ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

INVERSE KINEMATICS OF PUSH-UP EXERCISE USING ISB PROTOCOL FOR JCS

[1,2] Marcio de Oliveira Nunes, [1]Gustavo Leporace, [1]Alexandre Visintainer Pino, [1]Luciano Luporini Menegaldo and [1]Marcio Nogueira de Souza
[1]Federal Unversity of Rio de Janeiro, PEB – COPPE
[2]email: marcionunes@peb.ufrj.br

SUMMARY

This study consists in the inverse kinematics of the push-up exercise, using the concept of Joint Coordinate System (JCS) recommended by International Society of Biomechanics (ISB). The observed ranges of motion of the glenohumeral JCS angles were 121.46° ± 22.84°, 58.24° ± 4.77° and 102.52° ± 14.29° degrees, respectively (mean ± SD). The clavicle protraction/ retraction and elevation/ depression were 23.32 ± 8.19, 12.22 ± 6.03 degrees, respectively, and the posterior scapular tilt 35.61 ± 2.91 degrees.

INTRODUCTION

There are several methodologies to perform the inverse kinematics of human movement. Body segment attitude is commonly determined with a specific rotation sequence around axis which are orthogonal among each other [1]. In many cases this rotation does not occurs in the actual movement plane. The Joint Coordinate System (JCS) based on the concept of *floating axis*. A non-orthogonal coordinate system is used to generate angles that can be associated with a segment movement plane [2]. In this study, the JCSs for the shoulder complex are derived using joint angles definition as recommended by the International Society of Biomechanics (ISB). The particular movement addressed the push-up exercise.

METHODS

The push-up exercise was performed horizontally on the floor, with arms adducted and without knee support (Figure 1 – A). Six male volunteers participated in this study (n = 6), with age 27.2 ± 0.9 years (mean ± SD), body mass 83.8 ± 9.7 kg, and height 1.79 ± 0.04 m.

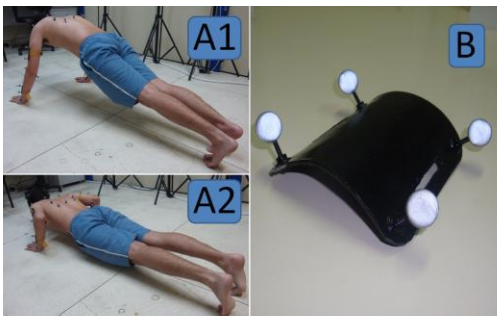

Figure 1: (A) Push-up exercise, lower phase is from 1 to 2 and upper phase is from 2 to 1; (B) Surface-Marker Cluster.

A motion analysis BTS Smart-D Motion Capture System (BTS Bioengineering, Italy) [3] was used to record the coordinates of each reflexive marker, 200 Hz of frequency sample. The coordinates were low-pass filtered (7 Hz) with an off-line Butterworth filter. The protocol of markers' placement on anatomical landmarks followed the ISB recommendations [4], as well as the orientation to calculate the local coordinate system (LCS) of each rigid body (*i.e.* thorax, clavicle, scapula, humerus and forearm) and the JCS of each joint. The joints assumed for shoulder complex were sternum-clavicular (SC), acromion-clavicular (AC) and glenohumeral (GH). GH rotation center is not captured directly [4]. It was estimated using the coefficients taken from a linear regression equation which only depends on the scapula landmarks [5].

The landmarks which belong to the anterior part of the body could not be captured by the cameras due to the position the volunteers assumed to perform the push-up. Surface-marker Clusters were built in the laboratory (Figure 1 – B) and used during the acquisition to generate a LCS embedded into each rigid body. A previous anatomical landmark calibration was recorded to reconstruct the trajectory of missing landmarks [6], before the exercise acquisition. In the exercise, anterior markers, used for calibration, were removed. The clusters were redundant, with four markers each and they were bent to suit on the body segment, minimizing the relative movement with the skin. The mathematical guidelines to use this technique are available in the literature [7].

RESULTS AND DISCUSSION

Table 1 shows the average range of motion values found the JCS angles in each joint. Figures 2 to 5 show angles associated with the first and third rotation axis of each joint during one cycle of push-up exercise. The vertical line represents the boundary between upper and lower phase.

Table 1: Range of angles for shoulder complex.

Angle	SC-α	SC-β	AC-γ	GH- γ_1	GH-β	GH- γ_2
Mean	23.32°	12.22°	35.61°	121.46°	58.24°	102.52°
SD	8.19°	6.03°	2.91°	22.84°	4.77°	14.29°

Values shown in degrees. Angles α, β and γ represent rotation around Z, X and Y axis, respectively. Data from right side.

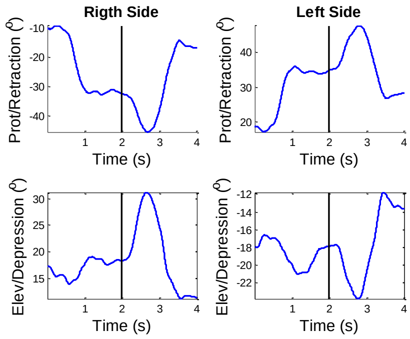

Figure 2: Sternum-clavicular JCS angles in degrees.

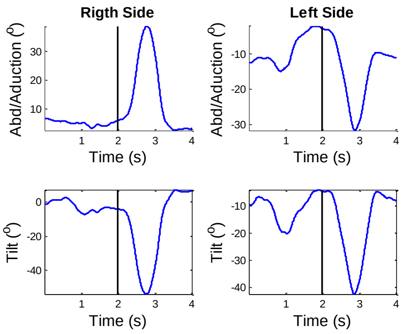

Figure 3: Acromion-clavicular JCS angles in degrees.

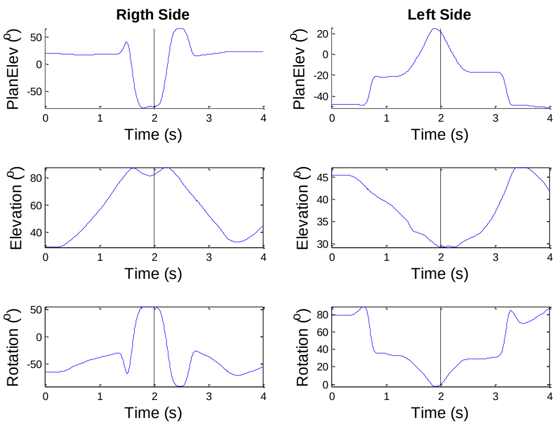

Figure 4: Gleno-humeral JCS angles in degrees.

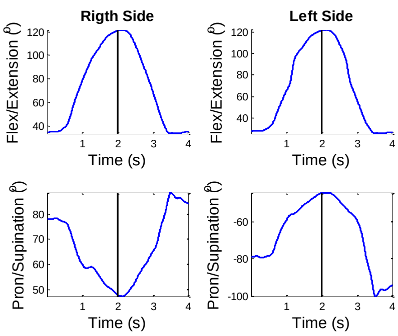

Figure 5: Elbow JCS angles in degrees.

The clavicle rotation around its longitudinal axis had values close to zero (approximately e-16) due to the way its LCS is generated [4]. Prot/Retraction (SC-α) and Elev/Depression (SC-β) angles had a high Pearson correlation, r=-0.96 and r=-0.86, respectively between right and left sides, as expected due to movement simmetry (Figure 2). Similar results are obtained for Scapula, which shows an abduction peak during the upper phase of the movement (Figure 3) and remains tilted posteriorly (AC-γ) throughout the movement. It shows, however, a negative peak during upper phase. The translation between the proximal and the distal body segments was not taken into account because both shared a common point in their joints.

Figure 4 shows the angles around $Y_{SCAPULA}$, $X_{HUMERUS}$ and $Y_{HUMERUS}$, which represent what is called plane of elevation, humerus elevation itself and rotation, respectively. The forearm, which started pronated, tended to supinate during the lower phase and recover its pronated position in the upper phase. The flexion/extension amplitude for elbow was 110.83 ± 7.66 (mean ± SD) (Figure 5). In addition, the use of surface-markers cluster was necessary to reconstruct the trajectory of markers without visual access to the cameras [6,7].

CONCLUSIONS

The study used an inverse kinematics protocol recommended by ISB and provided typical curves for JCS angles during push-up exercise.

ACKNOWLEDGEMENTS

The authors acknowledge funding for CAPES, CNPq FAPERJ and FINEP.

REFERENCES

1. Woltring HJ. Representation and calculation of 3-D joint movement. *Human Movement Science* **10**: 603-616, 1990.
2. Grood ES and Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: Application to the knee. *Journal of Biomechanical Enginnering* **105**: 136-144, 1983.
3. BTS Smart-D: High Frequency Digital System for Biomechanical Motion Analysis, *BTS Bioengineering*.
4. Ge Wu, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion – Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics* **38**: 981-992, 2005.
5. Meskers CGM, et al. In vivo estimation of the glenohumeral joint rotation center from scapular bony landmarks by linear regression. *Journal of Biomechanics* **31**: 93-96, 1998.
6. Cappozzo A, et al. Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics* **10**(4): 171-178, 1995.
7. Cappozzo A, et al. Surface-marker cluster design criteria for 3-D bone movement reconstruction. *IEEE Transactions on Biomedical Engineering*. **44**(12): 1165-1174, 1997.