An alternative method to quantify scapula-humeral rhythm

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SUMMARY
Methods to calculate scapulohumeral rhythm are based on non-coplanar angle ratios. Consequently the angle sequence and axis definition of the three-dimensional shoulder joint kinematics affect the results. A new method is proposed to minimize these limitations. The scapulothoracic and glenohumeral joint contributions show significant differences at all arm elevation angles with planar angles.

INTRODUCTION
The scapulohumeral rhythm refers to shoulder joint contribution to achieve full elevation of the arm \( \theta \), with respect to the thorax. It is used to assess rotator cuff injuries since it has a linear relationship with tear size [8]. Commonly, joint contribution is assessed using flexion of arm elevation with the scapulohumeral upward rotation [4]. This approach is convenient for a clinical diagnostic when using a goniometer, but lacks accuracy in three-dimensional (3D) kinematics where joint angles do not correspond to these planar angles. The main issue is related to the nonlinear relationship between each shoulder angle and arm elevation \( \theta \). Additionally, meta-analysis becomes impossible using this method since the axis definition and angle sequence [5] differ between studies.

To improve the inter-subject and inter-study comparison, an original approach to quantify the shoulder joint contribution in arm elevation is described in the following section. This method is independent of both the definition of the local coordinate systems and the angle sequence.

METHODS
Ten right hand dominant men volunteered to participate in this study. All the subjects were healthy and without any history of shoulder dysfunction based on the DASH questionnaire [7]. Subjects were of 26 to 31 years of age; body height was from 1.72 to 1.85 m and body mass from 62 to 89 kg. The University Ethics Committee approved the measurement procedure and the subjects signed an informed consent form prior to their participation. Twenty-one markers were positioned on the thorax (6), clavicle (4), scapula (6) and arm (5) to locate the functional joint centers, define anatomical axes and determine joint kinematics (Fig. 1). Additional markers were placed on the most dorsal point of the acromioclavicular joint, trigonum spinae and angulus inferior to define the anatomical coordinate systems in accordance with ISB recommendations [9].

Each participant maintained an upright static posture without tension in the scapular girdle and performed upper-limb and setup movements for locating the sternoclavicular, acromioclavicular, and glenohumeral joint centers [3] as well as the elbow axes of rotation [6]. They comprised arm flexion-extension to abduction-adduction with a 130° range of motion in four planes in between followed by an arm circumduction, five shrugs, five shoulder protractions, and isolated elbow flexions-extensions. Finally, participants were instructed to perform three arm elevations in the sagittal, scapular and frontal planes with the thumb pointing upward as in “full-can” exercises.

Figure 1: Marker placement and chain model definition with local axes (x in red for the lateral axis, y in green for the anteroposterior axis and z in blue for the vertical axis) and the generalized coordinates \( (q_{1-16}) \).

Joint kinematics were reconstructed using a personalized chain model with four rigid segments, namely the thorax, clavicle, scapula and humerus, linked by three ball-and-socket joints (Fig. 1). The position and orientation of the thorax are determined by six degrees of freedom (dof) and the shoulder has nine. The dof correspond to Bryan angles for the sternoclavicular joint, \( q_{SC} \) (protraction, elevation and rotation), and the acromioclavicular joint, \( q_{AC} \) (protraction, upward...
rotation and tilt), and Euler angles at the glenohumeral joint, \( q_{GH} \) (plane of elevation, elevation, rotation) [2]. Joint kinematics were reconstructed using a global optimization algorithm [1]. The arm elevation angle \( \theta \) is calculated from the orientation of the arm with respect to the thorax using the rotation around the floating axis, in a zyz angle sequence.

From the static posture, the glenohumeral \( dof (q_{GH}) \) were normalized to the reference configuration, \( q_{REF} \). This is defined with the elbow flexion axis coplanar to the scapular plane, \( q_{GH}^2 = 0 \) and the humerus longitudinal axis aligned with that of the thorax using algorithm 1, so that the arm elevation \( \theta_{REF} = 0 \):

Algorithm 1: Reference configuration at glenohumeral joint.

\[
\begin{align*}
q_{GH}^2 &= 0 \\
\text{while } \theta > 0 \\
q_{GH}^{x,y} &= q_{GH}^{x,y} - \left( \frac{\partial \theta}{\partial q_{GH}^{x,y}} \right)^+ \theta \\
\theta &= \text{ArmElevation} (q) \\
\text{end}
\end{align*}
\]

where + denotes the pseudo-inverse and \( x, y, z \) correspond to axes in Fig. 1.

At each time \( t \), the joint contribution is estimated by resetting successively the joints, GH, AC and then SC, to their reference angles, according to algorithm 2. The angle \( \theta_i \) corresponds to the contribution of the \( i \)th joint to the arm elevation with respect to thorax. The analysis focused only on the raising part in the frontal plane, every 5° from 20° to 110° of arm elevation with respect to the thorax, for the glenohumeral and scapulothoracic joints. The lowering phase was not considered in this abstract.

Algorithm 2: Joint contributions in arm elevation.

at time \( t \)

0. \( \theta_{GH,AC,SC} \leftarrow \text{ArmElevation} (q) \)
1. \( q_{GH}^{t} \leftarrow q_{REF}^{GH} \)
   \( \theta_{AC,SC} \leftarrow \text{ArmElevation} (q) \)
   \( \theta_{GH} \leftarrow \theta_{GH,AC,SC} - \theta_{AC,SC} \)
2. \( q_{AC}^{t} \leftarrow q_{REF}^{AC} \)
   \( \theta_{SC} \leftarrow \text{ArmElevation} (q) \)
3. \( \theta_{AC} \leftarrow \theta_{AC,SC} - \theta_{SC} \)

Paired \( t \)-tests were used to compare the time histories of the glenohumeral \( \theta_{GH} \) and scapulothoracic \( \theta_{AC,SC} \) angles estimated by the new method to the elevation angles of the scapula and the humerus, respectively.

RESULTS AND DISCUSSION

There are significant differences between arm elevation angles and glenohumeral (p<0.01) and scapulothoracic (p<0.022) contributions. The new approach gives larger values since it accounts for the spatial contribution of each joint, rather than only a planar angle. For example the scapulothoracic joint contributes with its elevation and posterior tilt. Moreover the sum of the angles \( \theta_{GH} + \theta_{AC,SC} \) correspond to the total arm elevation using this method and could be expressed in percents. The analysis of sternoclavicular and acromioclavicular contributions could give further insight into the shoulder mechanisms and coupling motions.

CONCLUSIONS

By considering only planar angles, the joint contribution is underestimated. The new approach described here accounts for the three-dimensional contribution of shoulder joints in arm elevation.

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REFERENCES