Physical Therapy in Sport xxx (2009) 1–7

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Scapular kinematics and scapulohumeral rhythm during resisted shoulder abduction – Implications for clinical practice

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ARTICLE INFO

Article history:
Received 15 December 2008
Received in revised form
21 May 2009
Accepted 22 May 2009
Available online xxx

Keywords:
Kinematics
Shoulder
Scapula
Rehabilitation

ABSTRACT

Objective: To offer a three-dimensional description of the scapular kinematics and scapulohumeral rhythm (SHR) in healthy subjects during quasi-static shoulder abduction. To analyze and compare the influence of loaded and unloaded conditions on scapula kinematics and SHR.

Design: Eleven subjects were analyzed using videogrammetry and the application of mathematical modelling during quasi-static shoulder abduction positions (intervals of $\approx 30°$).

Main outcome measurements: Scapular kinematic data under unloaded and loaded conditions.

Results: The scapula presented external rotation, upward rotation and posterior tilting during the studied movement. Analyzing the scapulohumeral rhythm, different behaviours were observed in the scapular movement planes. Loading condition increased scapular upward rotation and posterior tilt at 60° and 90° of abduction ($p > 0.01$).

Conclusions: Analyzed scapular kinematics and scapulohumeral rhythm showed differences between adopted loading conditions. The clinical applications of these findings are discussed.

1. Introduction

Shoulder disorders and pain commonly affect athletes who predominantly use their upper extremity in the sport (Altchek & Dines, 1995; Jobe & Pink, 1996; Ranson & Gregory, 2008). During throwing efforts the shoulder complex is exposed to a large range of motion (ROM), being extremely dependent on the combined movements among the sternoclavicular, acromioclavicular, scapulothoracic and glenohumeral joints (Fayad et al., 2006).

The glenohumeral joint shape and scapular mobility in relation to the thorax are mainly responsible for the great mobility found in this complex (de Groot, van Woensel, & van der Helm, 1999). The three-dimensional (3D) pattern of integrated movement between glenohumeral and scapulothoracic joints is known as the scapulohumeral rhythm (SHR) (Kebaetse, McClure, & Pratt, 1999; McClure, Michener, Sennett, & Karduna, 2001). Such integration allows the scapula to provide a stable base for glenohumeral movements and to be mobile to position the arm throughout its ROM (Kebaetse et al., 1999; Kibler, 1991; Myers, Laudner, Pasquale, Bradley, & Lephart, 2005). If the scapular position is altered this normal pattern of integrated movement is expected to be affected. For this reason, the SHR is assumed as a movement quality index of the shoulder complex in clinical practice (Pascoal, van der Helm, Pezarat, & Carita, 2000).

Altered scapular kinematics and associated shoulder dysfunction have clearly been demonstrated by some researchers. They have shown an association between abnormal scapular movement and shoulder pathologies such as impingement syndrome (Hebert, Moffet, McFadyen, & Dionne, 2002; McClure, Michener, & Karduna, 2006) and glenohumeral instability (Ogston & Ludewig, 2007), among others (Lin et al., 2005, 2006). Based on such evidence, rehabilitation programmes and protocols were developed focusing and emphasizing on appropriate scapular motion and stability retraining (Blanch, 2004; Burkhart, Morgan, & Kibler, 2003; Comerford & Mottram, 2001; Mottram, 1997).

According to the mentioned programmes and training principles, the load must be increased progressively during resistance exercises . However, it is not clear what the clinician would expect to happen to the scapular kinematics and SHR when applying

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doi:10.1016/j.ptsp.2009.05.005

external resistance to the performed tasks. In the literature, controversy exist whether external loads influence scapular motion or not. While some authors have reported that load does not significantly influence SHR (de Groot et al., 1999; Högfors, Peterson, Sigholm, & Herberts, 1991; Michiels & Grevenstein, 1995) other studies support the influence of load or resistance over scapular position and SHR (Kon, Nishinaka, Gamada, Tsutsui, & Banks, 2008; McQuade & Smidt, 1998; Pascoal et al., 2000). Detailed studies of the movement of the healthy shoulder complex are necessary to define parameters that would provide scientific evidence to support current rehabilitation protocols, as well as assist in the development of new treatment strategies according to physiotherapy evidence based principles (Hebert et al., 2002).

Therefore, the aim of the present study was to obtain a 3D description of the scapular kinematics and SHR under two loading conditions during quasi-static shoulder abduction. Furthermore, the influence of the applied loads on scapular data was analysed and compared.

2. Methods

This study was authorized by the ethics committee of the Federal University of Rio Grande do Sul and all subjects had given an informed written consent agreeing to participate.

2.1. Sample

Fourteen subjects were enrolled in the study. Upper-right extremity (URE) dominancy and muscle strength to abduct shoulder throughout $\approx 150^{\circ}$ of ROM were adopted as inclusion criteria. Exclusion criteria considered were: pain or history of injury to the right arm during the previous six months; frequent practice of physical activity (more than three times a week), avoiding training effects; and positive specific joint test. Based on these criteria two upper-left extremity dominant subjects and one presenting shoulder instability were excluded from the study.

Hence, the sample consisted of eleven subjects with mean age of 26.7(±5.2) years, mean height of 176(±6) cm and mean body mass of 74.8(±7.8) kg.

2.2. Instruments

Five digital video camcorders *JVC GR-DVL9800* (50 Hz sample frequency), five computers, five spotlights, five sturdy camera stands, one *Peak Performance 5.3* 3D calibrator, one manual goniometer, two dumbbells (3 and 4 kg), one wrist weight (0.5 kg), one double-faced tape roll and nineteen 12 mm round reflective markers were used.

2.3. Kinematic data

Kinematic data were obtained by means of videogrammetry. All cameras were positioned in different locations in such a way that, each reflective marker was simultaneously observed by at least two cameras. This setup made it possible to spatially reconstruct the 3D body segments using the direct linear transform method (DLT) (Abdel-Aziz, 1971).

To describe spatial position a global coordinates system (GCS) and a local coordinates system (LCS) were used (Winter, 2005; Wu et al., 2005). The GCS, established by means of a 3D calibrator, refers to the coordinates system of the environment where data collection was carried out and serves as a reference for the spatial position of spherical reflective markers. Such markers, with a diameter of 15 mm were placed at anatomical references according to the recommendations of the International Society of Biomechanics (Wu et al., 2005). The anatomical references used were: the seventh cervical vertebra (C7), the eighth thoracic vertebra (T8), Incisura Jugularis (IJ), Processus Xiphoideus (PX), Sternoclaviculare joint (SC), Acromioclaviculare joint (AC), Trigonum Scapulae (TS), Angulus Inferioris (AI), Angulus Acromialis (AA), Processus Coracoideus (PC), Glenohumeral rotation centre (GH), Lateral Epycondile (EL), Medial Epycondile (EM), Radial Styloid (RS), Ulnar Styloid (US), as illustrated in Fig. 1.

The GH center of rotation was estimated from five scapula bony landmarks using linear regression equations (Meskers, Van der Helm, Rozendaal, & Rozing, 1998). To avoid artefacts movements on EM and EL references, a technical mark consisted of three non-collinear retro reflective markers fixed in a cuff was attached to the subjects' arms (Schmidt, Disselhorst-Klug, Silny, & Rau, 1999).

Thorax, scapula, and humerus LCS were defined as proposed by Wu et al. (2005), adopting x as representative of posterior/anterior axis, y as representative of inferior/superior axis and z as representative of medial/lateral axis of each segment (considering the right hemibody). Consequently, the thorax movements occurring over the x axis were described as left bending (−)/right bending (+); over the y axis are described as left axial rotation (+)/right axial rotation (−); over the z axis are described as flexion (−)/extension (+). For the humeral segment, the x axis describes adduction (+)/abduction (−); y axis is representative of internal rotation (+)/external rotation (−); and z axis representative of flexion (+)/extension (−). Considering the scapula segment, scapular movements occurring over x describe upward (+) and downward rotation (−), over y the external (−) and internal rotation (+) and over z the posterior (−) and anterior (+) tilt, as shown in Fig. 2.

Each local coordinate system was defined as the following:

For the thorax segment: O_t = The origin is coincident with the IJ reflective marker; y_t = line that connects the midpoint between PX and T8 and the midpoint between IJ and C7, pointing upward; z_t = line perpendicular to the plane formed by IJ, C7, and the midpoint between PX and T8, pointing to the right; x_t = common line perpendicular to the z and y axis, pointing forward.

The following equations were used to define the thorax LCS:

$$j_t = \frac{\frac{(\mathrm{IJ}+\mathrm{C7})}{2} - \frac{(\mathrm{PX}+\mathrm{T8})}{2}}{\left\|\frac{(\mathrm{IJ}+\mathrm{C7})}{2} - \frac{(\mathrm{PX}+\mathrm{T8})}{2}\right\|} \tag{1}$$

$$k_t = \frac{(\mathrm{C7}-\mathrm{IJ}) \times (\mathrm{T8}-\mathrm{PX})}{\|(\mathrm{C7}-\mathrm{IJ}) \times (\mathrm{T8}-\mathrm{PX})\|} \tag{2}$$

$$i_t = \frac{j_t \times k_t}{\|j_t \times k_t\|} \tag{3}$$

where: i, j, k = unit vectors of the LCS;

For the scapula segment: Os = origin is coincident with the AA reflective marker; z_s = line which connects TS and AA, pointing to AA; x_s = line perpendicular to the plane formed by AI, AA, and TS, pointing forward; y_s = common line perpendicular to the x and z axis, pointing upward.

The following equations were used to define the scapular LCS:

$$\mathrm{Av}_s = \mathrm{AA} - \mathrm{AI} \tag{4}$$

$$k_s = \frac{\mathrm{Av}_s \times K_s}{\|(\mathrm{Av}_s \times K_s)\|} \tag{5}$$

$$i_s = \frac{(\mathrm{AA}-\mathrm{AI})}{\|(\mathrm{AA}-\mathrm{AI})\|} \tag{6}$$

$$j_s = \frac{(k_s \times i_s)}{\|(k_s \times i_s)\|} \tag{7}$$

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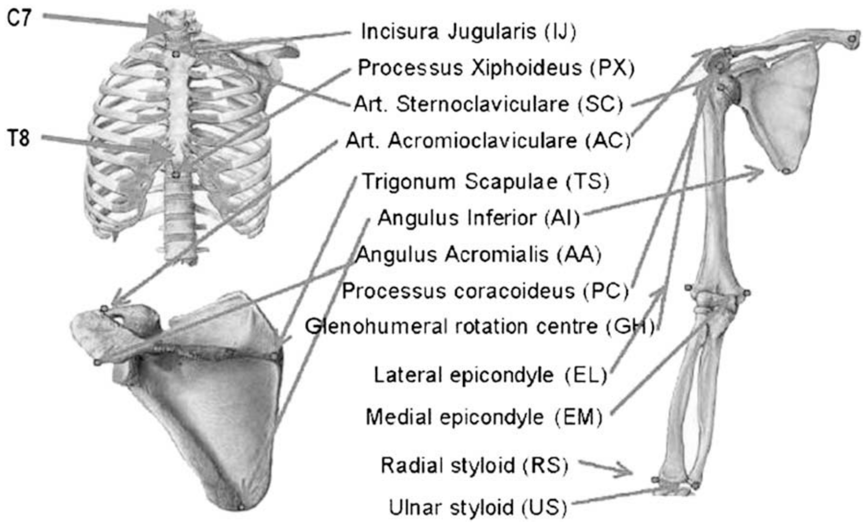

Fig. 1. Bony landmarks illustration (adapted from Wu et al. ISB recommendation on definition of joint coordinate systems of various joints for the reporting of human joint motion. Part II: shoulder, elbow, wrist and hand. *J Biomech 38*(5), 981–992.).

where: *i, j, k* = unit vectors of the LCS;Av = Auxiliar vector; For the arm segment; O_h = origin is coincident with GH; y_h = line which connects GH and the midpoint of EL and EM, pointing to GH; x_h = line perpendicular to the plane formed by EL, EM, and GH, pointing forward; z_h = common line perpendicular to the *y* and *z* axis, pointing to the right.

The following equations were used to define the humeral LCS:

$$j_h = \frac{(\mathrm{GH} - (\frac{\mathrm{LE}+\mathrm{ME}}{2}))}{\|(\mathrm{GH} - (\frac{\mathrm{LE}+\mathrm{ME}}{2}))\|} \tag{8}$$

$$\mathrm{Av1} = \frac{(\mathrm{LE} - \mathrm{GH})}{\|(\mathrm{LE} - \mathrm{GH})\|} \tag{9}$$

$$\mathrm{Av2} = \frac{(\mathrm{ME} - \mathrm{GH})}{\|(\mathrm{ME} - \mathrm{GH})\|} \tag{10}$$

$$i_h = \frac{(\mathrm{Av1} \times \mathrm{Av2})}{\|(\mathrm{Av1} \times \mathrm{Av2})\|} \tag{11}$$

$$k_h = \frac{(i_h \times j_h)}{\|(i_h \times j_h)\|} \tag{12}$$

where: Av1 = Auxiliar vector 1 for humerus; Av2 = Auxiliar vector 2 for humerus; *i, j, k* = unit vectors of the LCS;

For kinematic data capture, digitization and reconstruction of images, the videogrammetry system *Dvideow 5.0*® (Figueroa, Leite, & Barros, 2003) was used. Intracameras synchronism was performed by cameras' audio band (Figueroa et al., 2003). For kinematic data processing, one link segment model was applied in the software *Matlab* ® *7.0*. The mathematical model considers the upper limb as five rigid segments (hand, forearm, arm, scapula and trunk) connected (Ribeiro, 2006). The model is governed by Newton-Euler movement equations (Praagman, Stokdijk, Veeger, & Visser, 2000; Winter, 2005; Zatsiorsky, 2002). Equations (1) and (2) govern linear and angular movement, respectively.

$$\sum F = m \cdot a \tag{13}$$

where: F = force; *m* = mass; a = acceleration of the center of mass of the segment;

$$\sum M = \dot{H} \tag{14}$$

where: *M* = moment; *H* = time rate of the angular momentum of the segment;

Kinematics, kinetics, and anthropometric data are independent variables of the model; proximal net reaction forces and proximal

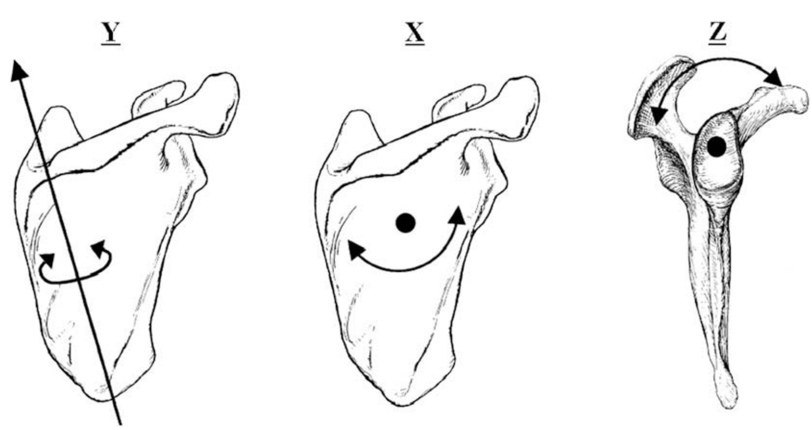

Fig. 2. Individual rotations and axis used to describe the scapular movement. *Y* – external /internal rotation; *X* – downward/upward rotation; *Z* – posterior/anterior tilt.

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net moments and kinematics joint description are dependent variables (Praagman et al., 2000; Vaughan, Davis, & O'connor, 1999). In the model, body segment parameters were calculated using anthropometric data described by Zatsiorsky (2002) and adjusted according to de Leva (1996). Consequently, the model permits quantification of kinetic and kinematic data. During the present study, the kinematic data will be discussed.

2.4. Experimental protocol

Subjects were submitted to four stages: assessment, stretching and warming up, preparation and data collection.

During assessment, anthropometric data were obtained and specific joint tests were applied. The latter were applied to all subjects by a physiotherapist and consisted of a ROM test until $\approx 150°$ of shoulder abduction, subacromial impingement test and anterior and posterior apprehension test (Tzannes & Murrell, 2002).

In the second stage subjects were instructed to stretch the shoulder flexor, extensor, horizontal adductor and abductor muscles and warm up. The warm up consisted of ten unloaded shoulder elevation repetitions in each movement plane (frontal, scapular and sagittal planes). During preparation, seventeen reflective markers were positioned at bony reference points along the trunk and URE of each subject.

After subject preparation, images were collected in the unloaded condition (gravity force only) and external loaded condition (with loads equivalent to 5% of individual body mass for standardization purposes). The collection order was randomized prior to the experiment. For each load condition six shoulder abduction (frontal plane of elevation) positions were recorded. This plane of movement was adopted upon its common use in exercises and rehabilitation protocols in clinical practice. Starting from a resting position subsequent positions were set with an interval of $\approx 30°$ measured with a manual goniometer. The fixed rod was placed perpendicularly to the ground and mobile rod along humeral axis. Recording lasted for no more than five seconds for each position with an interval of at least sixty seconds to avoid fatigue. In an attempt to minimize soft tissue influence on scapular markers positioning (angulus inferior, trigonum scapulae, processus coracoideus and acromioclavicular joint), the markers were repositioned by the same physiotherapist for each position.

2.5. Data analysis

A total of one hundred and thirty-one kinematic recordings were obtained and correspond to twelve positions of shoulder abduction (six unloaded and six externally loaded) for each subject (one recording was missed).

As shown in Fig. 3(A), from a mathematical model proposed by Ribeiro (2006) it was possible to obtain kinematic data of scapula and humerus positions in five observed movement intervals. Aiming to reduce data variability, scapular kinematic data was normalised by calculating the mean angle of the scapula throughout shoulder positions for each subject and subtracting it from the scapular angle of each shoulder position for every subject. The resulting value was then added to the mean scapular position across the six shoulder positions from all subjects. Data dispersion was analysed during the shoulder abduction. The R^2 was obtained and compared for the linear, second order and third order polynomial. As the third order polynomial showed the highest R^2 and appropriately represented the dispersion of data, an equation was obtained for each load condition in the three scapular movement planes. The cubic polynomial was previously shown by McQuade & Smidt (1998) to precisely illustrate the kinematics dispersion of the scapula, providing an ideal description of the SHR.

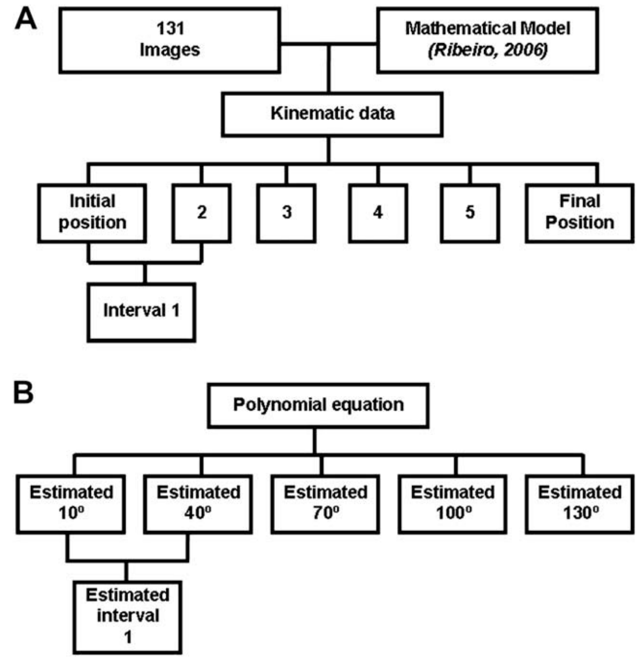

Fig. 3. Kinematic data processing diagram.

Based on the 3D reconstruction, normalised scapular positions were plotted with humeral abduction angles for all planes. Polynomial equations were obtained on these values, representing a mean estimate of the measured positions. When analyzing value dispersion, five humeral abduction angles were arbitrarily chosen (10°, 40°, 70°, 100° and 130°) as representatives of joint range data obtained from the sample. Four scapular movement intervals were then calculated from the difference between the estimated positions of the scapula, as demonstrated in Fig. 3(B). A total estimated ROM interval was calculated from the difference between the first and fifth estimated positions. The SHR was calculated for each interval from the ratio between humeral movement interval and the corresponding estimated scapular movement interval.

2.6. Statistical analysis

Four subjects were submitted to the same experimental protocol on two different days. The intra-class correlation coefficients (ICC) were calculated from the collected data. Such coefficient reflects the repeatability of the measuring method including instruments, bone reference palpation and the ability of subjects to repeat assessed positions (Ludewig, Cook, & Nawoczenski, 1996).

In order to verify data distribution a descriptive analysis was performed and the Shapiro-Wilk and Mauchly tests were applied. Once data presented a parametric distribution, a paired student's t test was adopted to compare scapular kinematic values in each observed position between load conditions. All analyses were done in the software *SPSS for windows (13.0)* adopting $p < 0.05$.

3. Results

An excellent degree of repeatability of the method was indicated by the ICC analysis. Humeral abduction and scapular upward rotation presented an ICC of 0.98 and 0.83, respectively.

The observed scapular kinematic behaviour during quasi-static shoulder abduction is presented in Fig. 4.

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In the initial position (resting), the scapula was in a neutral position in relation to upward/downward rotation in both the unloaded or loaded conditions. Regarding the other planes, a scapular positioning in internal rotation of ≈35° and anterior tilt of ≈15° was observed for both load conditions.

In the subsequent positions, a posterior tilt, upward and external rotation of the scapula was evident with little variation. The comparison of the scapular position between unloaded and loaded conditions revealed a greater upward rotation when the external load was applied at 60° and 90° of shoulder abduction ($p < 0.01$). A greater posterior tilt of the scapula was observed at 60° of the loaded shoulder abduction when compared to the unloaded condition ($p < 0.01$). No loading effect was found for scapular external rotation ($p > 0.05$).

Scapular movement variations, estimated using the third order polynomial, and SHR are described in Table 1. The first interval showed the greatest variation in the position of the scapula for external rotation and consequently, the smallest value of SHR. The opposite occurred for the upward rotation of the scapula in the same interval. The total estimated ROM of the scapular upward and external rotations presented greater values for the unloaded condition. In relation to the total estimated SHR, marked differences were observed between the loading conditions for posterior tilt as the total estimated ROM increased from 2.6° to 11.5°.

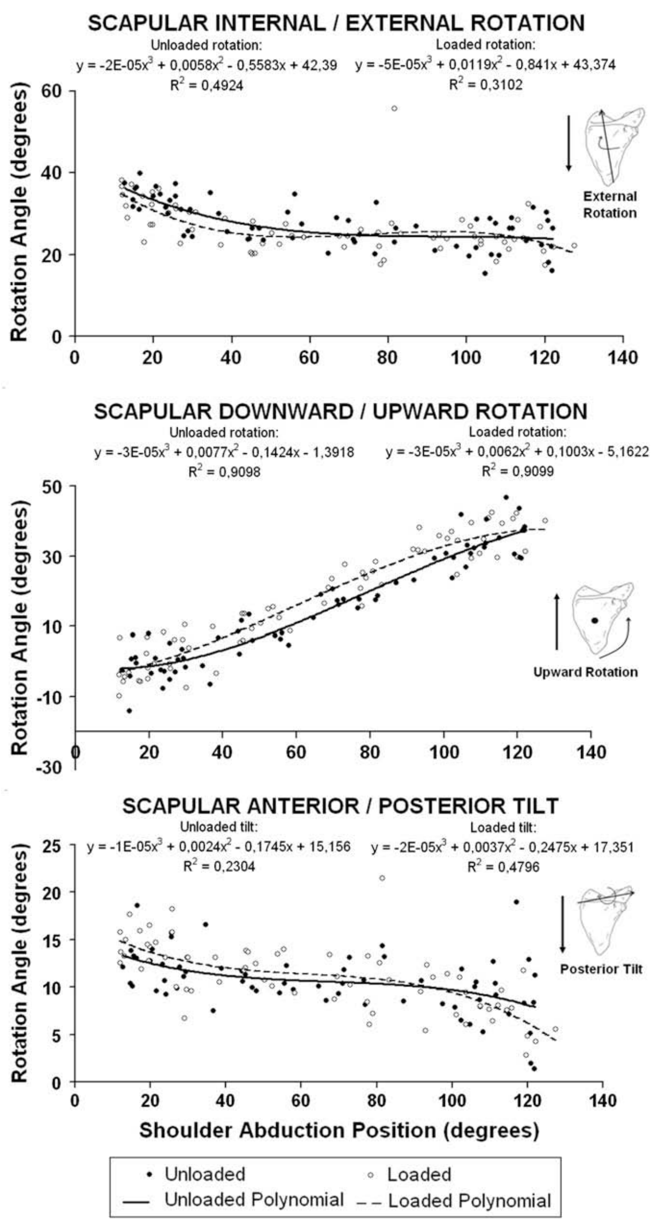

Fig. 4. Dispersion of normalised kinematic values.

4. Discussion

Based on the presented results, scapular behaviour was described during unloaded and loaded shoulder abduction. Scapular kinematic behaviour was described in relation to the thorax (scapulothoracic) and humerus (scapulohumeral). Despite limitations in quasi-static to dynamic movement extrapolations (Crosbie, Kilbreath, Hollmann, & York, 2008), it is believed that the former offers a reliable representation of the kinematic variations of the scapula (de Groot et al., 1999; Hebert et al., 2002; Kebaetse et al., 1999; Meskers, Vermeulen, de Groot, van Der Helm, & Rozing, 1998). Also, discrepancy between previous studies and our findings could be hypothetically explained to some extent by the opposing nature of the analysed movements. The static effort, despite being held for a short period, might have demanded a muscle recruiting pattern opposed to that seen by others studying dynamic movements.

According to Fig. 4, the present study had shown an initial scapular positioning in internal rotation, neutral up/downward rotation and anterior tilt. These findings are in agreement with those of Pascoal et al. (2000), in which the scapula presented ≈30° of protraction (combination of scapular internal rotation and gliding in relation to the thorax), ≈2° of upward rotation and ≈17° of anterior tilt at resting position prior to shoulder unloaded abduction. Recently, using the same movement, Fayad et al. (2006) reported an initial scapular position in 35.8°(±7.2) of protraction, 3.3°(±5.4) of upward rotation and 8.9°(±4.2) of anterior tilt.

Although the scapular behaviour reported herein is in agreement with previous research (Barnett, Duncan, & Johnson, 1999; Ebaugh, McClure, & Karduna, 2005; Fayad et al., 2006; de Groot et al., 1999; Kebaetse et al., 1999; McClure et al., 2006; Pascoal et al., 2000; Price, Franklin, Rodgers, Curless, & Johnson, 2000), there is some divergence in relation to the angle values reported in the literature. The reasons for this are manifold, but are mainly due to variations in scapular movement existing among individuals within the same population (de Groot et al., 1999).

When assessing external load influence on scapular kinematic behaviour the present study found similar external rotation angles between the loading conditions. Previously, de Groot et al. (1999) concluded that there is no influence of external load on scapular orientation in different humeral abduction positions. Such findings suggest that clinicians should observe the same pattern of external rotation when increasing the resistance applied to the same task.

Similarly, our participants presented a posterior tilt when abducting the shoulder with minimal influence from the resistance applied. However, at 60° of resisted abduction the scapula tilted further in a posterior direction and at 60° and 90° an increased upward rotation occurred. This loading effect corroborates with the findings reported by McQuade & Smidt (1998) that demonstrated the influence of minimal and maximal external loads' application on scapular position and SHR. Pascoal et al. (2000) also reported differences on the scapular kinematics caused by external load, despite not seeming to be affected by different load magnitudes.

More recently, Kon et al. (2008) investigated the influence of a 3-kg handheld weight (similar to the ±3.0 kg used in the present study) on the SHR during shoulder abduction on the scapular plane. They found a significant decrease of scapular upward rotation

Table 1
Scapular movement and SHR variation at intervals between estimated positions.

Humeral abductions	External rotation				Upward rotation				Posterior tilt			
ROM intervals (estimated positions)	ROM		SHR		ROM		SHR		ROM		SHR	
	UN	LO	UN	LO	UN	LO	UN	LO	UN	LO	UN	LO
10–40°	9.3	10.5	3.2	2.8	5.4	4.4	5.6	6.8	2.3	3.1	13.2	9.6
40–70°	3.2	−0.1	9.4	333.3[a]	12.8	9.1	2.3	3.3	0.1	0.8	285.7[a]	37.7[a]
70–100°	0.3	−2.6	97.1[a]	11.5	15.3	8.9	2.0	3.4	0.4	1.7	69.0[a]	17.7
100–130°	0.7	3.0	44.8[a]	10.1	12.9	3.9	2.3	7.8	−0.6	5.8	46.5[a]	5.1
Total (10–130°)	13.5	10.8	8.9	11.1	46.4	26.2	2.6	4.6	2.6	11.5	46.5	10.5

Negative values represent opposite movement; ROM – range of motion; UN – unloaded condition; LO – loaded condition; SHR – scapulohumeral rhythm.
[a] Indicates SHR values in which scapular movement was smaller than 1 degree.

between 35° and 45° of glenohumeral abduction under a loaded condition. This stabilization occurs at the time that gravity and the external load (external moment) counteract the acceleration generated by the abducting muscles (internal moment). Perceiving an increase on resistance the central nervous system (CNS) would reduce the scapular mobility to create a stable fixation for the glenohumeral movement. Throughout the ROM the external moment has a crescent behaviour reaching its magnitude peak at ≈90° of shoulder abduction. To hold the position or further abduct the joint one would have to generate equal or higher magnitude of internal moment. Hence, the CNS would need to reposition the scapula to guarantee that the glenoid cavity is facing an optimum direction, serving as a stable base and permitting the appropriate rotation of the humeral head. In this sense, our results may have revealed an attempt of the scapula to facilitate the final ROM of the shoulder by augmenting its tilt and rotation prior to stabilisation.

In the present study, when analyzing the SHR during estimated intervals in the loaded and unloaded conditions, smaller values were observed at the first and third interval for external and upward rotations, respectively. These findings could be explained by a greater contribution of scapular movement in shoulder abduction in these intervals. In this sense greater SHR values occur when the scapular ROM is reduced. The greater SHR value for upward rotation occurred at the first interval, when the scapula seems to discretely move, with a subsequent decrease and stabilization. This pattern was also shown by other studies (Crosbie et al., 2008; McQuade & Smidt, 1998). For posterior tilt, the SHR was inexistent after 40° for the unloaded condition due to minimal variation in scapular angle. Such small contribution by anterior/posterior tilt to the SHR may be related to the shoulder plane of movement, as previous studies have also demonstrated lower angle tilt values for abduction (Pascoal et al., 2000). When the contribution of the scapula towards shoulder movement is minimal, one should consider the SHR to be inexistent (i.e. intervals in which the scapular ROM is equal or less than 1°). Following the load effect, the third and forth intervals showed a marked increase in the posterior tilting. It would be expected to increase in amplitude when moving the shoulder in the sagittal plane and it will be analyzed in a further study.

Supposing that the repositioning observed in our results and reported additional stabilization of the scapula (Kon et al., 2008; McQuade & Smidt, 1998) occur when the neuromuscular control available is not enough to provide an orientated and stable base for the humerus, one should present with kinematic alterations only when exercising against a load higher than one can cope with. This rationale could bring insights to the clinical practice considering the principle of adaptation and whether scapular retraining should be done against resistance that causes kinematic alterations or not. In this way, the exercise progression could be guided by the ability of the individual to control the scapula and reproduce the same motion under different loads.

As it is dependent on many hard-to-assess physiological factors, the capacity of each subject to handle and adapt to new loads is not generally clear to fitness instructors and physiotherapists. Such uncertainty when defining appropriate new resistance might expose subjects to a load in excess of their physiological capacities. The association found in the literature between shoulder dysfunctions and scapular kinematic abnormalities highlights the need and importance of a careful assessment of such movements in clinical practice. The results of the present study in addition to those from previous studies may assist in the development of a complete clinical examination and rehabilitation program for patients suffering from shoulder dysfunction.

5. Conclusion

Scapula presented a posterior tilt, external and upward rotation movement during quasi-static shoulder abduction. A greater upward rotation at 60° and 90° occurred for the externally loaded condition. Likewise, at 60° of resisted abduction the scapula presented increased posterior tilt when compared to the unloaded condition.

Conflicts of interest

None of the listed authors have any conflict of interest related to the presented data. No funding has been used for this research.

Ethical statement

This study was authorized by the ethics committee of the Federal University of Rio Grande do Sul (application: 2007717; meeting: 10, act: 90, date: 19th of July 2007) and all subjects had given an informed written consent agreeing to participate.

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Please cite this article in press as: Forte, F.C., et al., Scapular kinematics and scapulohumeral rhythm during resisted shoulder abduction –..., Physical Therapy in Sport (2009), doi:10.1016/j.ptsp.2009.05.005

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