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Original article

Development of a novel index of shoulder's mobility based on the configuration space volume and its link to mono-axial amplitudes

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ABSTRACT

At first sight, shoulder mobility is frequently evaluated through mono-axial amplitude. Interestingly, for diagnosing shoulder hyperlaxity or frozen shoulder, external rotation of the arm whilst at the side (ER1) is commonly used. However, by definition, a mono-axial amplitude does not fully reflect shoulder global mobility. Our goal was to propose a novel index for measuring shoulder global mobility and secondly to evaluate the link between main mono-axial amplitudes and this new index.

Twenty-eight female subjects (mean age 24.8 years) without upper limb pathology participated in the study. The movements of their right dominant arm were measured with an opto-electronic motion capture system. They performed 5 mono-axial maximal amplitude motions (axial rotations in three different postures, flexion/extension and abduction from rest) and a global range of motion exploring all the reachable space around the three axes of rotation. From this, we computed the correlation coefficient between the volume of the reachable space and each possible linear combination of the 5 mono-axial amplitudes.

Even though ER1 is often chosen to assess global mobility, it demonstrated the lowest correlation with measured joint mobility. To assess shoulder global mobility, clinical routine examination should more take into account external/internal rotation with the shoulder abducted, then abduction and finally flexion/extension. However, further clinical testing in other populations has to be done to evaluate the potential generalization of this result.

1. Introduction

Musculoskeletal disorders of the shoulder commonly present to the clinician. Interestingly, shoulder mobility needs to be appropriately assessed for multiple specialties, including physiotherapy, rheumatology, sports medicine and orthopedic surgery. Many assessments concentrate upon one axis of shoulder mobility. As an example, evaluation of shoulder laxity in a context of shoulder instability is usually assessed using external rotation (Ropars et al., 2010). This shoulder external rotation is often assessed with the arm at the side (ER1) (Balg and Boileau, 2007) and can be measured in a supine, standing or a sitting position (Tennent et al., 2003). Indeed, ER1 has the advantage that it can be evaluated even when shoulder pain and movement restriction prevents examination with 90° of abduction (ER2). ER1 rotation is particularly relevant for the diagnosis and evaluation of treatments in patients with adhesive capsulitis (Robinson et al., 2012). However, ER1 only represents part of the range of motion in one axis, the other being IR1, the maximal internal rotation. IR1 is obviously difficult to measure as it involves moving the forearm onto the abdomen. To remove this major drawback the external/internal rotation amplitude can be also measured with the arm in 90° abduction (EIR2). This would be particularly helpful in sports for which this parameter could be linked to performance such as tennis or baseball (Kibler et al., 1996; Ellenbecker et al., 2002; Schmidt-Wiethoff et al., 2004; Borsa et al., 2005; Scher et al., 2010; Shanley et al., 2011).

Global shoulder mobility around three axes appears to be difficult to determine and it is unclear whether this could be correlated solely to ER1 or EIR2 movements. Meskers et al. (1998)

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stated that obtaining 3D descriptions of shoulder motions of patients suffering from various pathologies is of vital importance in the search for etiology and pathogenesis. More recently, Jaspers et al. (2009) denoted that although three-dimensional (3D) movement analysis seems promising to provide additional insights in the pathological upper limb movements, no consensus exists on the procedures for data collection, processing, analyzing and reporting of results, or what upper limb tasks should be assessed.

Several attempts have been made to develop a more global index of shoulder mobility, i.e. some kind of 3D range of motion. The first and most obvious one is the circumduction of a distal point (elbow or hand) with respect to the shoulder's joint center (Wang et al., 1998). This is only a bi-dimensional measurement of shoulder's mobility as a part of a sphere whose center is the shoulder joint and its radius is the segment's length. Recently, Kurillo et al. (2012) proposed a simple method based on video cameras to measure this circumduction in clinical practice. The major drawback of this study is that it largely neglects axial rotation. Magermans et al. (2005) built a database of upper-arm mobility within which five ranges of motion have been measured at the shoulder. Only mono-axial motions were considered and surprisingly, external rotation was not measured. Following the same idea, Aizawa et al. (2010) made 3D measurements of joints in activities of daily living and computed the ROM around each axis during these activities. These two previous studies do not allow the evaluation of global shoulder mobility. Klopčar et al. (2007) proposed to use the arm-reachable workspace (ARW) defined by Engin and Tümer (1989) in clinical applications. The ARW is the volume measured in Cartesian space that includes all the positions that can be taken by the wrist with respect to the shoulder. It takes into account both the shoulder and the elbow. In their case study, Klopčar et al. (2007) showed that their patient's frozen shoulder ARW continually increased during 10 months of therapy.

Following the concept of the ARW, the first goal of our study was to propose an index of shoulder mobility, the Shoulder Configuration Space Volume (SCSV). In mechanics and robotics, the configuration space is the set of all reachable combination of coordinates. Considering the shoulder as the joint between thorax and humerus, these coordinates are based upon the three joint angles defined by the International Society of Biomechanics (ISB) (Wu et al., 2005) recommendations as plane of elevation orientation, elevation and axial rotation.

Unfortunately, measuring SCSV is not always feasible in clinical practice as it needs 3D motion capture devices. It is much more feasible for each of the 5 mono-axial amplitudes to be measured using simple devices such as goniometers, even if precision is not always very high. Therefore, the second goal of our study was to evaluate how these amplitudes could correlate with SCSV.

2. Methods

2.1. Participants

A group of 28 female subjects aged between 20 and 30 (mean 24.8 years, SD ± 2.8) who were right hand dominant with no known pathology in their right upper extremity were recruited. All participants signed an informed consent before their inclusion and the study was approved by the local ethical committee (Rennes University Hospital).

2.2. Experimental procedure

Only motions of the right shoulder were measured in this study. To avoid coupling between elbow flexion/extension and shoulder kinematics due to bi-articular muscles, the elbow was maintained at a constant 90° of flexion with a custom designed splint. This splint was designed so that it did not disturb shoulder motion. The measurement methodology follows the recommendations of the International Society of Biomechanics (Wu et al., 2005) that are commonly used for upper limb motion capture and analysis. Subjects were equipped with 15 reflective markers placed on anatomical landmarks on the thorax and right upper limb (see Fig. 1). The 3D displacements of these markers were recorded at 120 Hz using a 12-camera motion capture system (Vicon MX40, Oxford Metrics, Oxford, UK).

Subjects performed the same set of 6 motions under 2 different conditions: actively, the subjects performed the motions to the extent of their ability and passively, the motions were performed by an experienced investigator. The same investigator performed all the passive sets of motions. In all cases, motions were performed at maximal amplitude.

Whatever the condition (active or passive motion), the first five motions were mono-axial rotations (see Fig. 2):

Fig. 1. Overview of markers placement with rigid custom designed splint at 90° of elbow flexion in neutral prono supination.