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The influence of extreme speeds on scapula kinematics and the importance of controlling the plane of elevation

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ABSTRACT

Background: The effect of high-speed movement on scapula kinematics is not clear from the literature. Understanding these effects is important for clinicians examining, managing and understanding scapula kinematic pathologies: impingement, glenohumeral instability, muscle patterning instability and athletic injuries. The scapula tracking methodology and the lack of quantified control of the movement's plane of elevation limits previous studies. The aim of the present study is to use improved dynamic scapula kinematic measurement to assess differences during planar movements across different speeds. Athletic and maximal speeds, neglected in previous studies, are the focus.

Methods: Thirteen subjects performed slow, fast and maximal scapula plane abduction and forward flexion. A previously validated skin-fixed scapula tracker was used and optimally calibrated. A stiff board controlled the plane of elevation. Scapula kinematics were consistent with the literature.

Findings: Large and statistically significant differences were found to exist between scapula kinematics at slow speeds compared to fast and maximal speeds in lateral rotation and protraction. Although some differences were observed in the plane of elevation between speeds, these were not considered to effect the conclusions.

Interpretation: The speed of movement should be considered an important factor affecting scapula kinematics. Clinical studies analysing muscle recruitment strategies and causes of injury in athletic tasks must account for changing kinematics rather than extrapolating slow or static measures and effective clinical examination and management of pathology must take these kinematic changes into account. Control of the plane of movement is challenging and its effectiveness must be quantified in future kinematic studies.

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1. Introduction

Understanding scapula kinematics is important in the analysis of pathologies and the biomechanics of the upper limb, both in a clinical (Fayad et al., 2008; Ludewig and Reynolds, 2009; Michener et al., 2004) and athletic setting (Bell-Jenje and Gray, 2005; Kibler and Sciascia, 2010; Laudner and Sipes, 2009; Meyer et al., 2008). There is evidence that changes in scapular motion are associated with impingement patients (Ludewig and Cook, 2000) and the causes of impingement (Bey et al., 2007; Hughes et al., 2012). Alterations in scapular orientation may contribute to glenohumeral instability (Matias and Pascoal, 2006; Warner et al., 1992). Muscle patterning instability is also associated with altered scapula kinematics, where altered muscle recruitment affects the joints mechanics (Ogston and Ludewig, 2007; Qi et al., 2012). Dynamic overhead activities of the upper limb may lead to the onset of pathologies such as impingement or muscle strains, and these athletes can also exhibit altered scapula kinematics (Abrams, 1991; Gerdes et al., 2006; Kibler, 1998). Detailed studies of dynamic and athletic scapula kinematics are therefore needed.

Inverse dynamics musculoskeletal models can provide further understanding of pathology and shoulder biomechanics, using kinematics as their input. Athletic shoulder studies have tended to define kinematics from static measures (Meyer et al., 2008) or regression equations (Happee and Van der Helm, 1995; Runciman, 1993; van Drongelen et al., 2011). Regression equations are not capable of predicting long timescale changes, abnormal kinematics or loading and speed effects.

The movements of the scapula are difficult to measure since the bone slides underneath the skin (Matsui et al., 2006). Athletic movements are also performed at high speed often exploring a large range of motion and requiring significant muscle contractions. There is controversy in the literature on the effect of speed on scapula kinematics. The literature looking at this effect is limited, with only one study considering the three-dimensional nature of the scapula movement and none investigating anything approaching the maximal speeds achieved in athletic tasks (Table 1). This study aims to contribute evidence to the debate on the effects of speed on scapula kinematics.

Michiels and Grevenstein (1995) found increased participation of the glenohumeral joint relative to the scapulothoracic joint during faster arm elevation in the scapular plane between relatively

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Table 1
Details of five available studies in the literature analysing the effect of speed on scapula kinematics. 'Lat/med' in the scapula rotation column refers to lateral/medial rotation of the scapula. The 'speeds' column refers to the elevation of the humerus (°/s) or the frequency of the motion (Hz). 'EM' refers to electromagnetic, and 'scaption' to arm elevation in the scapular plane (30° from the coronal plane). * indicates that the speed was not presented (described as active arm elevation).

Study	Sample size	Motion	Scapula rotations	Speeds	Measurement technique	Sampling rate
Michiels and Grevenstein (1995)	38	Scaption	Lat/med	34°/s (4.0 s) 70°/s (2.0 s)	X-rays	1.92 Hz
de Groot et al. (1998)	7	Scaption	Lat/med	0.04 Hz 0.25 Hz (4.0 s) 0.5 Hz (2.0 s)	X-rays	50 Hz
Johnson et al. (2001)	39	Scaption	Lat/med	Static dynamic*	Goniometer & 3D EM system	Not specified
Sugamoto et al. (2002)	19	Scaption	Lat/med	0.25 Hz (4.0 s) 0.5 Hz (2.0 s)	Fluoroscopy	7.5 Hz
Fayad et al. (2006)	30	Flexion & abduction	All 3 axes	Static 30°/s (4.7 s) 80°/s (1.8 s)	3D EM system	30 Hz

slow movements, but differences were negligibly small. Scapula plane abduction is defined as abduction in a plane 30° from the coronal plane and is referred to as scaption from here. The study used two-dimensional X-ray images at low sampling frequencies, thus only lateral rotation was studied and projection errors are possible (de Groot, 1999). The speeds reached were slow (maximum time to elevate of 2 s), and are thus not applicable to athletic activities.

Another two-dimensional study concluded that scapula kinematics could be interpolated from statically recorded positions of the bones, but only at sub-maximal speeds (de Groot et al., 1998). A goniometer and ST study then contradicted these findings, presenting a difference in scapular lateral rotation (the two other rotations were not presented) in static versus dynamic humeral elevation in the scapular plane (Johnson et al., 2001). The larger sample size in this study (Table 1) may make the conclusions more valid. A two-dimensional fluoroscopy study found that glenohumeral and scapulothoracic ratios were not fixed at high speed and differed significantly from those at low speeds (Sugamoto et al., 2002), although again the high speeds were relatively slow.

The most recent work utilised three-dimensional recording methods with a good sample size (Table 1) and concluded that scapular rotations did not differ between fast and slow movements (Fayad et al., 2006). The study also concluded that interpolation of statically recorded scapula rotations was not representative of dynamic scapula kinematics. The Acromial Method (AM) of tracking was used although it is not clear exactly where on the scapula the cluster was placed. It is presumed that the optimised placement of this method was not used, as published work on this is more recent than that paper (Shaheen et al., 2011a,b). The AMs accuracy remains lower in general than the scapula tracker (ST) method (Karduna et al., 2001; Prinold et al., 2011). The speeds in this study were the highest presented, but still small compared to athletic movements. It is the hypothesis of the current study that high speeds will effect a change in scapula kinematics.

Most gold-standard methods of scapula tracking are inherently static or only applicable in slow movements. Recent work has determined optimal methodologies for scapula tracking in dynamic activities utilising optimised marker placement (Shaheen et al., 2011a,b), scapula position calibration (Prinold et al., 2011) and Palpation (Shaheen et al., 2011a,b).

A limitation of all the speed effect studies discussed is that there is no acknowledgment of control or quantitative evaluation of the plane of elevation (PoE) in the movements. Although one study used an apparatus to constrain the feet and head (de Groot et al., 1998), the effect of this was not discussed. The most recent study (Fayad et al., 2006) looked at and compared three planes of elevation, finding significant differences in scapula rotation between the planes. These findings are consistent with other literature (Ludewig et al., 2009). However, the control of the plane of movement is not mentioned (Fayad et al., 2006). Since the plane has a significant effect on scapula kinematics it is vital that this parameter is controlled and thoroughly considered.

The hypothesis is therefore that high-speed movement will lead to different upper limb kinematics and increased difficulties in controlling the movement. The aim of the present study is to use improved scapula kinematic measurement techniques to assess these potential differences in scapular kinematics during simple, planar movements across different speeds, including athletic and maximal speeds. A robust description of the planes of elevation will also be considered.

2. Methods

2.1. Subjects

Sixteen healthy male subjects with no history of shoulder pathology participated in this study (age 25 ± 2 years). Informed consent was obtained from all subjects. Two subjects were excluded due to marker occlusion, and one subject due to incorrect speed control. The total sample size was thirteen.

2.2. Instrumentation/measurements

Kinematic data was collected using a 9-camera optical motion tracking system (Vicon, Oxford, UK) at 200 Hz. A lightweight scapula tracker (ST) was used with a cluster of three retro-reflective markers (Prinold et al., 2011). The device consists of a base attached to the mid portion of the scapula spine and an adjustable foot positioned on the meeting point between the acromion process and the scapula spine. This position has previously been found to be optimal for the attachment of skin-fixed scapula clusters (Shaheen et al., 2011a,b).

A Palpator (Johnson et al., 1993; Shaheen et al., 2011a,b) is used as a gold standard measurement of the scapula to calibrate the position of the ST cluster of markers to the scapula landmarks. This calibration was performed once for scaption trials; 90° humerothoracic elevation in the scaption plane, and once for forward flexion trials; 90° humerothoracic elevation in the frontal plane (Prinold et al., 2011). These calibration transformations were then applied to each trial of that subject. Errors associated with static palpation of landmarks are small at approximately 2° (de Groot, 1997).

A set of twenty-one retro-reflective markers was also used to track the thorax, clavicle, humerus and forearm segments (Shaheen et al., 2011a,b, Wu et al., 2005). The positions of the elbow epicondyles were defined as a rigid offset from a humerus technical frame. The glenohumeral centre of rotation was found with a least squares sphere fitting method (Gamage and Lasenby, 2002) without bias compensation as suggested in the literature (Halvorsen, 2003), due to a more recent

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