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Superficial shoulder muscle co-activations during lifting tasks: Influence of lifting height, weight and phase

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ABSTRACT

This study aimed to assess the level of co-activation of the superficial shoulder muscles during lifting movement. Boxes containing three different loads (6, 12, and 18 kg) were lifted by fourteen subjects from the waist to shoulder or eye level. The 3D kinematics and electromyograms of the three deltoids, latissimus dorsi and pectoralis major were recorded. A musculoskeletal model was used to determine direction of the moment arm of these muscles. Finally an index of muscle co-activation named the muscle focus was used to evaluate the effects of lifting height, weight lifted and phase (pulling, lifting and dropping phases) on superficial shoulder muscle coactivation. The muscle focus was lower (more co-contraction) during the dropping phase compared to the two other phases (-13%, $p < 0.001$). This was explained by greater muscle activations and by a change in the direction of the muscle moment arm as a function of glenohumeral joint position. Consequently, the function of the shoulder superficial muscles varied with respect to the glenohumeral joint position. To increase the superficial muscle coactivation during the dropping phase may be a solution to increase glenohumeral joint stiffness.

1. Introduction

The glenohumeral joint has the greatest articular mobility in the human body (Halder et al., 2001) with its six degrees of freedom (three rotations and three translations). However this mobility is at the expense of its stability (Veeger and van der Helm, 2007). Since the shapes of the humeral head and the glenoid fossa do not ensure a complete congruence, joint stability is partially ensured by the capacity of the muscles to increase joint stiffness (Granata and Gottipati, 2008). Glenohumeral joint stiffness is mainly provided by the rotator cuff muscles (i.e. supraspinatus, infraspinatus, subscapularis, and teres minor) (Lee et al., 2000) to limit humerus head translations (Escamilla et al., 2009; Sharkey and Marder, 1995). By contrast the main function of the superficial muscles inserted on the humerus shaft, such as the deltoids, pectoralis major, and latissimus dorsi, is to produce force to move the upper limb. However, some studies have pointed out that superficial muscles may also contribute to glenohumeral joint stiffness if they are activated with antagonistic efforts (Kido et al., 2003; Veeger and van der Helm, 2007). Consequently, in movements involving glenohumeral rotations, shoulder muscle coordination should produce a trade-off between force production to generate joint torque and maintaining glenohumeral joint stiffness (Veeger and van der Helm, 2007).

Joint stiffness is increased by the co-activation (i.e. the simultaneous activation of agonist and antagonist muscles) of the muscles crossing the joint (Basmajian and DeLuca, 1985; Hogan, 1980; Morgan et al., 1978; Stokes and Gardner-Morse, 2003). The co-contraction index, which is based on agonist/antagonist joint moment and electromyography, is usually calculated to reflect joint stiffness during multi-joint dynamic exercises (Kellis et al., 2003). This index has been mainly applied to knee (Patsika et al., 2014; Rao et al., 2009) and elbow joints (Song et al., 2013). In both of these joints, the definition of agonist and antagonist muscles is obvious since the moments produced by muscle pairs are in an opposite direction. Consequently, the equation of Falconer and Winter (1985) that quantifies the co-contraction index is relevant to reflect joint stiffness. However, for ball and socket joints, the moment arms of all the muscles that cross the joint are not strictly opposed. It therefore becomes more complicated to define agonist/antagonist pairs of muscles at the glenohumeral joint especially as the orientation of the muscles changes during arm rotation.

Another index, referred to the muscle focus (MF), may be more appropriate to assess the co-contraction of the muscles surrounding the glenohumeral joint. MF was developed to assess muscle

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selectivity, i.e. the capacity to activate only muscles that contribute to movement (Yao et al., 2004). It is based on the electromyography (EMG) recordings as well as the direction of the muscle moment arms that derive from a musculoskeletal model. MF value ranges between 0 and 1; the lower the MF, the greater the muscle co-contractions, meaning that the activated muscles act in opposite directions. Thus, MF enables to evaluate the resultant of the forces produced by a given set of muscles inserted on the same bone and acting around a common joint.

Among daily life activities, lifting tasks mostly involve the glenohumeral joint where kinematics and shoulder muscle activation vary with height and load (Anton et al., 2005; Yoon et al., 2012). A high and heavy lifting leads to a greater shoulder muscle activation and may also involve glenohumeral instability which are factors that reinforce shoulder injury risks. Therefore, we may wonder whether shoulder muscle co-contractions are influenced by lifting height, weight lifted, and task phase (pulling *vs.* lifting *vs.* dropping phases) to handle change in glenohumeral joint stiffness. Besides, although it is well known that rotator cuff muscles contribute to increasing glenohumeral joint stiffness (Escamilla et al., 2009), some questions remain concerning the contribution of superficial muscles to glenohumeral joint stiffness. To the best of our knowledge, no study has evaluated co-contractions of the superficial shoulder muscles with insertion on the humerus that drive glenohumeral kinematics during lifting tasks.

Hence, this study aimed to determine the level of co-activation of superficial shoulder muscles during lifting movements using MF; more specifically the effect of lifting height, weight lifted and movement phase on muscle co-activation was assessed. According to the MF definition, the studied muscles have to respect three conditions (i) be involved in glenohumeral movement (ii) be inserted on the humerus bone, and (iii) their activation must be able to be measured by EMG. Consequently, the five superficial muscles taken into consideration for this study included the anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, and the superior head of the latissimus dorsi. The hypothesis was that increased lifting height and/or weight, and the last phase of the movement (dropping phase) must lead to a lower MF because of (i) the greater muscle activation and (ii) higher antagonistic action of the shoulder muscles.

2. Methods

2.1. Participants

Fourteen healthy male subjects volunteered in this study (mean ± SD: age, 26.1 ± 1.32 years; height, 1.80 ± 0.04 m; mass, 75.2 ± 8.82 kg). They provided a written informed consent. The protocol was approved by the University Ethics Committee (N°11-068-CERSS-D). None of the participants presented current or previous shoulder, elbow, or wrist injury.

2.2. Instrumentation and data collection

Only the right side of each participant was analyzed, assuming that the right and left sides of the upper body behaved symmetrically (Nielsen et al., 1998). In accordance to a previous kinematic shoulder model (Jackson et al., 2012) (Fig. 1), 25 reflective markers were placed on the skin of the thorax (xiphoid process, 3 markers on the manubrium, 1st and 10th thoracic vertebrae), on the right side of the clavicle (sterno-clavicular joint, acromio-clavicular joint), scapula (acromion tip, acromial angle, inferior angle, trigonum spinae, superior angle), humerus (lateral and medial epicondyles), forearm (ulnar and radial styloid process), hand (proximal part of the 2nd and 3rd metacarpus, distal part of the 2nd and

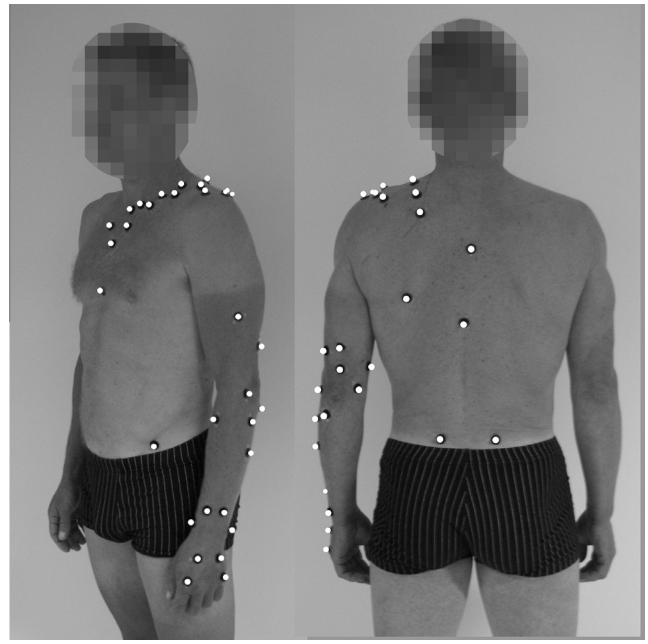

Fig. 1. Placement of the reflective markers in line with the model of Jackson et al. (2012).

5th metacarpus) and the box (four superior angles). Each trial was recorded using an 18-camera Vicon™ motion analysis system at 200 Hz (Oxford Metrics Ltd., Oxford, UK).

The electromyograms measurements (EMG) of the anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, and latissimus dorsi superior head muscles were taken with pairs of wireless surface electrodes at 1000 Hz (Trigno, Delsys Inc., Boston, MA). After shaving and cleaning the skin with alcohol, electrodes were positioned on the belly of the muscles according to the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommendations for electrode locations (Hermens et al., 2000). Kinematic and EMG signals were synchronized using the Nexus 1.8.2 software (Vicon, Oxford, UK).

The experimental tasks consisted in lifting a box between shelves. The size of the box was 0.08 × 0.395 × 0.345 m in height, width, and length respectively. To facilitate and standardize the grip of the box and ensure symmetrical movement, two handgrips were positioned on the right and left sides of the box.

2.3. Experimental procedures

Prior to the tests, isometric maximal voluntary contractions for five muscles (anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, and latissimus dorsi superior head) were randomly performed by the participant according to Ekstrom et al. (2005) and Boettcher et al. (2008) instructions (Table 1) to elicit maximum muscle activation. The participants had to exert maximum force against an experimenter during five seconds. Verbal encouragement was provided throughout the duration of the maximum effort. Two trials per muscle were performed. The rest interval was 30 s between repetitions and 60 s between trials for different muscles. The same experimenter performed all the testing sessions to reduce inter-subject variability in segment position and resistance.

To familiarize themselves with the procedure, participants performed a total of 24 sagittal lifting movements at different heights and with the three box masses. The experimental test consisted in lifting a box positioned on a shelf from hip level to a shelf located