is large and θ_{E1} is small (top-right plot in Fig. 5).

Table 2 shows that walking has the largest RMS errors, followed by throwing. This can be explained by reflecting on the results from Table 1 and Fig. 5: during walking the shoulder joint plane of elevation angle is relatively small and elbow flexion may be quite near 0°; during throwing the shoulder joint plane of elevation angle is very large and the elbow flexion angle may also by very small for short periods. Other activities, especially jogging and running, have comparatively smaller errors as can be seen.

The mathematical conversion from matrix to Euler angles [6] is complicated from a numerical point of view, which should consider rotation sequence dependence and gimbal lock errors. The "YXY" order recommend by the ISB for shoulder presentation may have the gimbal lock problem or amplitude coherence when movement either goes through a singular position (i.e. the arm alongside the trunk), or reaches the maximal range of movements [7]. Results from this study indicate that marker offsets may easily trigger such errors. In addition, small elbow flexion angles may also enlarge the errors to a great extent, especially when a big offset exists. Different activities include different shoulder ranges of motion. The errors should not be neglected especially during activities with shoulder elevations of near -90° and 90°, or elbow flexion of near 0°. In such cases, a more certain motion capture strategy or an optimized calculation method should be applied to determine the shoulder JCS with reduced potential errors.

4. Conclusion

This study has used a simple elbow marker offset model to investigate the effect of marker offsets to calculated shoulder rotation angle errors. The errors was estimated under different offset and elbow flexion angle conditions for both static poses and dynamic activities. The significant errors caused by marker offsets in specific shoulder JCS positions indicate that investigators should consider the shoulder joint angle errors depending on the specific activity being studied when applying the second method of the ISB for calculating shoulder joint rotation angles. The present study has only considered the fixed offset of the marker located at EM; a further step may be taken to study the influence of variable offsets and also of makers at other locations.

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