

## Original article

## Scapular positioning assessment: Is side-to-side comparison clinically acceptable?

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## ABSTRACT

Clinicians routinely assess scapular position and motion of the symptomatic shoulder taking as reference for the contralateral asymptomatic side. A different positioning between sides (scapular asymmetry) is often assumed as pathological, however, the symmetry of scapular kinematics in healthy individuals is yet to be demonstrated. This study tested the hypothesis of scapular symmetry during arm elevation. The 3-dimensional scapular positioning of the dominant and non-dominant shoulders of fourteen healthy young adults was simultaneously measured by a 6 degrees of freedom electromagnetic tracking device at three positions of arm elevation: rest, hands on hips, and 90° of shoulder abduction with internal rotation. The scapula on the dominant shoulder showed greater retraction ( $P < 0.001$ ;  $\eta^2_p = 0.68$ ) and upward rotation ( $P < 0.001$ ;  $\eta^2_p = 0.70$ ) at all positions of arm elevation. From rest to 90° of shoulder abduction, the mean ( $\pm$ SD) amount of scapular angular displacement was, respectively for dominant and non-dominant shoulders, 7.2° ( $\pm 7.8^\circ$ ) and 7.2° ( $\pm 4.4^\circ$ ) for retraction, 17.4° ( $\pm 5.1^\circ$ ) and 17.8° ( $\pm 6.4^\circ$ ) for upward rotation, and 3.8° ( $\pm 3.6^\circ$ ) and 0.9° ( $\pm 3.6^\circ$ ) for posterior tilting. These findings suggest that scapular positioning on the thorax are not the same despite the observation of an identical kinematic pattern during arm elevation. This should be taken into consideration when comparing scapular position and motion of symptomatic and contralateral shoulders.

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## 1. Introduction

Patients with subacromial impingement syndrome and glenohumeral instability often exhibit abnormal scapular kinematics of the ipsilateral shoulder during arm elevation, an impairment known as scapular dyskinesis or scapulothoracic dysfunction (Lukasiewicz et al., 1999; Ludewig and Cook, 2000; Matias and Pascoal, 2006; McClure et al., 2006; Ogston and Ludewig, 2007). Potential biomechanical mechanisms for such deviations include the tightness of the pectoralis minor muscle and of the glenohumeral joint peripheral connective tissue, augmented thoracic kyphosis, and impaired motor control of the scapulothoracic muscles (Kebaetse et al., 1999; Ludewig and Cook, 2000; Finley and Lee, 2003; Borstad, 2006; Matias and Pascoal, 2006; Yang et al., 2009). It is widely accepted that executing specially designed exercises and manual techniques to correct these mechanisms is essential for improving function and reducing pain (Wang et al., 1999; Voight and Thomson, 2000; Sahrmann, 2002; Burkhart et al., 2003; Ludewig and Borstad, 2003; Borstad and Ludewig, 2006; Cools et al., 2007); therefore, identifying abnormal patterns

of scapular kinematics is a key element of shoulder examination. However, the assessment of a bi-directional gliding mechanism combined with 3 rotations that is inter-dependent of the position and motion of the thorax, clavicle and arm, and covered by muscles and skin, can be challenging. Motion tracking devices allow 3-dimensional (3D) analysis of the shoulder motion with accuracy but these are very expensive and time-consuming to use in most clinical settings. A clinical instrument that can easily measure 3D scapular kinematics is yet to be developed, and the combination of several tape measurements between the dorsal spine and the scapula to estimate scapular position and orientation has shown disappointing correlations with tracking devices (Borstad, 2006; Morais, 2009). In addition, the relatively large between-subject variability of scapular position and motion seen in both healthy and symptomatic individuals poses difficulties to create valid and reliable cut-off values between what may be considered normal and what may be assumed as abnormal (de Groot, 1997; Ludewig and Cook, 2000; Borstad and Ludewig, 2002; Nijs et al., 2005; Lewis and Valentine, 2007).

A convenient solution to overcome part of these issues may involve comparing the ipsilateral shoulder kinematics with the contralateral side. Side-to-side differences in several aspects of the shoulder mechanics such as the range of motion (ROM), strength and

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proprioception are, to some extent, negligible (Ellenbecker and Davies, 2000; Aydin et al., 2001; Crockett et al., 2002; Valentine and Lewis, 2006; Roy et al., 2009). Moreover, the contralateral asymptomatic shoulder may provide a reliable basis for comparisons over time (e.g. to assess the result of the intervention) because the within-subject variability of scapular kinematics between measurements is low ( $1^{\circ}$ – $2^{\circ}$ ) (Borstad and Ludewig, 2002). Indeed, this procedure is commonly used in clinical settings, where the pattern of scapular position and motion during arm elevation is assessed using the contralateral side as a reference of the normal behavior. For clinical decision making, it is assumed that side-to-side scapular kinematics in healthy individuals is relatively identical or symmetrical, therefore, a different positioning between sides (scapular asymmetry) is deemed as dyskinetic (Kibler, 1998; Kibler et al., 2002; Donatelli and Wooden, 2010). However, robust evidence supporting symmetric 3D scapular position and motion during arm elevation in healthy individuals is lacking, confounding the interpretation (Lukasiewicz et al., 1999; Oyama et al., 2008; Uhl et al., 2009; Yoshizaki et al., 2009; Yano et al., 2010; Matsuki et al., 2011).

The purpose of this preliminary study was to describe and compare 3D scapular kinematics of dominant and non-dominant shoulders in healthy individuals. Preliminary data about scapular orientation at rest and during arm elevation between sides in this population was deemed necessary to clarify side-to-side comparisons performed in clinical settings to assess scapular positioning and dyskinesia. Our hypothesis was that in healthy subjects the scapula on the dominant side has the same 3D positioning as the contralateral scapula during arm elevation, supporting the clinical belief that the non-affected side could be assumed as reference of the normal scapular kinematics.

## 2. Methods

### 2.1. Subjects

Fourteen young adults ( $n = 14$ ), seven males, thirteen right-handed, mean ( $\pm$ SD; range) age of 21.1 years old ( $\pm 2.2$ ; 18–26), mean height of 1.66 m ( $\pm 0.11$  m; 1.54 m–1.90 m), and mean body weight of 65.8 kg ( $\pm 12.3$  kg; 51.5 kg–85.9 kg), volunteered to participate in this study. None of the subjects had a history of pain on the upper quadrant over the past 6 months or the involvement on asymmetric overhead sports activities on a regular basis. One investigator (N.M.), a physical and manual therapist with 12 years of experience in musculoskeletal conditions, attested that the participants had no side-to-side differences in the ROM, strength or motor abnormalities in scapular motion (e.g. winging) on both shoulders (Ombregt et al., 2003), leg length discrepancy above 15 mm (Beaudoin et al., 1999), and 3-dimensional rib cage and spinal deformations as scoliosis (Souchart and Ollier, 2002). All participants were informed about the purposes and procedures of the study, having signed the informed consent. The study had the approval of the Scientific Council of the Interdisciplinary Centre for the Study of Human Performance (CIPER) at the Faculty of Human Kinetics, Technical University of Lisbon, Portugal, regarding the protection of the rights of the participants and the confidentiality of the data.

### 2.2. Instruments

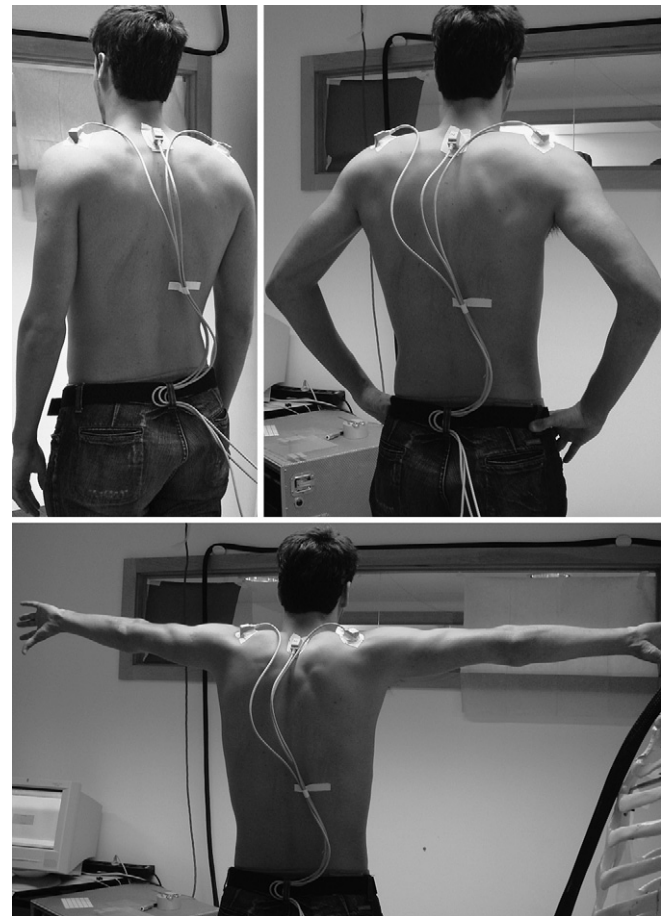
The 3D kinematics of the scapulas and thorax were collected by means of a 6 degrees of freedom (6DOF) electromagnetic tracking device (Hardware: “Flock of Birds system” Ascension Technology; Software: Motion Monitor v 7.0). The device allows simultaneous tracking and registration of the position and orientation of several sensors, when they are inserted in an extended electromagnetic field. According to the manufacturer, the static root-mean square

accuracy of the sensors at a distance from the transmitter of 1.52 m is up to 7.6 mm and  $0.5^{\circ}$ , respectively for position and orientation. Previous calibration of the electromagnetic field in our lab revealed a translational residual measurement error of about 3 mm for each coordinate and a rotational root-mean square area of less than  $2^{\circ}$  for each axis of rotation.

### 2.3. Procedures

The elevation of both arms was performed from the standing upright position with the arms alongside the trunk ( $0^{\circ}$ ) to hands on hips ( $45^{\circ}$ ) and then to  $90^{\circ}$  of shoulder abduction with internal rotation (thumbs pointing downwardly) (Fig. 1). The natural and self-balanced upright posture of the subjects was obtained following a standardized protocol (Greenfield et al., 1995). We intended to simulate closely the assessment of scapular positioning in clinical settings and this specific positioning of the arms and hands is often referenced to as such in the clinical literature, known as the lateral scapular slide test or LSST (Kibler, 1998; Voight and Thomson, 2000; Nijs et al., 2007; Donatelli and Wooden, 2010). To obtain symmetry in the positioning of the arms and hands, the testing protocol was practiced individually under the supervision of one investigator. After a few trials, subjects were able to perform the protocol repeatedly without any adjustment, thereby initiating the procedures for kinematic recording.

Sensors were firmly attached with double-sided adhesive tape and reinforced with sports tape to the skin overlying the spinous process of the first thoracic vertebra (T1) and the superior flat



**Fig. 1.** Sensors set-up and the three positions of arm elevation used to collect simultaneous bilateral scapular kinematics: rest or  $0^{\circ}$  (top left); hands on hips or  $45^{\circ}$  (top right); and  $90^{\circ}$  of shoulder abduction with full internal rotation (bottom).

surface of the acromion process of each scapula (Fig. 1). The coupling was further tested manually to ensure that no displacement could occur between the skin and the sensors, reducing artifact (Ludewig and Cook, 2000; Karduna et al., 2001). A fourth sensor, mounted on a hand-held stylus (approximately 6.5 cm), was used for the digitalization of standardized bony landmarks in order to link sensors to the local anatomical coordinate system and to subsequently calculate segments and joint rotations (Wu et al., 2005). One investigator manually identified selected bony landmarks and then digitized them using the stylus (Table 1). The error associated to the palpation method on 3D orientation of the thorax and scapulas has been previously estimated in approximately 2° (de Groot, 1997). Each position of the arms was maintained for a period of approximately 5 s for recordings.

2.4. Kinematic processing

Kinematic data were recorded at a sampling rate of 100 Hz and filtered with a low-pass 10-Hz Butterworth filter. Joint angles were calculated and expressed as Euler angles decompositions of the relative orientation of the scapulas with respect to the thorax. Thorax and scapulas local coordinate systems were calculated based on standard bony landmarks (Table 2). Scapular rotations were defined with the y-axis pointing upward, the x-axis from left to right and the z-axis backward. The YX'Z'' Euler sequence was used to describe scapular orientation. The first rotation was defined as protraction (positive)/retraction of the scapula (y-axis). The second rotation was defined around the twice rotated scapular x-axis: upward (positive)/downward rotation. The third rotation was defined around the rotated scapular z-axis: anterior/posterior (positive) tilting.

2.5. Data analysis

Statistical analysis was made by means of SPSS (version 17.0, SPSS Inc., Chicago, Illinois, USA). Three two-way repeated measures

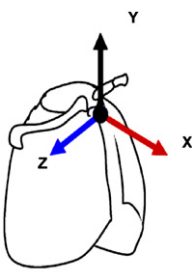
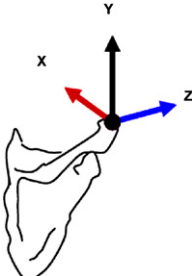
ANOVAs with interaction were performed to assess the effects of arm position (0°, 45° and 90° of shoulder abduction) and side (dominant and non-dominant shoulders) on scapular protraction/retraction, upward/downward rotation, and tilting. The Shapiro–Wilk and the Levene tests revealed that all data followed a normal distribution and that homoscedasticity could be assumed, respectively. When analysis of variance was significant, post-hoc comparisons were followed using Bonferroni correction to identify differences between any two pairs of means. 95% confidence intervals (CIs) were used to estimate the range of the mean differences between sides for each scapular rotation, and to assess the magnitude of scapular side-to-side differences throughout shoulder abduction. Significance level was set at  $P < 0.05$  and the power acceptable when superior to 0.8 (Maroco, 2007).

To complement inferential statistics, the effect size was estimated through Eta<sup>2</sup> partial ( $\eta^2_p$ ). Eta<sup>2</sup> partial measures the proportion of variation and error attributable to the factor excluding other factors from the total non-error variation, which in other words means that it describes the amount of variation of the dependent variable (scapular kinematics) explained by the factors arm position and side. For values  $\eta^2_p > 0.5$  the effect size is considered very large;  $0.25 < \eta^2_p \leq 0.50$  as large;  $0.05 < \eta^2_p \leq 0.25$  as moderate; and for  $\eta^2_p \leq 0.05$  the effect is small (Maroco, 2007).

3. Results

Scapular behavior throughout shoulder abduction, according to hand dominance, is shown in Fig. 2. The dominant shoulder demonstrated a more retracted ( $P < 0.001$ ) and upward rotated ( $P < 0.001$ ) positioning of the scapula at all levels of shoulder abduction (Fig. 2). For both scapular rotations the effect size was very large (protraction,  $\eta^2_p = 0.68$ ; upward rotation,  $\eta^2_p = 0.70$ ) and the power of the statistical test was high (1.0). Dominant scapula was, in average, also more posterior tilted than the non-dominant scapula but differences did not reach statistical significance ( $P = 0.178$ ; power = 0.27) and the effect size was low ( $\eta^2_p = 0.07$ ).

**Table 1**  
Bony landmarks used on the definition of the local coordinated system of the thorax and scapulas, according to Wu et al. (2005).

Segment	Bony landmarks	Local coordinate system
	Processus Xiphoideus (PX)	$Y_t$ : The line connecting the midpoint between PX and T8 and the midpoint between IJ and C7 pointing upward $Z_t$ : The line perpendicular to the plane formed by IJ, C7 and the midpoint between PX and T8 pointing to the right $X_t$ : The common line perpendicular to $Z_t$ and $Y_t$ -axis pointing forward $O_t$ : The origin coincident with IJ
	Incisura Jugularis (IJ)	
	Processus Spinosus of the 7th cervical vertebra (C7)	
	Processus Spinosus of the 8th thoracic vertebra (T8)	
	Processus Coracoideus (PC)	$Y_s$ : The common line perpendicular to $X_s$ and $Z_s$ -axis pointing upward $Z_s$ : The line connecting TS and AA pointing to AA $X_s$ : The line perpendicular to the plane formed by AI, AA and TS, pointing forward. Note that because of the use of AA instead of AC, this plane is not the same as the usual plane of the scapula bone $O_s$ : The origin coincident with AI
	Acromioclavicular joint (AC)	
	Angulus Acromialis (AA) Trigonum Spinae (TS)	
	Angulus Inferior (AI)	

**Table 2**

Studies that have compared side-to-side scapular kinematics in healthy populations.

Authors	Methods	Condition	Findings
Lukasiewicz et al. (1999)	3D electromechanical digitizer; non-impaired subjects ( $n = 20$ ); 8 males; age (mean $\pm$ SD) $34.4 \pm 7.5$ ; 15 right-handed	Static; arm elevation in the scapular plane ( $40^\circ$ to the frontal plane) measured at rest, $90^\circ$ and full ROM	Right scapula more downwardly rotated ( $\sim 6^\circ$ ) than the left one at the resting position (protraction and tilting not reported); similar magnitude of scapular upward rotation between sides at the ROM studied (data not available)
Oyama et al. (2008)	6DOF electromagnetic tracking device; asymmetric overhead sport athletes ( $n = 43$ ); all males; age, $\sim 22$ ; 40 right-handed	Static; resting position	Dominant scapula more protracted ( $\sim 4^\circ$ ) and anteriorly tilted ( $\sim 2^\circ$ ) ( $P < 0.05$ ); no statistical differences in upward rotation
Uhl et al. (2009)	6DOF electromagnetic tracking device; asymptomatic subjects ( $n = 21$ ); age, $24 \pm 3$ ; 11 males; 19 right-handed Position at rest offset to $0^\circ$	Dynamic; arm elevation in the scapular plane ( $45^\circ$ to the frontal plane) and sagittal planes measured from $0^\circ$ to $150^\circ$	71% (sagittal plane) to 77% (scapular plane) of the subjects showed scapular asymmetry (defined as a minimum of $8^\circ$ differences between sides for scapular protraction and/or $7^\circ$ for tilting and/or 1.6 cm for scapular elevation)
Yoshizaki et al. (2009)	3D motion analyzer (infrared cameras); college students ( $n = 18$ ); age, 24 (range, 19–30); 14 males; 14 right-handed Position at rest offset to $0^\circ$	Dynamic; arm elevation in the scapular plane ( $30^\circ$ to the frontal plane) measured full ROM	No differences between dominant and non-dominant shoulders kinematics ( $P > 0.05$ ); similar magnitude of scapular upward rotation between sides at the ROM studied; protraction and tilting not assessed
Yano et al. (2010)	3D motion analyzer (infrared cameras); college students ( $n = 21$ ); age, 23.7 (range, 18–32); 19 right-handed; 17 males Position at rest offset to $0^\circ$	Dynamic; arm elevation in scapular plane ( $30^\circ$ to the frontal plane) measured full ROM	No differences between dominant and non-dominant shoulders kinematics ( $P > 0.05$ ); similar magnitude of scapular retraction, upward rotation and posterior tilting between sides at the ROM studied
Matsuki et al. (2011)	3D-2D fluoroscopy; former athletes ( $n = 12$ ), including asymmetric overhead sports athletes ( $n = 4$ ); all males; age, 32 (27–36); all right-handed Position at rest offset to $0^\circ$ for protraction and tilting	Dynamic; arm elevation in the scapular plane measured full ROM	Dominant scapula more downwardly rotated ( $10^\circ$ at rest, $4^\circ$ at maximum arm elevation) than non-dominant ( $P < 0.001$ ); similar magnitude of retraction and posterior tilting between sides during elevation, upward rotation distanced by $4^\circ$
Current study	6DOF electromagnetic tracking device; young adults ( $n = 14$ ); 7 males; age, $21.1 \pm 2.2$ ; 13 right-handed	Static; arm elevation in the frontal plane measured at rest, hands on hips and $90^\circ$ of shoulder abduction with full internal rotation	Dominant scapula more retracted ( $\sim 20^\circ$ ) and upward rotated ( $\sim 15^\circ$ ) at all selected positions of arm elevation ( $P < 0.001$ ); similar magnitude of scapular rotations between sides at the ROM studied, but dominant scapula slightly more posteriorly tilted ( $\sim 3^\circ$ ) at $90^\circ$ of abduction ( $P < 0.027$ )

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; 6DOF, 6 degrees of freedom; ROM, range of motion.

Differences between sides were verified early, at the resting position (scapular posture), with mean differences (95% CI) of  $19.3^\circ$  ( $15.9^\circ$ – $22.7^\circ$ ) for protraction,  $16.7^\circ$  ( $12.8^\circ$ – $20.7^\circ$ ) for upward rotation, and  $1.3^\circ$  ( $0.2^\circ$ – $2.5^\circ$ ) for tilting. From rest to  $90^\circ$  of abduction, both shoulders increased scapular retraction ( $P < 0.001$ ;  $\eta^2_p = 0.59$ ; power = 1.0), upward rotation ( $P < 0.001$ ;  $\eta^2_p = 0.86$ ; power = 1.0) and posterior tilting ( $P < 0.001$ ;  $\eta^2_p = 0.45$ ; power = 1.0). The mean ( $\pm$ SD) amount of scapular angular displacement was, respectively for dominant and non-dominant shoulders,  $7.2^\circ$  ( $\pm 7.8^\circ$ ) and  $7.2^\circ$  ( $\pm 4.4^\circ$ ) for retraction,  $17.4^\circ$  ( $\pm 5.1^\circ$ ) and  $17.8^\circ$  ( $\pm 6.4^\circ$ ) for upward rotation, and  $3.8^\circ$  ( $\pm 3.6^\circ$ ) and  $0.9^\circ$  ( $\pm 3.6^\circ$ ) for posterior tilting. Compared to the resting position, mean scapular side-to-side differences at  $90^\circ$  of shoulder abduction have changed little. Individual differences between side-to-side differences recorded at rest and at  $90^\circ$  of shoulder for each scapular rotation are displayed in Fig. 3. A small interaction of side and arm abduction was found only for scapular tilting at  $90^\circ$  of abduction ( $P = 0.027$ ;  $\eta^2_p = 0.15$ ; power = 0.65) with an increase of the asymmetry (Fig. 2).

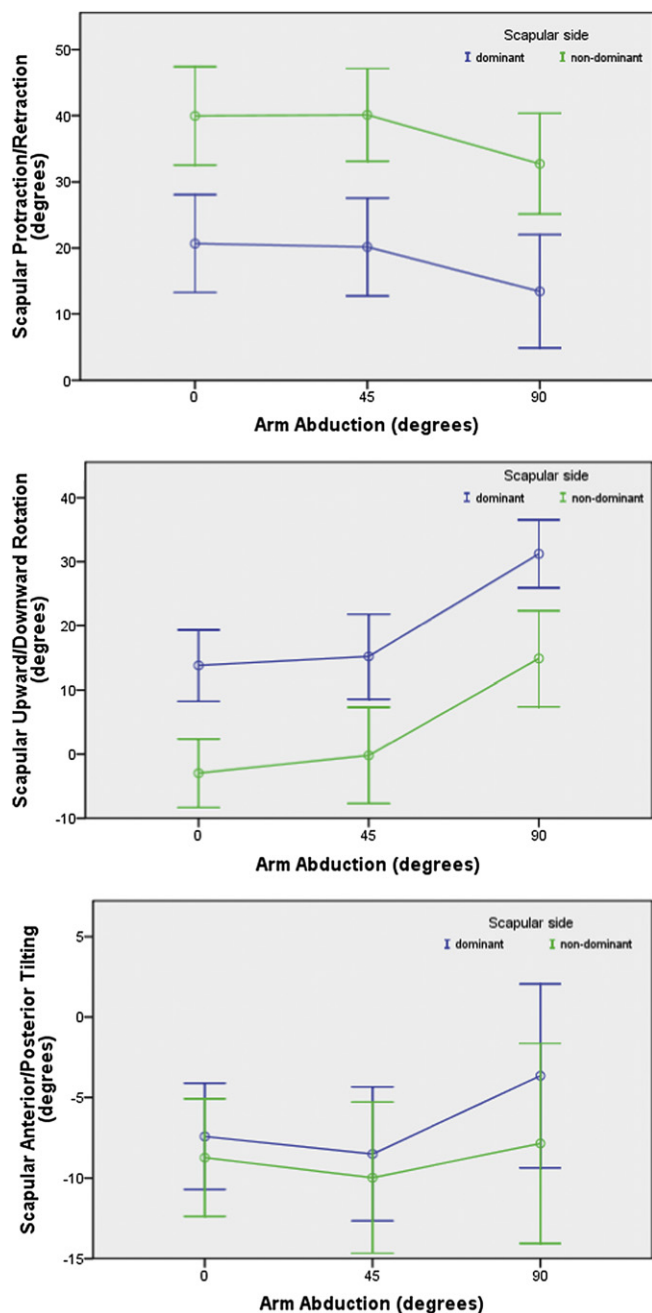
#### 4. Discussion

This study showed that at rest and throughout shoulder abduction, scapular positioning differs between dominant and non-dominant arms. The initial hypothesis of matched scapular positioning between sides could not be confirmed, therefore, we must accept that side-to-side differences might be expected in healthy shoulders.

The symmetry of scapular kinematics is still disputed despite its common application in clinical settings for assessing scapular

position and motion. This issue has been poorly addressed in the literature, but the majority of the studies confirmed statistical differences between sides in the scapular kinematics of healthy populations (Table 2). Using a 3D electromechanical digitizer, Lukasiewicz et al. (1999) reported side-to-side differences in scapular upward/downward rotation of non-impaired subjects. Similar results were also obtained between dominant and non-dominant shoulders through 2D–3D fluoroscopy imaging in a group of healthy ex-athletes (Matsuki et al., 2011). By means of a 6DOF electromagnetic tracking device, Uhl et al. (2009) verified a prevalence of 71%–77% of asymmetric scapular motion in any plane of orientation in asymptomatic subjects. Using a 6DOF electromagnetic tracking device, overhead sports athletes showed a multi-planar pattern of asymmetry namely in scapular protraction/retraction (internal/external rotation in the original study) and tilting, but not upward/downward rotation (Oyama et al., 2008). The observation of asymmetric scapular positioning in this study was not surprising, given that most kinematic investigations demonstrated side-to-side differences in scapular position and motion of healthy populations. However, we added that hand dominance might have an important effect on scapular kinematics, specifically on scapular protraction and upward rotation ( $\eta^2_p > 0.65$ ), therefore it should be accounted clinically and in future researches related to scapular kinematics. Divergences across studies, regarding the pattern and the magnitude of scapular asymmetry, are possibly related to several important methodological differences (i.e., the plane of arm elevation and the specific range of motion studied, static versus dynamic conditions, differing measurement techniques and instruments, simultaneous versus consecutive

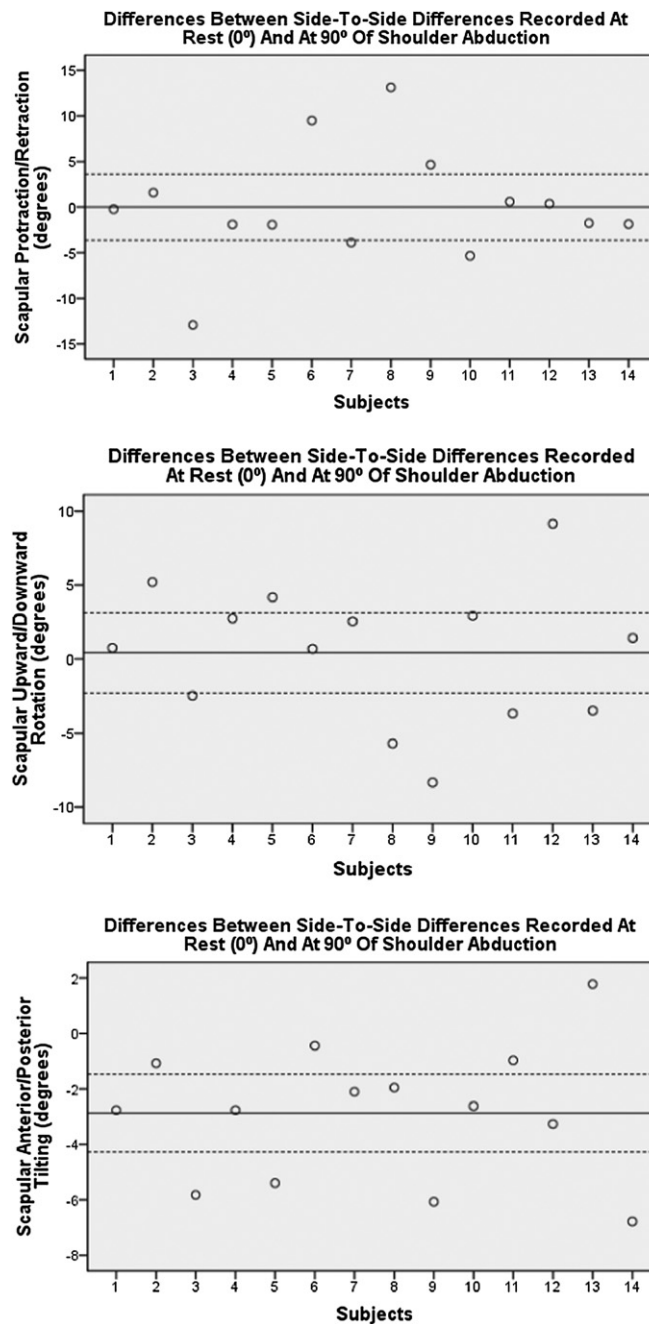




**Fig. 2.** Mean scapular rotations at 0°, 45°, and 90° of arm abduction for dominant and non-dominant arms: protraction/retraction (top); upward/downward rotation (middle); anterior/posterior tilting (bottom). The error bars illustrate the standard deviation and positive values signify protraction, upward rotation, and posterior tilting. Dominant scapula was always more retracted ( $P < 0.001$ ), upwardly rotated ( $P < 0.001$ ) and posteriorly tilted (not statistically significant) at all arm positions. Between 0° and 90° of abduction, differences were significant for all scapular rotations ( $P < 0.001$ ). No interaction effect of arm position and side was found, except for scapular tilting at 90° of abduction ( $P < 0.027$ ).

recordings, and distinctive methods used to calculate angles), and different populations studied (e.g. athletes versus non-athletes) (Table 2).

The mean amount of scapular angular displacement from 0° to 90° of shoulder abduction found in this study was within the range of previous studies, except for tilting (Ludewig et al., 1996; Meskers et al., 1998; Lukasiewicz et al., 1999; McClure et al., 2001; Yano et al., 2010; Matsuki et al., 2011). This happened mainly because we encouraged internal rotation of the shoulders at 90° of abduction



**Fig. 3.** Differences between scapular side-to-side differences recorded at rest (0°) and at 90° of shoulder abduction: protraction/retraction (top); upward/downward rotation (middle); anterior/posterior tilting (bottom). Full lines represent the mean differences and dotted lines represent the upper and lower 95% confidence intervals limits of the mean differences. Scapular protraction/retraction: mean differences = 0.005°; upper limit = 3.618°; lower limit = -3.627°. Scapular upward/downward rotation: mean differences = 0.421°; upper limit = 3.123°; lower limit = -2.281°. Scapular anterior/posterior tilting: mean differences = -2.875°; upper limit = -1.474°; lower limit = -4.276°.

(thumbs pointing downwardly) instead of the usual external rotation (thumbs pointing upwardly), resulting in less scapular posterior tilting (Borich et al., 2006). Some clinical studies suggested that side-to-side differences in asymptomatic individuals are common but progressively decrease from rest to 90° of shoulder abduction with internal rotation (Kibler, 1998; Odom et al., 2001; McKenna et al., 2004). We could not confirm such pattern of dependency between the magnitude of scapular symmetry and position of the

arms. The results of the ANOVAs tests showed that the combination of the independent variables side and arm position could not explain the variation found for scapular protraction/retraction and upward/downward rotation. A small interaction effect was found for tilting, being the dominant scapula a little more posteriorly tilted ( $\sim 3^\circ$ ) than the non-dominant scapula at  $90^\circ$  of shoulder abduction. This goes in the opposite direction to that reported previously, i.e., more rather than less asymmetry. The disagreement is probably related to differing measurement techniques and instruments (Morais, 2009), i.e., linear distances (translation) and measuring tape (Kibler, 1998; Odom et al., 2001; McKenna et al., 2004) versus Euler angles (rotation) and a 6DOF electromagnetic tracking device (current study). The small yet augmented scapular posterior tilting at  $90^\circ$  of abduction found in this study is likely related to different motor control of the dominant arm at this range of shoulder motion, such as augmented myoelectric activity of the serratus anterior and lower trapezius muscles (Yoshizaki et al., 2009). Because we did not use electromyography to link scapulothoracic muscles activity to scapular kinematics, this can be only speculative. However, in order to improve the interpretation of side-to-side differences in shoulder mechanics this should be addressed in future studies.

Five kinematic studies (including the current study) identified side-to-side differences in scapular position and motion whereas three others [one just partially (Matsuki et al., 2011)] demonstrated symmetry in the scapular kinematics of dominant and non-dominant shoulders (Yoshizaki et al., 2009; Yano et al., 2010) (Table 2). Apart from several methodological differences related to factors expressed above that could explain, in part, the apparent conflicting results, a closer look to the methods used to describe scapular rotations revealed that angular values at the starting position on those studies were offset to  $0^\circ$ . This procedure reduces side-to-side variability related to scapular posture, however, as our results imply, scapular asymmetry can be largely attributed to differences between dominant and non-dominant shoulders at the resting position (scapular posture) (Fig. 2). This is likely the result of specific side-related adaptations of the musculoskeletal system, such as imbalance of the resting length of scapulothoracic muscles, from the repetitive but different use, both in frequency and pattern, of the dominant and non-dominant arms (Borstad, 2006; Duff and Sainburg, 2007; Wang and Sainburg, 2007; Oyama et al., 2008; Matsuki et al., 2011). We also found that the mean amount of scapular angular displacement from rest to  $90^\circ$  of abduction in the dominant and non-dominant shoulders was quite similar, which in practice suggest an identical or symmetrical scapular kinematic pattern despite the different positioning on the thorax. This sounds paradoxical, but most studies that examined side-to-side scapular behavior during arm elevation also acknowledged it, with more or less emphasis (Lukasiewicz et al., 1999; Yoshizaki et al., 2009; Yano et al., 2010; Matsuki et al., 2011). Some confirmed, as we did, that side-to-side differences detected at the resting position of the arms have changed little throughout elevation (Lukasiewicz et al., 1999; Matsuki et al., 2011), whereas others having offset the initial position to  $0^\circ$  avoided initial side-to-side differences and found symmetric scapular motion (Yoshizaki et al., 2009; Yano et al., 2010; Matsuki et al., 2011).

In most clinical settings, scapular position and motion on one shoulder is assessed using the contralateral shoulder as reference of the normal scapular kinematics. Our data support this practice given that both the pattern and the magnitude of scapular rotations throughout shoulder abduction were, in average, relatively identical on both shoulders. However, our data also suggest that scapular resting position should always be considered because of the potential side-to-side differences related to hand dominance. Asymmetric scapular posture is often interpreted as an impairment associated to glenohumeral conditions (Kibler, 1998; Voight and

Thomson, 2000; Kibler et al., 2002; Burkhart et al., 2003; Kibler and McMullen, 2003; Uhl et al., 2009; Donatelli and Wooden, 2010), or as an adaptation to chronic unilateral overhead sports activities (Oyama et al., 2008). Yet, we verified that in healthy and non-athlete subjects, side-to-side differences might also be possible. These are likely to be identified clinically, as an  $8^\circ$  difference between sides is sufficient to be detected with acceptable precision through visual inspection (Uhl et al., 2009), and it is a value smaller than the inferior limits of the confidence intervals estimated in this study for all scapular rotations ( $\sim 13^\circ$ ), except scapular tilting (maximum  $\sim 3^\circ$ ). The important clinical question that follows is: if asymmetric scapular posture could be a normal finding, how to differentiate in such cases between hand dominance-related asymmetry and impaired asymmetry (scapular dyskinesis)? Our data suggest that hand dominance-related asymmetry might be more or less obviously detectable with the arms at rest, but it could remain fairly identical throughout shoulders abduction, since only small mean differences with relatively narrow 95% confidence intervals were found between side-to-side differences recorded at rest and at  $90^\circ$  of shoulder abduction (Fig. 3). It may look like a symmetric scapular behavior during elevation of the arms despite the different positioning on the thorax. In people with scapular dyskinesis, on the other hand, the scapular kinematics of the symptomatic shoulder is expected to behave differently from the “normal”, as a result of some potential biomechanical mechanisms already highlighted elsewhere in this manuscript (Lukasiewicz et al., 1999; Ludewig and Cook, 2000; Borstad, 2006; Matias and Pascoal, 2006; McClure et al., 2006; Ogston and Ludewig, 2007; Yang et al., 2009). Thus, testing posture-dynamics association of scapular kinematics (or semi-dynamics as in this study) bilaterally would be preferred to clinically interpret the asymmetry given that scapular posture alone is unlikely to provide sufficient discriminative information about the presence of shoulder symptoms or scapular dyskinesis (Nijs et al., 2005; Lewis and Valentine, 2007). Nevertheless, scapular posture should always be thoroughly addressed because of its value to assess the resting length of scapulothoracic muscles, to predict scapulohumeral rhythm, and as we have added, to estimate hand dominance-related scapular asymmetry (Groot and Brand, 2001; Pascoal et al., 2001; Borstad, 2006, 2008).

Several kinematic studies have considered scapular dyskinesis in people with glenohumeral joint complaints when during arm elevation it was observed a  $5^\circ$ – $12^\circ$  difference for scapular protraction,  $4^\circ$ – $8^\circ$  for upward rotation, and/or  $3^\circ$ – $8^\circ$  for tilting (Lukasiewicz et al., 1999; Ludewig and Cook, 2000; Matias and Pascoal, 2006; McClure et al., 2006; Ogston and Ludewig, 2007). These values are, in general, higher than the 95% confidence intervals limits of the side-to-side differences throughout shoulder abduction estimated in this study for each scapula rotation (Fig. 3), therefore side-to-side comparisons to identify scapular dyskinesis appear to be feasible. Nevertheless, given the small values in question it is unlikely that a detailed description of the mechanical behavior (e.g. the pattern observed) could be performed clinically through visual inspection (Uhl et al., 2009). Because altered scapular kinematics might be linked to a more specific biomechanical mechanism, instruments that can measure scapular positioning with accuracy in clinical settings are desired in order to increase the possibilities of a good mechanical diagnosis, which potentially could improve the selection of therapy(ies) and treatment outcomes. Tape measurements although easy to obtain showed several problems regarding construct validity as already expressed elsewhere in this manuscript. Inclinator, in alternative, showed good validity and reliability in measuring scapular upward rotation, but studies regarding the other scapular rotations are needed (Johnson et al., 2001; Watson et al., 2005). Many current

smartphones have tri-axis accelerometers and gyroscopes built-in, therefore the possibility of measuring 3D scapular position and orientation with these devices sounds appealing.

Some limitations in this study are noteworthy and we hope to correct them in future studies. First, because we privileged the simultaneous recording of scapulas kinematics, we were unable to track directly the position of humeri in space with instrumentation. As an alternative, humeri positioning was assessed qualitatively through visual inspection of the investigator involved in training the testing protocol with the subjects. We do not believe, however, that absence of humeri kinematic data have exerted a strong influence on the results. Experienced clinicians can easily identify side-to-side symmetry/asymmetry in shoulder motion (Uhl et al., 2009), therefore, the major purpose of achieving symmetric arm positioning in space to compare side-to-side scapular kinematics was guaranteed. Nevertheless, we recognize that a more rigid control of humeri through instrumentation could give enhanced information about the side-to-side approach for the assessment of scapular position and motion. A second limitation is related to the accuracy of the estimated confidence intervals given the small sample size. This is a major concern because we observed that part of the subjects (half for scapular upward rotation and more than a half for scapular tilting) lied outside the 95% CIs of the mean differences between the side-to-side differences recorded at rest and at 90° of shoulder abduction (Fig. 3). The values found are within the range of those reported for individuals with shoulder conditions as mentioned above, which takes us back to the original problem that motivated this study. A larger sample size would likely provide narrower confidence intervals and a better visualization on whether this is related to only a few subjects or is generalized. If so, clinical decision about “normal” and “abnormal” scapular kinematics (alias “symmetric” and “asymmetric” using side-to-side comparisons) might not always be a black or white classification and should be taken along with other factors, such as symptoms. More studies using larger samples and different populations, such as overhead throwing athletes and people with shoulder symptoms, are needed to provide normative data and develop appropriate discriminative and diagnostic criteria. Lastly, our findings may only be valid from rest to 90° of abduction in quasi-static conditions, therefore generalization should be done with caution though most studies using different instruments, testing conditions and methods used to calculate angles support our findings (Lukasiewicz et al., 1999; Oyama et al., 2008; Yoshizaki et al., 2009; Yano et al., 2010; Matsuki et al., 2011).

## 5. Conclusion

Scapular resting position differs between dominant and non-dominant shoulders despite the observation of an identical kinematic pattern during arm elevation. Hand dominance-related scapular asymmetry should be taken into consideration when comparing scapular position and motion of symptomatic and contralateral shoulders.

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