UNIVERSIDADE TÉCNICA DE LISBOA
FACULDADE DE MOTRICIDADE HUMANA

SHOULDER MORPHOFUNCTIONAL ADAPTATIONS ON OVERHEAD-THROWING ATHLETES

Implications for physiotherapy throwing-shoulder examination

Dissertação elaborada com vista à obtenção do Grau de Doutor em
Motricidade Humana, Especialidade de Ciências da Fisioterapia

Orientador: Doutor Augusto Gil Brites de Andrade Pascoal

Júri

Presidente: Reitor da Universidade Técnica de Lisboa.

Vogais: Doutor João Paulo Vilas Boas Soares Campos, Professor Catedrático da Faculdade de Desporto da Universidade do Porto

Doutor António Prieto Veloso, Professor Catedrático da Faculdade de Motricidade Humana da Universidade Técnica de Lisboa

Doutora Paula M. Ludewig, Professora Associada da University of Minnesota (EUA), Program in Physical Therapy, Department of Physical Medicine & Rehabilitation

Doutor Augusto Gil Brites de Andrade Pascoal, Professor Auxiliar da Faculdade de Motricidade Humana da Universidade Técnica de Lisboa

Doutor Raul Alexandre Nunes da Silva Oliveira, Professor Auxiliar da Faculdade de Motricidade Humana da Universidade Técnica de Lisboa

Andrea Miguel Lopes Rodrigues Ribeiro

Outubro 2012

Aos meus anjos da guarda, os meus filhos; José Miguel e Afonso Miguel.

Ao meu marido Afonso.

Aos meus pais e irmão Carlos, que nunca me deixaram só!

O trabalho desenvolvido no decorrer desta tese teve o financiamento da Fundação para a Ciência e Tecnologia através da Bolsa Individual de Doutoramento SFRH/BD/41155/2007.

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

TABLE OF CONTENTS

FIGURES

TABLES

ABBREVIATIONS

3D	Three-Dimensional
DOF	Degree-Of-Freedom
ER	External Rotation
ERG	External Rotation Gain
ES	Effect Size
GH	Glenohumeral Joint
GH	Glenohumeral Angles
GIRD	Glenohumeral Internal Rotation Deficit
HRA	Humeral Retroversion Angle
HRs	Scapulohumeral Rotation
HRt	Humeral Axial Rotation
IR	Internal Rotation
IR-ER-ROM	Internal-External Rotation Range-Of-Motion
ISB	International Society of Biomechanics
ISBS	International Society of Biomechanics in Sport
LCS	Local Coordinated System
OTSAP	Overhead Throwing Shoulder Adaptation Pattern
ROM	Range-Of-Motion
SH	Scapulohumeral Angles
SPSS	Statistical Package for Social Sciences
SSC	Stretch-Shorten System
Sxt	Scapular Upward-Downward Rotation
Syt	Scapular Protraction-Retraction
Szt	Scapular Spinal Tilt
TH	Thoracohumeral Angles
Tukey HSD	Tukey Honestly Significant Difference
w.r.t.	With Respect To

AGRADECIMENTOS/ ACKNOWLEDGEMENTS

Chegado o momento da entrega deste documento, olho para trás e vejo sorrisos, lágrimas; marcas que jamais deixarão de fazer parte de mim e de todos os que me rodeiam. Foi um percurso longo, por vezes tortuoso e difícil. Uma subida a uma enorme montanha, uma prova de resistência intensa, nunca só, sem alguma vez sair do trilho até à alvorada. Trilhar este caminho só foi possível com a mobilização de uma grande energia, vontade e perseverança que trazem consigo força, vigor e paz, indispensáveis em cada momento da caminhada, para encontrar o melhor rumo, fazer as melhores opções e tomar as melhores decisões.

Este caminho não foi percorrido na solidão. Foi um trabalho coletivo, embora a sua redação e responsabilidade sejam um ato individual.

Assim este trabalho não teria sido possível sem a ajuda e apoio de muitas pessoas, a quem estarei eternamente grata:

Em primeiro lugar ao Professor Doutor Augusto Gil Pascoal que acreditou em mim aceitando-me como sua aluna de doutoramento. À sua total disponibilidade, desde o primeiro momento. A sua presença foi constante, não obstante a distância, nunca me senti sozinha. Não tenho palavras para agradecer a hora que me recebeu, lendo e acompanhando todo o trabalho passo a passo, Muito obrigada.

Gostaria também de agradecer a todos os membros do júri pelo tempo dispensado na leitura e apreciação da minha tese.

Ao meu primo Pedro Miguel Pereira Ribeiro, pelo precioso auxílio na recolha dos dados e apoio incondicional, os teus preciosismos valeram ouro, Obrigada primão!

A minha eterna gratidão para o Dr. Melo Monteiro, para o João, Lídia, Avó Sílvia, Cláudia e Isidro, sem vós nada disto teria sido possível.

Aos amigos que sempre disseram presente, Nuno Morais, Isabel Loureiro, Ermelinda, Rui Castelar, Ricardo Matias, José Miguel Leite, José Teixeira, D. Fernanda, Rosinha, Eurico Peixoto, Rita Oliveira, Alan Coccato, todos grandes amigos e companheiros, sempre disponíveis para ajudar e acima de tudo para me ouvirem.

Ao Nuno, Marina, Márcio e Lago, eu sei que não fui fácil de aturar....

Ao Vitória Sport Clube, minha eterna paixão, pelo apoio das suas direções, compreensão e disponibilidade. Aos jogadores e treinadores, a todos, muito obrigada.

Ao Fermentões, pela disponibilidade imediata, assim como aos seus atletas.

Ao Xico Andebol por todo o apoio.

À Faculdade de Motricidade Humana por ter aprovado esta investigação e me ter permitido crescer pessoal e profissionalmente.

Aos meus pais, sim a vós que sempre me encorajaste e apoiaste de forma incondicional, que me substituíram vezes sem conta no papel de mãe... não sei como vos agradecer. Apenas posso dizer que vos adoro!

A ti Carlos, meu irmão, que tantas vezes me ouviste e me impediste de desistir, obrigada pelas palavras de incentivo quando já estava “sem pilhas” e por estares sempre do meu lado. És e sempre serás o meu menino!

À minha avó Carminda, que quase não me viu, durante largos meses, ao meu Padrinho Miguel Ribeiro; graças a si o dispositivo foi criado, e este estudo seguiu o seu caminho, e a toda a família que me ama, Tia Mila, Tio Ferreira, Tia Velha (Sónia), Né, Madrinha,

Tio Guilherme e Tia Sameiro, Tio Nandinho e Mila e aos primos,António Carlos, Sofia, Rita, Maria João, Pedro, João Pedro a todos obrigada.

Ao Chico, à Zé, Mariazinha e Fernando, ainda deu para nos divertirmos! Obrigada por me verem e por me tratarem como uma filha.

Finalmente, um grande e carinhoso agradecimento ao Afonso, pelo seu amor, paciência e apoio,,e a vós meus lindos filhos: José Miguel e Afonso Miguel; desculpem ter sido tão ausente, desculpem não ter brincado quando me pediram, desculpem por estar sempre a trabalhar, obrigada por serem a luz na minha vida e com o vosso sorriso conseguirem mostrar-me que o caminho é sempre para a frente

Não quero nunca esquecer todos os que para mim se tornaram estrelas e que farão sempre parte da minha vida, Avó Dulce, Avô Fernando, Avô António e Irene, muito obrigada por olharem por mim, por brilharem no céu, todos os dias, e por secarem as minha lágrimas tantas e tantas vezes...

SHOULDER MORPHOFUNCTIONAL ADAPTATIONS ON OVERHEAD-THROWING ATHLETES. IMPLICATIONS FOR PHYSIOTHERAPY THROWING-SHOULDER EXAMINATION

Andrea Ribeiro & Augusto Gil Pascoal

ABSTRACT

The overhead throwing motion is a highly skilled movement, particularly demanding to the shoulder due to high strength levels and/or acceleration applied to the hand and by the elevated degree of control and precision required to position the arm in space. The shoulders of those involved in repeated forceful overhead throwing, the overhead-throwing athletes, undergo a range of neural, soft tissues and skeletal adaptations that could be described as, the "*overhead-throwing shoulder adaptive pattern*" (OTSAP). The main goal of overall studies in this thesis was to characterize the dominant overhead-throwing shoulder adaptive pattern of non-symptomatic overhead throwing athletes, comparing with a non-athletic population. Additionally, while comparing volleyball and team-handball players, we looked for specific sport-related components of the OTSAP. Knowledge on OTSAP is important for those involved on training, but also for sport physiotherapist during shoulder functional assessment. Some components of the OTSAP could be mistaken by injury signs or risk factors. Structural (osseous) and functional changes were identified on the dominant shoulder of volleyball and team-handball players. Some were similar of those described in baseball players, and others were sport-related. Thus, the OTSAP should be considered by the physiotherapist during overhead-throwing shoulder assessment.

Keywords: *shoulder, athlete, physiotherapy, overhead, throwing, volleyball, team-handball, adaptations, humeral rotational pattern, humeral retroversion angle.*

SHOULDER MORPHOFUNCTIONAL ADAPTATIONS ON OVERHEAD-THROWING ATHLETES. IMPLICATIONS FOR PHYSIOTHERAPY THROWING-SHOULDER EXAMINATION

Andrea Ribeiro & Augusto Gil Pascoal

RESUMO

O movimento de lançamento é altamente especializado e particularmente exigente para o ombro devido aos excessivos níveis de carga/aceleração aplicados. Atletas cujos ombros estão envolvidos em movimentos repetidos de lançamento, consideram-se, na literatura anglo-saxónica, atletas "*overhead*". Estes são sujeitos a um conjunto de adaptações neurais, tecidulares e ósseas que podem ser descritas como, o **"padrão de adaptação do ombro do atleta overhead" (**PAOAO). O principal objetivo da tese foi caracterizar o padrão de adaptação do ombro dominante, não sintomático, dos atletas "*overhead*", comparando-os com não atletas. Adicionalmente, comparando voleibolistas e andebolistas, procurou-se encontrar componentes específicos da modalidade praticada inerentes ao PAOAO. O conhecimento detalhado deste PAOAO é crucial para os intervenientes em processos de treino, e para o fisioterapeuta responsável por uma avaliação detalhada do ombro, sob pena de alguns dos componentes do PAOAO serem erroneamente considerados como sinais de lesão ou fatores de risco. Foram identificadas alterações estruturais e funcionais no ombro dominante de voleibolistas e andebolistas. Algumas são similares às encontradas em jogadores de beisebol, enquanto outras estão diretamente relacionadas com a prática desportiva específica. Assim, este PAOAO deverá ser tido em consideração pelo fisioterapeuta aquando da avaliação do ombro do atleta "*overhead*".

Palavras-chave: *ombro, atleta, fisioterapia, lançamento, voleibol, andebol, adaptações, padrão de rotação umeral, ângulo de retroversão do úmero, omoplata.*

CHAPTER 1 - GENERAL INTRODUCTION

Overview

Overhead-throwing athletes include, among others, baseball pitchers, swimmers, team-handball players, volleyball or tennis players. These athletes perform specific sports gesture, known as overhead activity; such as throwing, passing, hitting, spiking or even swimming stroke, where the hand describes overhead trajectories

The overhead throwing motion is a highly skilled movement performed at high velocity, which requires synchronicity, neuromuscular control, flexibility, muscular strength and coordination (Wilk et al., 2009). For the shoulder, these overhead activities are particularly demanding due to the huge strength levels and/or acceleration applied to the hand and by the elevated degree of control and precision required positioning arm in space. Competitive overhead throwing athletes perform at the extremes of glenohumeral range-of-motion and place tremendous repetitive stresses on their shoulders (McConnell, Donnelly, Hamner, Dunne, & Besier, 2012). From a functional standpoint these overhead-activities require repetitive overhead motions where the arm is forcefully propelled forward from near maximal external rotation to internal rotation (Borsa, Laudner, & Sauers, 2008). It is estimated that the magnitude of strength in shoulder external to internal rotation in baseball throwing is about 111 Nm (Levine et al., 2006), which clearly shows the stress imposed on the athlete´s shoulder.

The mechanical stresses associated with overhead-throwing activities are likely to induce the development of a variety of adaptations within and around the tissues of the dominant (throwing) shoulder. These adaptations in bone and soft-tissues (connective tissue) seem to be the origin of secondary adaptations on overhead-throwing shoulder function. Altered shoulder mobility has been reported in overhead athletes (Borsa et al., 2008). Debate exits about whether this altered shoulder mobility is inherent, which may pre-select an athlete to a certain overhead sport, or acquired through adaptive change in shoulder joint. Discussion continues as to whether these adaptations arise from soft-tissue (e.g. capsule and ligaments) or from osseous adaptations within and around the shoulder. However, in literature a selection of adaptive changes were identified and described on the morphology and function of the dominant shoulder of overhead-throwing athletes. These changes resulting from the extreme physiological demands of overhead-throwing activity, which are sport-related adaptations, configure an unique adaptive pattern on the dominant overhead-throwing shoulder: the overhead-throwing shoulder adaptive pattern (OTSAP). In essence this adaptive pattern represents a shoulder attempt to maintain balance between the needed flexibility (to allow more external rotation) and the necessary stability for the throwing motion (Osbahr, Cannon, & Speer, 2002).

The OTSAP could be divided in two main groups of adaptations: structural and functional adaptations. Structural adaptations refer to changes on composition and ultrastructure architecture of bone and soft-tissue (connective tissue) within and around the dominant shoulder of overhead athletes. These adaptations include bony adaptations on the proximal humerus (R. Whiteley, Adams, Nicholson, & Ginn, 2010) and adaptations on glenohumeral capsuloligamentous structures (Reagan et al., 2002; Tokish, Curtin, Kim, Hawkins, & Torry, 2008). The adaptations on the connective tissue that composes the shoulder (soft-tissue structure) namely, the glenohumeral capsule, ligaments and tendons around the glenohumeral joint, were described in overhead-throwing athletes as a mix of anterior capsular laxity and posterior capsular tightness (Crockett et al., 2002; Grossman et al., 2005; Reagan et al., 2002). Regarding osseous adaptations, side-to-side studies reported increased humeral retroversion angles in the dominant humerus of baseball (Crockett et al., 2002; Mair, Uhl, Robbe, &

Brindle, 2004; Reagan et al., 2002; Tokish et al., 2008), team-handball (Pieper, 1998) and volleyball players (Schwab & Blanch, 2009). It is thought that change in retroversion angle occur in the proximal physis of the humerus over time in young pre-adolescent athletes when the proximal epiphysis is not yet completely fused (Yamamoto et al., 2006). In fact, it is known that most of the humeral growth takes place in the proximal physis, particularly after 11 years of age (Pritchett, 1991). Recently Wyland et al. (2012) demonstrated that beyond the humeral retroversion also glenoid retroversion angle was significantly greater on the throwing side than on the non-throwing side, suggesting that further studies must be addressed to the scapular osseous adaptation on the dominant shoulder of overhead-throwing athletes.

Functional adaptations refer to adaptive changes in the rotational motion pattern at the dominant glenohumeral joint of overhead-throwing athletes, but also to changes on scapulothoracic stability and mobility, particularly on scapular resting position and scapular kinematics during arm motion.

In overhead-throwing athletes, the adaptive changes in the glenohumeral rotational motion pattern were identified when shoulder rotation was evaluated at 90º abduction. These include an increased range of external rotation, commonly described as the external rotation gain, and a corresponding decrease in internal rotation range-of-motion, the glenohumeral internal rotation deficit (Tokish et al., 2008; Torres & Gomes, 2009; Wilk et al., 2011). For overhead-throwing sports, a greater external rotation range-of-motion allows for more arm cocking, therefore providing a greater hand velocity during the acceleration phase of the throwing cycle with advantage on ball-release/spike phase of the throw (Borsa, Dover, Wilk, & Reinold, 2006; Crockett et al., 2002). Curiously, the total arc of shoulder rotation, i.e. the external plus the internal rotation range, did not show statistically significant differences between the throwing and non-throwing shoulder (Borsa et al., 2008). The total arc of rotation in the overhead-throwing shoulder seems to adapt by shifting backwards favoring external rotation at the expense of internal rotation. Some authors refer this adaptation in the rotational arc shift phenomenon as the “total motion concept” (Borsa et al., 2008; Wilk et al., 2011) or posterior shift (Borich, Bright, Lorello, Cieminski, & Buisman, 2006; Cieminski, 2007; McCully, Kumar, Lazarus, & Karduna, 2005; Tokish et al., 2008; Wilk et al., 2009).

Most of the studies about the overhead-throwing shoulder adaptive pattern were made on the dominant shoulder of baseball players, particularly on baseball pitchers. This thesis explores the assumption that the overhead-throwing activities involved in volleyball and team-handball, could induce shoulder sport-related adaptations, similar to those described in baseball players (Braun, Kokmeyer, & Millett, 2009; Warden, Bogenschutz, Smith, & Gutierrez, 2009; Werner, Gill, Murray, Cook, & Hawkins, 2001; Wilk et al., 2011). In fact, in volleyball the spike could be considered as an overhead activity in which the efficacy depends on the magnitude of the contact force between hand and ball. Volleyball spike is used to the strike the ball in the way that it lands on the opponent´s court and cannot be defended. A player makes a series of steps (the “approach”), jumps and swings at the ball. Ideally the contact moment with the ball should be at the apex of the hitter´s jump with the hitter´s arm fully extended above the head and slightly forward, making the highest possible contact while maintaining the ability to deliver a powerful hit. The hitter uses arm swing, wrist snap and a rapid forward contraction of the entire body to drive the ball. Similarly, in team-handball arm throwing is the major activity which is used to pass the ball between team members and to score goals. A fast throwing is considered as an advantage for the game which explains the focused on training about throwing technique (Tillar & Cabri, 2012).

Some side-to-side studies described the specific adaptive changes in the dominant shoulder of volleyball (Schwab & Blanch, 2009) and team-handball (Pieper, 1998) players comparing with the non-dominant side. In literature changes in the humeral retroversion angle (HRA) were found for side to side differences, measured passively. A lack of information exists about active external rotation motion and also comparing retroversion between different groups rather than just side to side comparisons. Knowledge on overhead-throwing shoulder adaptive pattern (OTSAP) is important for those involved on training, in order to promote safe sport-related adaptive changes to improve sport performance, but also for clinicians during shoulder injury assessment and prevention. On clinics, some of the adaptive changes included in the OTSAP could be mistaken by with injury signs or even be assumed as injury risk factors. This could happen during shoulder functional assessment performed by sport´s physiotherapist in order to establish diagnosis and defining a rehabilitation program. Among others, shoulder examination includes shoulder posture assessment (static examination), range-of-motion assessment and shoulder strength evaluation (dynamic examination) by comparison with the contralateral side. Often, these side-to-side changes are reported as the origin of shoulder pain and/or shoulder dysfunction. However, these changes could be normal adaptive changes included in the OTSAP. For example, a certain degree of shoulder instability or shoulder impingement could be present on the dominant (painful) overhead-throwing shoulder based on the identification of the external rotation gain. Thus, the rationale behind this thesis is the contribution for the clarification about what it is the normal adaptive pattern of the overhead-throwing shoulder and what could be assumed as injury risk factors. The characterization of the OTSAP in a non-symptomatic overhead-throwing athlete’s population was assumed as the first step towards the goal of clarifying what are the limits of shoulder function optimization by training and the injury risk factors.

Research goals

The shoulders of those involved in repeated forceful overhead throwing undergo a range of neural, soft tissues (muscular and capsular and ligaments), and skeletal adaptations that could be described as the overhead-throwing shoulder adaptive pattern (OTSAP). Thus, the major goal of this dissertation was to characterize the dominant overhead-throwing shoulder adaptive pattern of non-symptomatic overhead throwing athletes, comparing with a non-athletic population. Additionally, while comparing the dominant shoulder of volleyball and team-handball players, we look for specific sport-related components of the OTSAP.

Dissertation Structure

This thesis is a compilation of six papers, Chapter 4 to 6. To them, was added a General Introduction chapter (Chapter 1), Review of literature (Chapter 2), Methodology (Chapter 3) and General Discussion (Chapter 7). Appendices were also added to give further information about clinical tests mentioned on Chapters 3 to 6.

In Chapter 2 (Literature Review) the most relevant studies about throwing shoulder and throwing shoulder adaptations are reviewed. The main concern was to give the reader the necessary framework to the understanding of the following chapters, where results from the experimental work are presented.

Chapter 3 (Methodology) comprises demographic data from the whole sample, used in this thesis as long as explored methodological aspects and also statistical procedures.

In this thesis we started to look for structural, osseous adaptations, Chapter 4. From a skeletal perspective, it is shown that throwing shoulders have more humeral retroversion when compared with the non-throwing shoulder. Alterations in humeral retroversion are thought to develop over time when the proximal humeral epiphysis is not yet completely fused. In “Humeral retroversion angle and its relationship with active shoulder external rotation range-of-motion in volleyball and team-handball players”, we compared the humeral retroversion angle of the dominant shoulder of volleyball and team-handball players with a control group. We also looked for the relationship between humeral retroversion angle and functional adaptations, such as, active shoulder external rotation range-of-motion.

Throwing athletes have been shown to display altered rotational range-of-motion patterns in the dominant shoulder that favors increased external rotation and limited internal rotation range-of-motion. Concerning external rotation range-of-motion, studies often use goniometry as a part of shoulder assessment (Ellenbecker & Roetert, 2002; Ellenbecker, Roetert, Piorkowski, & Schulz, 1996; Tokish et al., 2008; Torres & Gomes, 2009; Wilk et al., 2011). This end-range is determined by capsular end-feel (Awan, Smith, & Boon, 2002; Barlow, Benjamin, Birt, & Hughes, 2002; Reagan et al., 2002), by capsular liftoff (Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990) or by pain (Andrews AW & RW, 1989), as opposed to an objective assessment of torque. Also these studies use passive motion in supine, where the scapula is stabilized on the table.

In Chapter 5 two studies are presented which intend to clarify some methodological aspects concerning the overhead throwing shoulder rotational pattern changes, and how to evaluate these specifically in the overhead throwing athlete. The first study, “*The effects of testing subject position (Seated vs. Supine) in shoulder external rotation*” analyzed the effects of subject testing position on shoulder external rotation range-of-motion, particularly on shoulder external rotation end-range determination. The other study presented in Chapter 5, "*Shoulder rotation range-of-motion in throwing athletes. The effect of active or passive end-range determination*", explore the effect of passive vs. active end-range determination on shoulder external rotation ROM.

In Chapter 6, two studies are included about the contribution of scapular motion on shoulder rotational pattern. A third study was included about the postural changes identified on scapular resting position in overhead-throwing athletes. The assessment of the glenohumeral internal and external rotation range-of-motion is a standard part of a shoulder clinical examination. However, the contribution of shoulder girdle in the rotational motion pattern often is not considered by clinicians. In fact, during physiotherapy examination, arm passive motion is often used to test glenohumeral range-of-motion while at the same time scapula is stabilized. However, on sport overhead activities, scapular stability and mobility are crucial on the kinetic chain that involves the lower limb, the trunk and the upper limb. The first study presented on Chapter 6, "*The scapular contribution to the amplitude of shoulder external rotation on throwing athletes*" explores the contribution of scapular stability and/or mobility to the shoulder external rotation ROM, on thrower athletes. The second study in Chapter 6, entitle "*Scapular contribution for the end-range of shoulder axial rotation. Scapular behavior in overhead athletes*" also looked for scapular contribution on shoulder external rotation ROM, but also for scapular motion in internal rotation in overhead throwing athletes, adding information about internal rotation which was not acquired in the first mentioned study.

The third study presented in Chapter 6, entitle "*Resting Scapular posture in overhead throwing athletes*" looked for asymmetries between both scapula's in overhead-throwing athletes by comparison with a non-athletic population. It was assumed that this information could be helpful on shoulder physiotherapy examination, particularly on shoulder static examination.

Publications

Papers in publications with impact factor

Parts of this thesis have been published, accepted for publication, or submitted for publication:

Ribeiro A, Pascoal AG. *The relationship between the humeral retroversion angle and the active shoulder rotation in volleyball players.* Journal Biomechanics. 2012: 45(S1), S626.

Ribeiro A, Pascoal AG. *Scapular contribution for the end-range of shoulder axial rotation. Scapula behavior in overhead athletes.* International Journal Sports Science and Medicine. 2012: 11, 676-681.

Ribeiro A, Pascoal AG. *Shoulder rotation range-of-motion assessment in throwing athletes. The effect of active or passive end-range determination*. Physiotherapy Theory and Practice. (Under review).

Ribeiro, A., Pascoal, AG and Ludewig, PM. *Humeral Retroversion Angle And Its Relationship With Active Shoulder External Rotation Range-Of-Motion In Volleyball And team-handball Players.* American Journal Sports Medicine (Under review)

Ribeiro, A. and Pascoal AG. *Resting Scapular Posture in Healthy Overhead Throwing Athletes.* Manual Therapy (Under review).

Ribeiro, A. and Pascoal, AG. *The Effects Of Testing Subject Position (Seated Vs. Supine) In Shoulder External Rotation*. Physical Therapy (Under review).

Book chapters

Ribeiro A, Pascoal AG, Morais N. *The Scapular Contribution to the Amplitude of Shoulder External Rotation on Throwing Athletes*. In: Jorge RMN, Tavares JMRS, Pinotti M, Slade A, eds. Technologies for medical sciences: Springer, 2012:227-239.

Communications in proceedings with refereeing:

Parts of this thesis and additional exploration of data were presented in congresses and published in abstract books and in special issues of scientific journals:

Ribeiro A, Pascoal AG, Ludewig PM. *Humeral retroversion angle and its relationship with active shoulder external rotation range-of-motion in volleyball and European team-handball players*. IXth Conference of the International Shoulder Group. Aberystwyth University, Wales, UK, 2012:69-70.

Ribeiro A, Pascoal AG, Ribeiro P. *Humeral retroversion in overhead throwing athletes.* In: ISBS, ed. 29th Conference of the International Society of Biomechanics in Sports. Oporto, Portugal, 2011:125.

Ribeiro A, Pascoal AG, Ribeiro P. *The throwing shoulder. Scapular contribution for the end-range of shoulder axial rotation*. Coloquium 511 on Biomechanics of Human Motion. Azores, Portugal, 2011:22.

Ribeiro A, Pascoal AG. *Shoulder external rotation range-of-motion assessment on thrower athletes, the effects of testing end-range determination (active vs. passive).* XXIIIrd International Society of Biomechanics. Belgium, 2011. (http://isbweb.org/images/conf/2011/ScientificProgram/ISB2011_ScientificProgram.htm)

Ribeiro A, Pascoal AG. *The contribution of the scapular patterns to the amplitude of shoulder external rotation on thrower athletes*. In: Natal J, Tavares J, Pinotti M, Slade A, eds. 6th International Conference of Technology and Medical Sciences. Oporto, Portugal: Taylor & Francis, 2010:275-278.

Ribeiro A, Pascoal AG. *Assessment of the external rotation range-of-motion on thrower athletes. The effects of testing end-range determination (active vs. passive).* 1st International Conference of Applied Bionics and Biomechanics. Venice, Italy, 2010.

Ribeiro A, Pascoal AG. *Humeral and scapular 3D position in thrower athletes at end-range internal and external rotation during active fast and slow arm movements.* XXII Congress of the International Society of Biomechanics. Cape Town, South Africa, 2009:543.

Pascoal AG, Madureira E, Cascais C, Ribeiro A, Neves S. *Differences on range of motion of active humeral rotation in throwing athletes*. In: ISG, ed. Shoulder biomechanics, ergonomics and sport. Bologna, Italy, 2008.

Ribeiro A, Pascoal AG. *The external shoulder rotation range-of- motion on thrower athletes. The effects of testing subject position (seated vs. supine) and en-range determination (active vs. passive).* Shoulder Biomechanics International Shoulder Group. Minneapolis, 2010:31.

Ribeiro A, Pascoal AG. *Effect of active v. passive end-range determination on shoulder axial rotation in thrower athletes.* International Conference on Biomechanics in Sport. Michigan, USA, 2010: July. (https://ojs.ub.uni-konstanz.de/cpa/article/view/4548/4235)

CHAPTER 2 - REVIEW OF LITERATURE

The Overhead Throwing Shoulder

The term “overhead throwing athlete” involves all participants in overhead throwing activities, where the sports gesture encompasses repetitive overhead throwing actions of the dominant shoulder. Examples of these sport activities are team-handball, volleyball, baseball or tennis. But in this group we can also find athletes which perform cyclic arm activities such as swimmers.

This overhead throwing motion is an extremely skillful and intricate movement which is very stressful on the shoulder joint complex. The overhead throwing athlete places extraordinary demands on this complex. Excessively high stresses are applied to the shoulder joint because of the tremendous forces generated by the athlete.

Kinematics of the throwing arm (with ball) is frequently described as a particular sequence of phases, the “*throwing cycle*” (Wagner et al., 2012; Werner et al., 2006), that includes the initial and late cocking phases, where the arm assumes an elevated-external rotated position, followed by an acceleration and a follow-through (deceleration) phases. At the end of the acceleration phase the object (ball) is released or stroked. On throwing athletes, during the deceleration phase, the posterior rotator cuff musculature acts eccentrically. The goal is to decelerate or “*brake*” the internal rotation and horizontal adduction arm motion, generated during the acceleration phase. The act of throwing requires a coordinated motion that progresses from the toes to the fingertips. This sequence of events has been described conceptually as kinetic chain (McMullen & Uhl, 2000). For the kinetic chain to work effectively, sequential muscle activity is required so that the energy which is generated in the lower body can be transmitted to the upper body through the arm, hand, and fingers, and finally to the ball. The ball velocity is determined by the efficiency of this process. Body rotation, timing and positioning of the scapula are key elements in this kinetic chain. Any physical condition that alters kinetic chain components, especially one that affects the so called "*core*" (trunk, back and proximal parts of the lower limbs), will alter more distal segments and may result in the development of a dysfunctional shoulder (Braun et al., 2009; McMullen & Uhl, 2000).

Altered mobility patterns have been consistently reported in the dominant shoulder of elite baseball pitchers (Borsa et al., 2006; Borsa, Jacobson, Scibek, & Dover, 2005; Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988; Downar & Sauers, 2005; Ellenbecker et al., 2002; Joseph B. Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Osbahr et al., 2002; Reagan et al., 2002).Shoulder mobility in the overhead athlete has been found to be both excessive (hypermobile) and limited (hypomobile) compared with shoulders that are not exposed to overhead sports. This altered shoulder mobility is thought to develop secondary to adaptive structural and functional changes to the shoulder joint resulting from the extreme physiological demands of overhead activity. Researchers have speculated as to whether these structural adaptations compromise shoulder stability, thus exposing the overhead athlete to injury, or if these adaptations predispose the subject to be an elite overhead throwing athlete.

The mentioned changes/adaptations which result from the extreme physiological demands of overhead-throwing activity, and seem to be sports-related adaptations, configure an unique adaptive pattern on the dominant overhead-throwing shoulder: the overhead-throwing shoulder adaptive pattern (OTSAP). This adaptive pattern represents a shoulder attempt to maintain balance between the needed flexibility (to allow more external rotation) and the necessary stability for the throwing motion (Osbahr et al., 2002).

These alterations have been discussed concerning baseball players (Murachovsky et al., 2008; Oyama, Myers, Wassinger, Daniel Ricci, & Lephart, 2008; Tokish et al., 2008; R.

Whiteley, Ginn, Nicholson, & Adams, 2006; Yamamoto et al., 2006), but in Europe, this is not an usual sport. Among throwing sports, volleyball and team-handball are quite popular in the "old continent". What kind of shoulder adaptations do these athletes present? Are these similar to the ones shown by baseball players?

Volleyball and team-handball have also been referred as "*overhead activities*" (Pieper, 1998; Schwab & Blanch, 2009; Seil, Rupp, Tempelhof, & Kohn, 1998; Wang & Cochrane, 2001a). For some authors they are considered to represent typical overarm movements of throwing or hitting a ball and where ball velocity is the main performance variable (Wagner et al., 2012).This labeling suggests that some assumptions regarding the throwing shoulder adaptation on volleyball and team-handball players could be similar as adaptations described about baseball players (Tripp, Yochem, & Uhl, 2007; Warden et al., 2009; Werner et al., 2006; Wilk et al., 2009). However, this holds not to be true. Osseous side-to-side adaptations were described on throwing humerus of volleyball and team-handball players (Pieper, 1998; Schwab & Blanch, 2009), similar as in baseball players. However nature and implications of these are different and must be analyzed in detail by comparison with a non-thrower population.

The volleyball serve and spike involve an overhead throwing motion that is similar to baseball pitching and American football throwing. Unlike baseball pitching that has quantified the shoulder forces and torques that are generated during the volleyball serve and spike. Nevertheless, because the motion is overhead and extremely rapid, similar to baseball, it is hypothesized that high shoulder forces are generated, especially during the volleyball spike. To support this hypothesis, numerous injuries occur each year in volleyball, primarily involving muscle and ligament injuries during blocking and spiking.

The volleyball spike has been divided into phases that resemble a slightly simplified version of the general overhead throwing motion seen in baseball (Yamamoto et al., 2006). In this method, five phases were defined, with a general cocking phase encompassing both the early and late cocking phases of the overhand throw. In spike at the moment of contact, the hitter's arm is fully extended above his or her head and slightly forward, making the highest possible contact while maintaining the ability to deliver a powerful hit. The hitter uses arm swing, wrist snap, and a rapid forward contraction of the entire body to drive the ball.

Although volleyball attackers can employ different styles, and therefore different kinematics, the ball gets generally in contact with the hand, above and slightly anterior to the hitting shoulder. As a result, the arm motion is constantly adjusted throughout the spike so that contact can occur in an optimal location. This could lead one to hypothesize that the mechanics of the swing are not necessarily as important in volleyball as in other overhead sports such as baseball or team-handball, or rather, that the dynamic aspect of the ‘set’ in volleyball requires attackers to be equally dynamic in their upper limb mechanics during an attack sequence.

In elite team-handball, shooting on goal is one of the most important aspects of the game. For a shot to be successful, it requires maximum ball velocity and precision as well as an element of surprise do the defensive players and goalkeeper. But how is this shot performed, how is this throw executed?

Team-handball throw can be divided into 4 phases; arm cocking phase, acceleration phase, ball release point and end of throw (Wagner & Muller, 2008), at the beginning of the movement progressive external rotation of the humerus corresponds to a movement towards the front of the elbow which reaches maximum velocity. The wrist continues to swing towards the back taking advantage of the weight of the ball. This movement can be assimilated into a rotation, around a hypothetical horizontal axis, passing near the wrist. At the end of this rotation the humerus starts to reverse. Everything now happens as if the force was swinging in other direction, around a hypothetical axis always near the wrist. This movement provokes an apparent slowing down of the elbow directing itself towards the back, while the ball accelerates, pushed by the hand. The speed of the wrist near the hypothetical axis declines weakly. At time zero, the deceleration of the elbow compared with the wrist is equal to the acceleration of the ball also relative to the wrist. This can only be explained by the existence of the hypothetical axis. Final bending of the fingers is an important part of this final swinging movement (Chagneau, Delamarche, & Levasseur, 1992). Fradet *et al.* (2004) found some particularities in team-handball kinematics sports motion. In fact they noted that the forearm was not very extended at ball release, on the contrary baseball pitching has shown higher forearm extension (Fleisig, Andrews, Dillman, & Escamilla, 1995). If the upper arm horizontal adduction was the same than other throwing activities, the humeral rotation was really different. The maximal external humeral rotation was less than the one found in baseball pitching and football passing (Fleisig et al., 1995). Moreover at ball release, the upper arm was slightly internally rotated at ball release, while in the same phase baseball pitching and football passing show more internal rotation. Regarding temporal parameters once again baseball pitching, the time of maximal humeral external rotation and the time of maximal forearm flexion was later for baseball pitching than those of team-handball throwing and football passing and for maximal external humeral rotation. To conclude, the main difference found between team-handball throwing and other throwing was the upper arm external rotation (Fradet, Kulpa, Multon, & Delamarche, 2002).

Volleyball and team-handball are different with respect to the kinematic and kinetic pattern of the throwing cycle and consequently in the repetitive stress imposed to the shoulder which is beneath osseous and soft tissue adaptations.

In team-handball throw, the throwing arm must accelerate the additional weight of the handball whereas in volleyball spike there is no additional weight that has to be accelerated (Wagner et al., 2012). Wagner found differences in shoulder internal rotation and shoulder flexion angle in the cocking pass of volleyball spike when compared to team-handball throw. In fact volleyball players perform some shoulder flexion at takeoff which leads a delay in maximal shoulder hyperextension angle during spike. They also concluded that overarm movements are similar but not identical due to specific adaptations based on technical and tactical components of different games as well as different body movements (Wagner et al., 2012).

On team-handball the weight of the ball at the end-range of the acceleration phase in the cocking phase of the throwing cycle could force the shoulder into more external rotation and increasing this range. This extra mass is not present in volleyball spiking. The loss of internal rotation range may also be related to differences in throwing a ball as in opposition of striking it. At the time of throwing release, momentum maintenance suggests that the internally rotated arm, after the loss of the extra mass (the ball), would accelerate its motion. Consequently, the throwing arm would require greater deceleration than while striking a ball (volleyball). Energy of the internally rotated arm is dissipated into the ball. Relative tension exerted by the internal and external rotator muscles on proximal humeral epiphysis seems to be different on the dominant shoulder of volleyball and team-handball players. On both activities, forces towards internal rotation are higher than to external rotation. However, on volleyball the magnitude of external forces seems to be even weaker than in team-handball because of the reduced activity of the external rotator muscles on the last phase of the throwing cycle. In fact, during arm deceleration *phase* on volleyball striking, shoulder internal rotation energy could be totally or partially dissipated into the ball, which could explain the atrophy of some shoulder external rotators muscles. In a prospective cross-sectional study, Lajtai et al. (2009) reported a 30% prevalence of infraspinatus muscle atrophy among the dominant (hitting) shoulder of beach volleyball players. The authors also report a significantly reduction on external rotation strength on all players when compared with the non-dominant shoulder. Players with atrophy had significantly more loss of external rotation strength (2.3 kg) than players without atrophy (0.8 kg; $P = .0210$).

Overhead Throwing Shoulder Adaptive Pattern

During the overhead throwing motion, due to the repetitive sports gesture, the mechanical stimuli will induce alterations into the micro-structure (composition) and architecture in soft tissues such as; capsule, ligaments, tendon and bone. These will reverberate in shoulder function, inducing changes that could or could not be related to pathology, or are just shoulder adaptations of the throwing motion towards sports gesture optimization.

The living material used in the construction of human joints is connective tissue in the form of ligaments, tendons, bursae, cartilage, disks, plates, menisci, labra, fat pads and sesamoid bones. The bony components are also composed of connective tissue. Generally, the structure of the connective tissue is characterized by the presence of a large extracellular matrix and a wide dispersion of cells (Hamill & Knutzen, 2009).All of the mentioned structures can be described as heterogeneous in that they are composed of a variety of solid and semi-solid components including water, collagen and other composite materials. The composition of the different structures reflects very specific functions. The heterogeneous nature of connective tissue structures causes these structures to exhibit properties (strength and elasticity) that vary according to their orientation in space when a constant force is applied (Levangie & Norkin, 2011).

Although connective tissue appears in many forms throughout the body, all connective tissue exhibits the common property of viscoelasticity. The behavior of viscoelastic materials is a combination of the properties of elasticity and viscosity. Elasticity refers to a material´s ability to return to its original state following deformation after removal of the deforming load. When a material is stretched, it has work done on it and its energy increases. An elastic material stores energy and keeps the energy available so that the stretched elastic material can recoil immediately to its original dimensions following removal of the distractive force. Elasticity implies that length changes or deformations are directly proportional to the applied forces or loads. Viscosity refers to a material´s ability to dampen shearing forces. When forces are applied to viscous materials they exhibit time-and-rate dependent properties (Hamill & Knutzen, 2009).

When load forces are applied to a structure, meaning load by an external force or forces applied to a structure, these are called mechanical load. The type of internal mechanical resistance (stress) and strain (deformation) that develops in human structures is dependent on the nature of the material, type of load, and the rate and duration of loading. When a structure can no longer support load, the structure is said to have failed (Levangie & Norkin, 2011).

Viscoelastic materials are capable of undergoing deformation either a tensile or compressive force and of returning to their original state following the removal of the force. Under normal conditions viscoelastic materials do not return to their original state immediately. Viscoelastic materials have time-dependent mechanical properties; they are sensitive to the duration of the force application. When a viscoelastic material is subjected to either a constant compressive or tensile load the material deforms and continues to deform over a finite length of time even if the load remains constant. Deformation of the tissue continues until a state of equilibrium is reached. This phenomenon is called **creep** and is attributed to different mechanisms is according with the materials.

In bone, creep in compression has been attributed to the slip of lamellae within the osteons and the flow of the interstitial fluid. In articular cartilage subjected to a compressive force, creep is attributed to the gradual loss of fluid from the tissue. Viscoelastic materials respond differently to different rates of loading. When viscoelastic materials are loaded rapidly, they exhibit greater resistance to deformation than occurs if they are loaded more slowly. Generally, the higher the rate and the longer the duration of the applied force, the greater the deformation.

Viscoelastic materials do not store all of the energy that is transferred to them when they are deformed by an applied force, and thus the transferred energy is not available for recovery. When a force is applied and then removed, some of the energy created during the stretching or compression of the material may be dissipated in the form of heat and therefore the material may not return to its original dimensions. The loss of energy is called **hysteresis**, which is exhibited by viscoelastic materials when they are subjected to the application and removal of forces (Ambrosio, Netti, & Nicolais, 2002).

When connective tissue is subjected to sudden, prolonged, or excessive forces, the elastic limits of the tissue may be exceeded and the tissue may enter the plastic range. In the plastic range the tissue is permanently deformed or is no longer able to return to its original state following the removal of a deforming force. This situation is similar to what occurs when ligaments are overstretched and become lax. The ligaments are no longer capable of returning to their original length after being elongated and remain in a partial state of elongation.

Stress/strain curves for bone demonstrate that cortical bone is stiffer than cancellous bone meaning that cortical bone can withstand greater stress but less strain than cancellous bone. The application of high loads maintained for a short period of time or low loads held for a long period of time will produce high stress and strain. The rate, frequency, duration and type of loading affects bone in that repeated loadings, either high repetition coupled with low load or low repetition with high load, can cause permanent strain and lead to bone failure. Bone loses stiffness and strength with repetitive loading as result of creep strain. Creep strain occurs when a tissue is loaded repetitively during the time the material is undergoing creep (Ambrosio et al., 2002).

All components of shoulder are subjected to continuous changing forces during the throwing activity. The ability of these materials to withstand these forces that provide critical support and protection for shoulder joint, are of extreme importance.

The above mentioned constant loading, such occurs in prolonged throwing, subjects the joints and their supporting structures to the effects of load deformation and **creep**. Ligaments subjected to constant tensile loads will creep and may undergo excessive lengthening. Cartilage subjected to constant compressive loading may creep and may undergo excessive deformation. Joints and their supporting structures subjected to repetitive loading may be injured and fail because they do not have time to recover their original dimensions before they are subjected to another loading cycle. Thus these structures are subjected to repeated loading while they are still deforming. But these joints may adapt to these mechanical loads, may have altered ranges-of-motion, for example, to avoid injury due to stressful loads (Dwelly, Tripp, Tripp, Eberman, & Gorin, 2009; Oyama et al., 2008; Schwab & Blanch, 2009; Torres & Gomes, 2009; Warden et al., 2009).

Structural adaptations

Several studies have documented osseous and capsuloligamentous adaptations on the dominant shoulder of the thrower by comparing with the non-dominant side (Dwelly et al., 2009; Oyama et al., 2008; Schwab & Blanch, 2009; Torres & Gomes, 2009; Warden et al., 2009) or with the dominant shoulder of non-athletes (Crockett et al., 2002; Murachovsky et al., 2008).These adaptations are assumed to be beneficial for throwing athletes. These changes occur in the connective tissue composition and/or architecture and are described as **structural adaptations**. Other authors though do not look at these adaptations as single benefits but as abnormal stresses at the joints and the surrounding tissues which may cause shoulder pain, decreased performance or some unspecific shoulder disorders (P. McClure, Tate, Kareha, Irwin, & Zlupko, 2009; P. W. McClure, Michener, Sennett, & Karduna, 2001).

Osseous adaptations on the throwing shoulder

Adaptive osseous changes include increased humeral and glenoid retroversion. Repetitive stress to the proximal humeral epiphysis from throwing is thought to induce an adaptive bone remodeling response that favors humeral retroversion. Some studies about young baseball players suggest that humeral retroversion and subsequent motion adaptation develops during probably between 12 and 16 years, while growth plates are open (Crockett et al., 2002; Osbahr et al., 2002; Reagan et al., 2002).

Some studies suggested an osseous adaptation as a possible explanation for the increased external rotation observed on the throwing arm, namely an increase on the angle of the humeral head retroversion (Crockett et al., 2002). In a radiographic study, involving 100 shoulders, Kronberg *et al.* (1990) reported an average retroversion of 33° in the dominant and 29° in the non-dominant shoulder. Murachovsky *et al.* (2007) in a study involving seventeen team-handball athletes reported an average retroversion of 36º in players who started earlier practicing (10 years age) and 26º in the ones that started later in life practicing team-handball.

Humeral Retroversion Angle

The humeral retroversion or humeral retroversion angle (HRA) refers to the acute angle, in a medial and posterior direction, between the proximal and distal articular surfaces of the humerus (Hernigou, Duparc, & Hernigou, 2002; R. Whiteley et al., 2006; Yamamoto et al., 2006). The HRA, also referred as the "humeral torsion", describes the amount of 'twisting' of the longitudinal axis of the humerus and is a measure of orientation of the humeral head with respect to the elbow joint (Hernigou et al., 2002; R. Whiteley et al., 2006). Normally, the proximal surface is internally rotated with respect to the distal surface. This is often described as anti-version (Yamamoto et al., 2006) with the external rotation of the distal surface with respect to the proximal surface being described as retroversion.

Since the early studies of Krahl *et al.* (1945) and Krahl (1947) a considerable variability on the humeral retroversion angles values has been reported. Krahl (1947) defines some normative data revealing that the average values of humeral retroversion were 15.6º for Caucasian adults and 17,4º for Afro-American adults. Edelson (1999) also reported significant differences in HRA values between specimens, northern Chinese and white

Americans (44.6º and 30.3º, respectively). More recently, Boileau *et al.* (2008) reported for normal adult population HRA values ranging from 10º to 40º. Differences between dominant and non-dominant arm were also analyzed, however a lack of consensus exists about this specific issue. While some studies reported considerable differences between contralateral measurements (Cassagnaud, Maynou, Petroff, Dujardin, & Mestdagh, 2003; Edelson, 1999), others did not found a significant difference (Oztuna, Ozturk, Eskandari, & Kuyurtar, 2002). Krahl (1947) was the first to reveal the decrease on HRA values during human development. Using a scatterplot of humeral retroversion and ages, the author was able to verify that the HRA decreases during early development and then ceases to change, in the adult age (approximately at 18-20 years of age). Based on these findings a distinction was suggested between a primary and a secondary humeral torsion. The primary or hereditary equates to be the amount of bony twist that is initially presented in fetal development. Krahl (1947) using a limited number of specimens stabilized the primary torsion on approximately 48º. The association between shoulder axial rotation range-of-motion, growth was also analyzed by Meister *et al.* (2005) in a sample of 294 baseball *Little* League players and adolescents, with ages ranging from 8 to 16 years. Results showed that total axial rotation (total range-of-motion), flexion and internal rotation motion decreased as age increased. In the same way, Levine *et al.* (2006) showed in a sample of 298 baseball athletes, divided into 3 different age groups (Group 1, N=100, age: 8-12 years; Group 2, N= 100, age: 13 - 14 years; Group 3, N=98, age: 15-28 years) that the passive dominant shoulder external rotation range-of-motion, recorded at ≈90º abduction, is increased when compared with the non-dominant shoulder, this increased appears with increasing age (Groups 2 and 3). At same time a decrease in shoulder internal rotation, collected at same conditions, decreasing with age in groups 2 and 3. When comparing dominant to non-dominant shoulder motion within each group, a significant increase in dominant shoulder external rotation in abduction was found in all 3 age groups. Comparison of the differences in external rotation in abduction between the dominant and non-dominant shoulders demonstrated an increase with increasing age. Comparison of differences in internal rotation in abduction between dominant and non-dominant shoulders demonstrated a decrease with increasing age.

The secondary humeral torsion or acquired torsion is due to the muscular forces exerting a pull via their attachments to various anatomic points on the humerus (Cieminski, 2007; Yamamoto et al., 2006). This humeral torsion involves the action of opposite forces exerted by the stronger internal shoulder rotators and weaker external rotators, which set up torsional stresses across the proximal humeral epiphysis. Some authors suggest that this secondary torsion is responsible for the deceleration in rate of de-rotation of the humerus (V. E. Krahl, 1947; Yamamoto et al., 2006). The rate of humeral de-rotation can be slowed down to greater extent, resulting in a larger humeral retroversion angle, when the muscular activity increases around the glenohumeral joint, such as during repetitive overhand athletic activities. The work by Edelson (1999) seems to confirm this progression throughout the human life.

Where is the torsion: proximal epiphysis or humerus diaphysis?

The proximal humeral epiphysis was noted to be the most likely site from which the torsion can occur. It was theorized that the presence of relatively soft bone, as the site of active site of the humerus, as well as the presence of hyaline cartilage at the epiphyseal plate, reduces the ability of the proximal epiphysis to resist torsional stress. This assumption was recently confirmed by the work of Sabick *et al.* (2005) on young baseball pitchers. Osbahr *et al.* (2002) theorized about the mechanism beneath the osseous adaptation based on the concept of an envelope of function or load acceptance for joints. According to this concept, during skeletal development if forces or stresses stay within the range of load acceptance but begin to reach the highest level of load, then physiologic and adaptive remodeling occurs.

The work of Pieper *et al.* (1998) was the first to provide evidence about osseous adaptation of the humerus in the form of increased retroversion angle in the throwing arm of team-handball players. Since then, other studies provided similar evidence for the throwing arm of baseball players, including professional (Chant, Litchfield, Griffin, & Thain, 2007; Cieminski, 2007; Crockett et al., 2002) and college baseball pitchers (Osbahr et al., 2002), or position players (Reagan et al., 2002), and elite volleyball players (Schwab & Blanch, 2009). These studies reported differences on the HRA between dominant (throwing) and non-dominant arm and between throwing athletes and non-throwing athletes (control). Most of the information available about HRA differences between dominant and non-dominant arm refers to baseball players. Chant *et al.* (2007) reported an average side-to-side difference of 10.6º on 19 competitive players. On team-handball players, the average side-to-side difference was reported by Pieper *et al.* (1998) as 14.4º average while Murachovsky *et al.* (2007) presented a value of 3.06º. Schwab & Blanch (2009) found on twenty-four elite volleyball players a side-to-side difference of 9.6º.

On non-athletes no significant side-to-side differences on HRA were found (Chant et al., 2007; Crockett et al., 2002; Murachovsky et al., 2007; Osbahr et al., 2002; R. J. Whiteley, Ginn, Nicholson, & Adams, 2009) which seems to be in line with the findings of the radiographic study of Kronberg *et al.* (1990) who found an average HRA of 33° and 29º for the dominant an the non-dominant shoulder, respectively. The first prospective study about injury incidence and its relation to the humeral torsion in overhead throwing athletes was made by Whiteley *et al.* (2009) using a sample of 35 baseball players, with a mean age of 16,6 years that was followed during 30 months. It was then measured bilaterally the humeral retroversion angle using ultrasound to standardize the location of the bicipital groove, the amount of humeral torsion was measured in both arms. Athletes were frequently contacted by the examiners who collected information about injury and days of absent practice. At the end of 30 months, from the 35 of the followed athletes, 19 had one or more injuries (maximum 3) in total 506 training days were lost, with a mean of 26, 6 days, due to injury. Authors demonstrated that, as expected, the humeral torsion of the dominant arm was statistically significant to the non-dominant arm ($p<0.01$). When they compared the humeral retroversion values of athletes that have had injuries with athletes with no injuries, they verified that, although no differences were found between dominant shoulders ($p=0, 47$), there was a statistical significant decrease in humeral retroversion angle in non-dominant shoulders from the ones that had one or more injuries ($p=0, 04$). Whiteley *et al.* (2009) concluded, that the occurrence of injuries related to the throwing motion was predictable, in a significant degree, by the amount of humeral torsion in the non-dominant arm (which represents the genetic contribution) and not for the amount of humeral torsion in the dominant arm (genetic contribution + torsion acquired by activity), of which as higher was the humeral retroversion angle, higher would be the risk of injury. The injured group in this study can be defined as the group that started to throw with less humeral retroversion angle comparing to the non-injury group because the genetic component (seen in the non-dominant shoulder, because this is not submitted to the repetition of the throwing motion) it is statistical significantly smaller than in athletes without injury history, being the glenohumeral joint in higher risk of stress effects than the one the throwing motion causes, while the humeral torsion resulting from sports practice develops.

It is believed that increased ROM through osseous changes may provide an adaptive benefit, sparing the joint capsule from excessive strain and disruption, maintaining glenohumeral joint stability (Borsa et al., 2008). More external rotation range in the dominant arm, may also improve performance allowing increased cocking of the throwing arm therefore leading to higher ability to generate power and speed or release (Wang & Cochrane, 2001b). This retroversion seems to increase the available external rotation range-of-motion (ROM) but at the same time reduces the ability of the rotator cuff to control high forces or velocities through the extremes of shoulder ROM which could lead to excessive humeral head translation and culminate in shoulder pain (Crockett et al., 2002; Ellenbecker et al., 2002). Thus, it remains unclear whether there are benefits or disadvantages associated to changes in humeral retroversion.

It has been speculated that retroversion acts as controlling mechanism for overhead activity such as throwing preventing excessive strain on the glenohumeral capsulo-ligamentous structures. Kronberg *et al.* (1990) found that, in normal shoulders, greater retroversion of the humerus was consistently related with an increased range of external rotation at 90° of shoulder abduction, but no differences were found between subjects' dominant and non-dominant shoulders for each tested range-of-motion.

On throwing athletes an increased humeral retroversion seems to be beneficial by two reasons. First, the greater retroversion of the humerus potentiates an increase of external rotation range-of-motion at the glenohumeral joint with advantages on the available energy that could be stored within the kinetic chain of the throwing cycle, particularly on the cocking phase, and therefore may allow greater arm velocity to be generated. It is theorized that more external rotation range in the dominant arm, could allow increased cocking of the throwing arm and thus increasing the ability to generate power and speed on release (Wang & Cochrane, 2001a). Second, an increased range-of-motion through osseous changes may provide an adaptive benefit for glenohumeral joint stability, sparing the joint capsule from excessive strain and disruption (Borsa et al., 2008). Consequently the joint could be more stable to anterior forces, because the anterior soft tissue structures would have to stretch less for a given amount of external rotation. If the soft tissues are able to stay within their elastic range, they will be better stabilizers of the glenohumeral joint.

Previous studies could establish an association between an increased HRA and a lower incidence of throwing-arm injury, in baseball players (R. Whiteley et al., 2006). However, the most common theory suggested that a shift towards retroversion could be an increase risk factor to shoulder injury. As mentioned before the associated increased available external rotation range-of-motion may cause a reduced ability of the rotator cuff to control high forces or velocities through the extremes of shoulder range which could potentially lead to excessive humeral head translation and culminate with shoulder pain (Crockett et al., 2002; Ellenbecker et al., 2002). Some studies found a paradoxical relationship between loss of internal rotation range-of-motion and increase in external rotation range-of-motion in dominant arm of throwing athletes (Borsa, Wilk, et al., 2005; Crockett et al., 2002; Osbahr et al., 2002; Reagan et al., 2002). These authors suggested that these changes could not be only due to capsule laxity and posterior capsular tightness and that osseous component may contribute to this kind of adaptations. To a better evaluation of this theme, a bigger knowledge about the normal development of the humeral retroversion angle, it is suggested a study which compares the dominant shoulder of an overhead athlete with the dominant shoulder of a non-athlete.

On the other hand, no statistical significant differences were found between the total range-of-motion and glenohumeral laxity, external and internal rotation (recorded at 90º de abduction), flexion or horizontal adduction between dominant and non-dominant arm. Also, no differences were found between the existence of GIRD and the contribution of tissues in the asymptomatic population. Laxity of the posterior capsule did not show differences between the group with GIRD and the group without GIRD, and also no significant correlation was found between laxity of the posterior capsule and changes in internal rotation range-of-motion. Tokish *et al.* (2008) conclusions are according to Crockett *et al.* (2002) but different from Pieper (1998) and Myers *et al.* (2006) in what concerns to an eventual contribution of the external rotation of the posterior capsule towards reduction of the internal rotation range-of-motion.

Adaptations on glenohumeral capsuloligamentous structures

Humeral retroversion may not be the only mechanism that explains the external rotation gain in throwing athletes. It seems that the looseness of the connective tissue that surrounds and stabilizes the glenohumeral joint may also play a role.

The glenohumeral joint is a multiaxial ball-and-socket synovial joint. The articular surfaces, the head of the humerus and the glenoid fossa of the scapula, although reciprocally curved, are oval and are not sections of true spheres. Because the head of the humerus is larger than the glenoid fossa, only part of the humeral head can be in articulation with the glenoid fossa in any position of the joint. The surfaces are not congruent, and the joint is loose packed. Full congruence and the close-packed position are obtained when the humerus is abducted and rotated laterally (Gardener, 1998).

Ligaments are important structures that provide stabilization. The inferior glenohumeral ligament complex (IGHLC) is considered to be the most restraining structure at the late cocking position (Kuhn, Bey, Huston, Blasier, & Soslowsky, 2000; Turkel, Panio, Marshall, & Girgis, 1981) followed by the coracohumeral ligament (Kuhn et al., 2000). It is likely that with the continuous excessive external rotation in throwing mechanics, the anterior capsule and the anterior band of the IGHLC may become looser than normal subjects (Herrington, 1998; Mihata, Lee, McGarry, Abe, & Lee, 2004). This laxity may not only affect osteokinematics (increased external rotation) but also arthrokinematics with increased translations of the humeral head in the glenoid cavity, predisposing the glenohumeral joint to instability (Mihata et al., 2004). Normally, at late cocking position, the humerus head must spin around its center of rotation and translates posteriorly (J. P. Baeyens, Van Roy, & Clarys, 2000; Harryman et al., 1990; Howell, Galinat, Renzi, & Marone, 1988). Although not fully understood, this translation may be due to increased stiffness of the collagen fibers of anterior band of the IGHLC that forces the head posteriorly when fully stretched, a mechanism known as the hammock effect (Burkhart, Morgan, & Kibler, 2003a). Looseness of the anterior band of the IGHLC may be responsible for shoulder complaints in team-handball players that showed a more anterior translation (no posterior translation) at late cocking position (J. Baeyens, Van Roy, De Schepper, Declercq, & Clarijs, 2001). The link between elongation of the anterior band of the IGHLC, increased anterior and inferior humerus head translations and humeral external rotation was demonstrated in cadaveric models (Mihata et al., 2004).

Functional adaptations

The kinematic/kinetic pattern in overhead throwing activities, the throwing cycle is to impart a high velocity or force on the distal segment, handoff the upper limb (McMullen

& Uhl, 2000). The ultimate velocity of the distal segment depends on the velocity of the proximal segment and on the interaction of these. This repetitive throwing at high velocities over time leads to chronic shoulder adaptations (Dillman, Fleisig, & Andrews, 1993; Osbahr et al., 2002). Physical examination of the dominant shoulder of overhead throwing athletes consistently shows changes on glenohumeral rotational range-of-motion, namely on external rotation, when compared with non-athletes (Osbahr et al., 2002; Oyama et al., 2008). Most overhead athletes exhibit an obvious motion disparity, whereby external rotation is excessive (external rotation gain, ERG) and shoulder internal rotation is limited when measured at 90° of abduction (Crockett et al., 2002; Meister, 2000b; Pieper, 1998; Reagan et al., 2002). According to Seroyer *et al.* (2009) the total arc of motion in the dominant arm is preserved, so any gain of external rotation should be offset by a comparable decrease in IR, resulting in the same total rotational arc.

The loss of internal rotation of the throwing shoulder has been referred to as glenohumeral internal rotation deficit (GIRD). The posterior shift in the total arc of motion is considered to be a physiological adaptation of the shoulder joint to throwing. Burkhart *et al* (2003c) described glenohumeral internal rotation deficit as an alternative mechanism for primary progression of “internal impingement-like” changes in the shoulder. This GIRD is based on a high prevalence of posterior capsular contractures and also contractures of the posterior band of the inferior glenohumeral ligament in the overhead athlete, so several explanations (Borich et al., 2006; Torres & Gomes, 2009; Wilk et al., 2011) have been given to this shift with increased external rotation and decreased internal rotation of the abducted shoulder. Additionally, it is also known that the injury mechanism on overhead athletes is mostly related to the throwing motion and the end-range shoulder external rotation (ER). As mentioned before the range-of-motion of the dominant arm of an asymptomatic elite-level overhead athlete typically is shifted posteriorly, with increased external rotation and decreased internal rotation of the abducted shoulder.

Changes on glenohumeral rotational pattern

In general, the shoulder rotational adaptation on the asymptomatic dominant throwing shoulder of an elite-level athlete was described by an increased external rotation range-of-motion and a correspondent decrease in the internal rotation range-of-motion, while the total range-of-motion is kept unchanged, in a condition called the "*posterior shift*" (Borich et al., 2006; McCully et al., 2005; Tokish et al., 2008; Wilk et al., 2009).

This adaptive pattern was mostly described in goniometric studies (Barlow et al., 2002; Downar & Sauers, 2005; Ellenbecker et al., 1996) where the athletes were tested in a supine or a sitting position with the arm placed at 90° of abduction. The arm is then passively rotated from the extreme position (end-range) internal rotation until the end-range of external rotation, or vice-versa. Following this standard goniometry procedure, the shoulder rotation end-range is determined by the examiner according with the capsular end-feel (Awan et al., 2002; Barlow et al., 2002), the scapular liftoff (Warner et al., 1990) momentum or perceived pain (Andrews AW & RW, 1989). A few studies described the changes on the rotational pattern using an active end-range determination (Ellenbecker & Roetert, 2002; Hayes, Walton, Szomor, & Murrell, 2001) and no studies to date have specifically investigated how humeral rotational pattern is affected by active or passive end-range determination in overhead athletes. The posterior shift in the total range-of-motion of motion is considered to be a physiological adaptation of the shoulder joint to throwing.

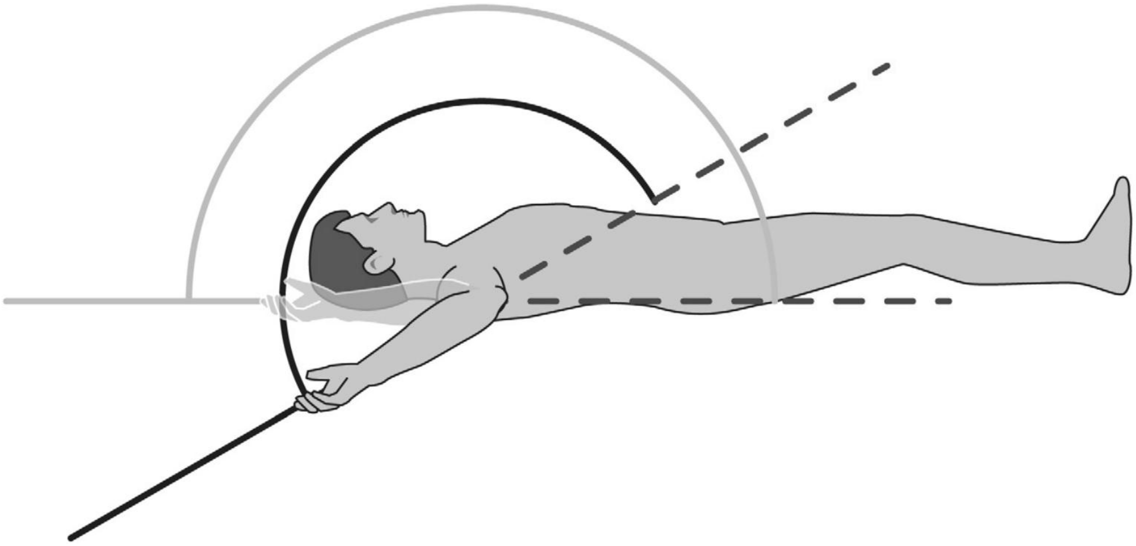


Figure 1: The arc of motion of the throwing shoulder is shifted posteriorly, with increased external rotation and decreased internal rotation of the abducted shoulder

The arc of motion of the throwing shoulder is shifted posteriorly, with increased external rotation and decreased internal rotation of the abducted shoulder. According to Wilk *et al.* (2009) most throwing athletes exhibit an obvious motion disparity, whereby shoulder external rotation (ER) is excessive and internal rotation (IR) is limited when measured at 90º of abduction. This loss of IR on the throwing shoulder, referred as the "*glenohumeral internal rotation deficit*" (GIRD) (Crockett et al., 2002; Nakamizo, Nakamura, Nobuhara, & Yamamoto, 2008; Pieper, 1998) is suggested to be caused by the external rotation of the posterior capsule induced by the increased range-of-motion of external rotation in the late cocking phase. This allows hyper-external rotation as the posterior capsule reaches maximum length while the anterior capsule still allows for additional external rotation. Burkhart *et al.* (2003a) described the GIRD as an alternative mechanism for primary progression of "*internal impingement-like*" changes in the shoulder. The glenohumeral internal rotation deficit model is based on the high prevalence of posterior capsular contractures and contractures of the posterior band of the inferior glenohumeral ligament in thrower shoulders. When a posterior capsular contracture occurs, the center of rotation of the humerus, or the contact point of the humerus on the glenoid, is shifted postero-superiorly. This shift functionally increases the length of the anterior aspect of the capsule, which provides more clearance for the greater tuberosity, diminishing the glenohumeral contact point of the anterior-inferior aspect of the capsule with proximal part of the humerus. As a result, the biceps anchor is peeled back under tension, causing injury to the postero-superior structures, especially the postero-superior aspect of the labrum The so-called peel-back progression mechanism permits further laxity of the anterior aspect of the capsule (Burkhart et al., 2003a, 2003c). With the glenohumeral internal rotation deficit model, one attempts to identify throwing athletes at risk for shoulder injury by quantifying the internal rotation deficit individuals are considered to have a clinically relevant glenohumeral internal rotation deficit when there is a loss of internal rotation of the throwing shoulder as compared with the non-throwing side. Such deficits are commonly found in overhead throwing athletes, when compared with measurements on the contralateral side, as well as concomitant increases in external rotation.

The presence of GIRD in baseball athletes was analyzed by Nakamizo *et al.* (2008) in a study which intended to evaluate the external rotation and internal rotation range-of-motion and compare kinetic patterns in baseball throwing athletes with and without internal rotation deficit (GIRD). Sample was composed of 25 young (11, 4 ± 0, 8 years) baseball throwing athletes, asymptomatic, divided into 2 groups after measuring the maximal internal rotation range-of-motion (arm ≈90º abduction): with GIRD and without GIRD. In both groups no differences were found concerning external rotation range-of-motion between dominant and non-dominant arm. Although this, in the throwing motion, in the late cocking phase, just immediately before the member acceleration, a statistical significant increase in external rotation range-of-motion was found in the group with GIRD. Concerning the evaluation of the angular movements no differences were found in any of the components of the throwing motion, neither the late cocking phase or in the deceleration phase (immediately after throwing the ball) when comparing both groups. The explanation advanced by the authors corroborates Pieper *et al.* (1998) and Crocket *et al.* (2002) arguments, suggesting the contribution of the external rotation of the posterior capsule in the increase of shoulder external rotation at the end of the late cocking phase.

Concerning variations of the range-of-motion of glenohumeral axial rotation, Dwelly *et al.* (2009) showed, using a sample of 29 male baseball players and 19 female softball athletes, the existence of a significant increase in external rotation range-of-motion and no differences in the internal rotation range-of-motion during one season. It is not clear, if the existence of this dislocation of glenohumeral range-of-motion of motion towards external rotation, with the external rotation of the posterior capsule can lead to any kind of impingement. To clarify this issue, Myers *et al.* (2006) compared 11 baseball throwing athletes with impingement symptoms with a similar number of asymptomatic players (control), verifying that in the athletes group the internal rotation range-of-motion was decreased and also the posterior capsule was retracted. They did not observe any external rotation range-of-motion increase in the athletes group with internal impingement when compared with the control group. These results suggest that external rotation of the posterior shoulder capsule is associated with internal impingement and can eventually be indicated as a possible cause of this clinical condition.

Acquired Glenohumeral Hyperlaxity

The theory of acquired anterior hyperlaxity on the dominant glenohumeral joint of overhead athletes was first proposed by Jobe *et al.* (1989) and describes a gradual stretching out of the anterior capsuloligamentous structures of the glenohumeral joint, producing a lax and mechanically unstable shoulder.

The anterior band of the inferior glenohumeral ligament complex, located on the anterior-inferior side of the joint is one of the primary static stabilizing structures responsible by restriction on the anterior humeral translation (Gardener, 1998). This structure is under maximal strain during arm abduction and external rotation. Stretching of the capsuloligamentous restraints as a result of this chronic strain is thought to result in subtle anterior humeral head translation (micro-instability) and postero-superior labral pathology Some authors suggest that the combination of micro-instability and labral tearing could be responsible for the gain in external rotation ROM in the dominant arm of overhead athletes (Stefko, Tibone, Cawley, ElAttrache, & McMahon, 1997). Walch *et al.* (1991) suggested that anterior hyperlaxity results in the subsequent development of internal impingement in throwers. It is hypothesized that the repetition of the extreme arm positions inherent in overhead activity, such as the late-cocking stage of throwing, involve extreme glenohumeral external rotation, abduction and horizontal extension. In this position, the humeral head has been shown to contact the undersurface of the supraspinatus tendon in the posterior-superior glenoid region.

In several populations of asymptomatic overhead athletes, a few studies reported a minimal anterior humeral translation in the functional test position of abduction and external rotation (Borsa, Wilk, et al., 2005; Ellenbecker et al., 1996).

These findings suggest that in non-pathological overhead throwing shoulders the glenohumeral anterior-inferior restraints are not stretched out and remain intact and stable. More recently, data from Sethi *et al.* (2004) provide evidence supporting the link between increased shoulder laxity and gain in external rotation ROM in the dominant arm of overhead athletes.

Grossman *et al.* (2005) in a study with ten cadaveric shoulders tested the humeral rotational range-of-motion using a customized shoulder-testing device. With the humerus positioned in 90º abduction and at the end-of-range of external rotation, the glenohumeral translations in anterior, posterior, superior, and inferior directions were measured. To simulate anterior laxity due to posterior capsular contracture, the capsule was nondestructively stretched 30% beyond maximum external rotation with the shoulder at 90º abduction. This was followed by the creation of a 10-mm posterior capsular contracture. Rotational humeral shift and translational tests were performed for the intact normal shoulder, after anterior capsular stretching, and after simulated posterior capsular contracture. Authors concluded that anterior laxity could be protective to the glenohumeral joint given that allows the humeral rotation and its position more inferiorly and away from the rotator cuff, to the coraco-acromial range-of-motion and the debrum´s postero-inferior portion. They also showed, that the posterior capsular contracture caused the postero-superior migration of the humeral head, and could possibly increase the contact of this one with the debrum and the rotator cuff at the end of the late cocking phase suggesting, that internal impingement can result in the posterior capsule contracture and not in anterior laxity.

However the theory of internal impingement, the theory of the mechanism of *peel-back* may not explain adequately the physiopathology of the shoulder of the overhead athlete. In a study with cadaveric shoulders, Huffman *et al.* (2006) simulated the posterior capsule contracture and anterior capsule laxity while the arm was preconditioned in successive positions of the throwing baseball cycle, since cocking phase until follow-through phase. Results showed important kinematic changes in the cocking and follow-through phases due to posterior capsule contracture. Tracking the multiple advantages in a study with corpses one of its limitations is the absence of muscle forces. However, it allows outline the role of the anterior capsular laxity in combination with the posterior capsule contracture.

Some studies analyzed the effect of posterior muscular and capsule, coracoacromial and coracohumeral ligaments stretch programs with the purpose to reduce GIRD. It is in this context that Lintner *et al.* (2007) can be included, eighty-five male professional pitchers were evaluated in this study. Players were divided into 2 groups based on length of participation in an appropriate internal rotation stretch program. Group 1 consisted of players who had been in a stretching program or its equivalent for 3 or more years, and group 2 were those who were not.

Results revealed that a stretching program is decisive for internal rotation ability or for the total range-of-motion. It is important to highlight without questioning the importance of the results found by Lintner *et al.* (2007) in fact we do not have enough information about players performance or the quality of the throwing motion after intervention. On the other side, we believe that a prospective study accompanying the evolution of ranges of motion, and also the size of soft tissues and periarticular structures, it would be better to test the hypothesis.

Adaptation in scapulothoracic joint function

The scapula is a large, thin, triangular bone, which the major function is to assist upper limb motion by orienting the glenoid cavity of the scapula for the moving humerus. Scapula is connected to the thorax via a muscle-bone-muscle articulation, with no true articular cavities, the scapulothoracic joint. This joint consists of a broad soft-tissue interface formed by the contact between the anterior surface of the scapula and the posterior and lateral surface of the thorax. Scapula and thorax are separated by the serratus anterior and subscapularis muscles and their surrounding fascias. Functionally the scapulothoracic joint is a gliding mechanism between the concave anterior surface of the scapula on the convex posterior and lateral surface of the thoracic cage (Gardener, 1998).

Scapula plays an important role in normal shoulder function. Proper tridimensional (3D) positioning of the scapula is crucial in allowing full and non-impaired motion of the upper extremity. The resting 3D orientation of the scapula on the thorax has been reported to include slight upward rotation, anterior tilting, and protraction (internal rotation). During planar humeral elevation above shoulder level, the scapula moves into progressive upward rotation, slight external rotation (external rotation) at higher elevation angles, and decreased anterior tilting (scapulohumeral rhythm). These scapular motions are believed necessary during glenohumeral elevation to maximize the distance between the greater tuberosity and acromion process, thus maintaining adequate size of the subacromial space (Borich et al., 2006). In fact, the scapulohumeral rhythm enables an appropriate force-length relationships for the scapulohumeral muscles (e.g. deltoid) and simultaneously optimize the concavity-compression mechanism of the rotator cuff muscles of the humeral head against the cavity (Kibler, 1998; Labriola, Lee, Debski, & McMahon, 2005; Lazarus, Sidles, Harryman Ii, & Matsen Iii, 1996; Terry & Chopp, 2000; Wilk, Arrigo, & Andrews, 1997; Zatsiorsky, 1998).

Scapular position on the thorax is determined, in part by the thorax shape and resting tone and net vectors of the axioscapular muscles, levator scapulae, pectoralis minor, rhomboids, serratus anterior and trapezius (Lewis, Green, & Wright, 2005). These are also known as scapular stabilizers. As the name indicates, they link the arm to the thorax and the thoracic spine via the scapula bone. The rhomboids and the serratus anterior muscles attach to the medial border of the scapula and the levator scapulae and the inferior portions of trapezius muscles connect to its superior border, specifically at the spine. In conjunction with the pectoralis minor muscle, that anteriorly inserts on the tip of the coracoid process, this postero- lateral muscles couple their actions allowing scapular motion and stability. Unbalancing of these coupling forces may impair glenohumeral structures (e.g. subacromial structures) or be impaired by glenohumeral disorders such as instability and impingement syndrome (Hebert, Moffet, McFadyen, & Dionne, 2002; Kebaetse, McClure, & Pratt, 1999; P.M. Ludewig & Cook, 2000; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; Matias & Pascoal, 2006; P. W. McClure, Michener, & Karduna, 2006).

In sports in which demands placed on the shoulder are extremely high, the quality of movement depends on the interaction between scapular and glenohumeral kinematics. Abnormal scapular kinematics and associated muscle dysfunction are assumed to contribute to shoulder pain and pathology (Forthomme, Crielaard, & Croisier, 2008). Nevertheless the exact cause, or the precise underlying mechanism, changes in scapula alignment in theory it will promote changes in musculoskeletal tissues, followed by permanent (reversible or irreversible) altered alignment at rest and changed dynamics (McConnell et al., 2012).

Scapula has an important role in all throwing actions due to the fact that enlarges the arm movement. Changes in scapular stability and mobility (dyskinesis) can be cause or consequence in the performance of the athletes’ shoulder or in some other shoulder pathologies (Borsa et al., 2008). Scapular positioning is crucial for the periescapular muscles and also for the stability of the glenohumeral joint promoting congruence between the glenoid and the humeral head. In fact, the important role that scapula plays in shoulder function is that of being a link in the proximal-to-distal sequencing of velocity, energy, and forces that allows the most appropriate shoulder function. For the most shoulder activities, this sequencing starts at the ground. The individual body segments, or links, are coordinated in their movements by muscle activity and body positions to generate, summate, and transfer force through these segments to the terminal link. This sequencing is usually termed “kinetic chain” (McMullen & Uhl, 2000). The scapula is pivotal in transferring the large forces and high energy from the major source for force and energy, the legs, back, and trunk to the actual delivery mechanism of the energy and force the arm and the hand (Kibler, 1998). Breaking this sequence , as it seems to happen in the action of the inferior limbs and trunk is interrupted in the glenohumeral joint, with implications in the behavior of the upper limb and force concentration towards instability (Forthomme et al., 2008; Kibler, 1998; J. B. Myers, Laudner, Pasquale, Bradley, & Lephart, 2005).

However, little is known about the relative contribution of scapular position on the range-of-motion of shoulder external rotation. Changes in scapular position, both dynamic and static, play critical roles in pathologic processes in the overhead athlete, and yet the contribution on scapulothoracic motion to throwing is currently one of the least studied and understood entities in the overhead athlete. As mentioned, it can negatively impact shoulder function in several ways, for example, in order for overhead athletes to reach the extremes of motion, the scapula must rotate counter clockwise (in sagittal plane of the right arm) so that the acromion elevates to prevent impingement. The scapula must also retract appropriately to keep the glenoid vault centered under the humerus, maintaining stability. If the scapula fails to retract appropriately, there is hyperangulation of the humerus relative to the glenoid and excessive stress is placed on the anterior aspect of the capsule. This will probably lead to an increase in external shoulder rotation and a decrease in internal rotation with the arm abducted.

During the throwing motion athletes were expected to present some kind of scapular intervention, which seems to be more advantageous for the overhead athlete, allowing a more stable glenohumeral joint, an also because the movement with the scapula intervention could increase the displacement range-of-motion of the hand, with benefits to hit or spike the ball. This should be seen in athletes but not in non-athletes, if it is an adaptation due to sports practice. At the rehabilitation of the athlete´s shoulder, after an injury the normal athlete function has to be restored, so if the overhead athlete presents an adaptation, during rehabilitation this has to be preserved.

Concerning scapula, in literature authors have focused their attention in order to explain shoulder pain always associated with pathology (Borich et al., 2006). Mentioned adaptations have been reported in scapular asymmetry, related with scapulo-humeral rhythm. No studies to date have looked for scapular behavior associated to rotational motion, or trying to understand if these are normal movements or pathological ones.

The analysis of morphofunctional adaptations of the shoulder in the overhead athlete cannot be circumscribed to the glenohumeral, but should include the other shoulder joints, particularly to the scapulothoracic joint. The position of the scapula with respect to the thorax is crucial for the stability and mobility of the glenohumeral joint, this could be cause/consequence to shoulder injuries and dysfunctions of the overhead athlete. In a kinematic study with 21 overhead athletes who had been participating in organized, competitive baseball for at least the past 5 years (9 pitchers and 12 field position players) and a control group which consisted of 21 male subjects who were matched according to age, height, mass and dominant limb to the subjects in throwing group but with no significant history of participation in overhead athletics, Myers *et al.* (2005), verified that athletes in shoulder abduction in the scapular plane, the scapula assumed a position more in upward rotation, protraction and anterior spinal tilt. The reduction of the posterior tilt (anterior tilt positioning) is determinant for the increase of the sub-acromial volume being also a protector of the impingement condition. On the other hand, also protraction accentuates the probability of impingement while aligning the acromion and the coracoacromial range-of-motion with the humeral head and humerus. This effect is more evident with the pattern of shoulder internal rotation. Myers *et al.* (2005) propose that overhead athletes develop chronic adaptations that most likely contribute to or result from the throwing motion and may result in improved throwing skill. Another point is that they may contribute to injury prevention or possibly contribute to injury prevention or even contribute to shoulder injury.

The results of Myers *et al.* (2005) were corroborated by Oyama *et al.* (2008) in a study about scapular resting position, with a sample of 43 male athletes, 15 baseball pitchers, 15 volleyball players and 13 tennis players. Results showed that in all athletes the scapula was in protraction and anterior tilt, and no asymmetry between both scapulae was found. Laudner *et al.* (2007) in a study with a sample of 15 baseball pitchers and 15 asymptomatic field position players could find that baseball pitchers have less scapular protraction than field position players. This difference can be explained by the glenohumeral laxity, or even by the muscular fatigue due to repetitive throwing. Besides this, the study showed statistically significant differences at 60º and 90º of abduction, the numerical differences seem to be small (3.9º and 4.4º, respectively), and may not be enough to explain the tissue compression in consequence to the reduction of the sub-acromial space.

In the presence of shoulder pathology it seems to exist also, an alignment alteration and in scapular function which is related to the muscle function of muscles responsible for stability and mobility of the shoulder girdle. Cools *et al.* (2003) in a study which evaluates the timing of trapezius muscle activity in response and deltoids during the glenohumeral motion showed that, significant group differences exist regarding timing of scapular muscle activity in relation to onset of deltoid muscle activity and among the three trapezius muscle parts, when comparing the overhead athletes group with impingement symptoms (N = 69) to the asymptomatic athletes group (N = 39) Compared to non-injured subjects, those with impingement showed a delay in muscle activation of the middle and lower trapezius muscle and a lack of coordination between the different trapezius muscle parts. They concluded that overhead athletes with impingement symptoms showed abnormal muscle recruitment patterns in the middle and lower trapezius muscle. The findings of this study support the theory that shoulder impingement may be related to delayed onset of middle and lower trapezius muscle activity and may have implications for the nonsurgical treatment of patients with impingement syndrome. The same authors, in another study (Cools, Witvrouw, Mahieu, & Danneels, 2005) compared 30 overhead athletes (volleyball and tennis players) with chronic shoulder impingement symptoms and 30 overhead athletes without a history of shoulder pain. They found that overhead athletes with impingement symptoms demonstrated strength deficits and muscular imbalance in scapular muscles while compared with uninjured athletes. Differences found inter-group and intra-group in both velocities revealed a presence of dysfunction in multiple degrees of muscular function. These findings support the hypothesis that shoulder impingement may be related to scapulothoracic muscle dysfunction and may have implications for the conservative treatment of impingement syndrome.

Laudner *et al.* (2006) completed this information when comparing 11 baseball players diagnosed with pathologic internal impingement, with a control group of 11 throwing athletes with no history of upper extremity injury. Results revealed that athletes with impingement demonstrated statistically significant scapular orientation and position differences compared to healthy throwing athletes with no history of injury. Specifically throwing athletes with pathologic internal impingement presented an increased sternoclavicular joint elevation and scapular posterior tilt positions during humeral elevation in the scapular plane, as compared to healthy throwing athletes. In short, functional changes seem to occur in the positioning and scapula movement on the dominant side of the symptomatic overhead athlete, although there are not many studies about this theme, fact that does not allow us to make an extended result comparison. Myers *et al.* (2006) mentioned an increase in external rotation of the scapula when the humerus is abducted actively in its plane. This change can be seen as a protective behavior on shoulder joint (as long as it raises the subacromial space). However, they seem to have more internal rotation range-of-motion while adducting the shoulder besides the increase of internal rotation in the resting position (Oyama et al., 2008) which induces the opposite effect of external rotation raise (reduces subacromial space).

In Laudner *et al.* (2006) study, on the contrary to Myers *et al.* (2006) (who used as controls non-athletes) the dominant scapular motion was compared between 15 baseball players and 15 field position players. Authors showed a decrease in scapular external rotation of overhead athletes. It seems, that Myers *et al.* (2006) deserves extra confidence because athletes were compared with non-athletes. Laudner *et al.* (2006) in their study also mention that differences found are numerically small in absolute value.

Scapular dyskinesis and SICK scapula

Some adaptive changes on posture and scapular motion, in overhead-throwing athletes, have been related to scapulothoracic dysfunction or shoulder pathology. The most know of those conditions are the "*scapular dyskinesis*" and the "SICK scapula".

The "SICK" (scapula) is the acronym of the signs and symptoms associated with this syndrome (Burkhart, Morgan, & Kibler, 2003b): **S**capular malposition, **I**nferior medial border prominence, **C**oracoid pain changes on scapular motion (**K**inesis). This syndrome is another cause of shoulder pain in the throwing athlete. The hallmark feature of this syndrome is asymmetric malposition of the scapula in the dominant throwing shoulder, which usually appears on examination as if one shoulder is lower than the other (Burkhart et al., 2003b). The term "*scapular dyskinesis*" identifies postural changes (rest position) or even scapular motion that occurs associated to arm motions namely arm elevation (Boon & Smith, 2000; Burkhart et al., 2003b; Gumina, Carbone, & Postacchini, 2009; Kibler & Sciascia, 2010; Tate, McClure, Kareha, Irwin, & Barbe, 2009). Clinically speaking these changes in the scapular kinematics are usually described as "*floating scapula*" or "*scapular asymmetry*" (Kibler & Sciascia, 2010) being associated to joint dysfunction of the shoulder complex, namely in the scapulothoracic joint. Some authors as Kibler *et al.* (2002) have demonstrated the concern to classify the scapular dyskinesis trying to associate postural pattern changes and also shoulder pathologies. In sports context scapular dyskinesis has been associated to athletes who sports gesture includes repetitive motion of the upper limb with the hand above the head. In the anglo-saxonic literature these athletes are named as "overhead athletes" (Wilk et al., 2011; Wilk et al., 2009; Wortler, 2010).

Other adaptations

The sensorimotor system is responsible for coordination and also stability. It is also a major component of function and performance in athletic activity. This system has to have an adequate function to allow the more complex motor activities, such as throwing. Fatigue decreases sensorimotor system function´s predisposing the shoulder to injury. Although some of these alterations, may predispose shoulder to a better performance.

Adaptations in Proprioception

The changes in proprioception and dominant shoulder position of an overhead athlete are not very studied yet. Dover *et al.* (2003) performed a study that had the purpose to answer this question, with a sample of 100 female athletes without shoulder dysfunction (50 softball players and 50 non-overhead athletes). After 3 measurements of active bilateral range-of-motion of external/internal rotation, flexion and extension of the shoulder, authors determined the perception of position of the athletes shoulder, using the “error” between dominant and non-dominant, after joint repositioning to a position explained by the examiner, without any visual feedback (the examiner positioned the athlete upper limb, asking her to maintain the position for 3 seconds, and then returning back to the neutral position).

Dover *et al.* (2003) concluded that dominant shoulder of softball athletes exhibit a significant increase of external range-of-motion (dominant = 104.8º ± 12.7, non-dominant = 100.1º ± 11.8, $p < 0.001$) associated to a significant decrease of internal rotation range-of-motion (dominant = 94.9º ± 12.8, non-dominant = 101.9º ± 12.6, $p = 0.008$). In the control group, it was only statistically significant the external rotation range-of-motion (dominant = 97.5º ± 11.4, non-dominant = 93.8º ± 12.2, $p = 0.014$).

Concerning the position sense no statistical significant differences were found related to the field position in the softball athletes, but these present a significant decrease in the external rotation sense of position of dominant limb while compared with the non-dominant one and with the control group. Based on these results, Dover *et al.* (2003) state that there is a decrease shoulder proprioception in external rotation of asymptomatic female overhead athletes. These alterations may be due to congenital influences or adaptive changes that occur as a result of sport-specific requirements for overhead throwing athletes. With changes to the capsular and muscular structures around the shoulder joint, Ruffini and Pacinian corpuscles may be affected, thus resulting in partial differentiation and proprioceptive deficits. Tripp *et al.* (2007) intended to examine the effect of functional fatigue on the upper extremity position (scapulothoracic joint, glenohumeral, elbow and wrist) reproduction in overhead throwing athletes, with 16 healthy collegiate baseball players. Authors measured active multijoint reproduction of 2 positions: arm clock and ball release. These measurements were made to evaluate the position sense in the dominant upper limb, asking the athletes to put their arm in the cocking position (the position at which forward acceleration of your arm should begin) and the ball release position (the position at which you release the ball, your release point), during 3 trials with and 3 trials without visual feedback (closed eyes). To evaluate fatigue, was asked to throw the ball with maximum velocity and accuracy when prompted by the tester (every 5 seconds). Authors considered subjects fatigued, ending the throwing protocol, when they reported an exertion level exceeding 14 or after 160 throws, in Borg´s scale. Immediately after the throwing protocol, authors retested participants in the same manner as for the prefatigue measures. Authors concluded, based on the results that muscular fatigue decreases overall upper extremity acuity in both positions tested. Fatigue also affected the reposition acuity of the scapulothoracic, glenohumeral, elbow and wrist joints individually. Tripp *et al.* (2007) explained that results could be due to the fact that these positions are in the mean range-of-motion of the joints, where the position sense depends a lot from the information from the muscular receptors, which become differentiated with fatigue, and with this there is a major difficulty to understand the position sense. Although these authors did not establish a straight relation between proprioception deficits and injuries, it seems important to conclude if these deficits exist in overhead athletes, especially in the position sense, resulting in more injury incidence. Another issue is if these deficits can be in some way corrected or improved through proprioceptive training in asymptomatic athletes, preventing shoulder injuries.

Adaptations on Shoulder Muscles Strength

The great magnitude forces in muscle occur when an external force exceeds that produced by the muscle and the muscle lengthens, producing an eccentric contraction and negative work. Because the muscle´s force can be maximized when contracting eccentrically, damage to the contractile and cytoskeletal components of the muscle and to the muscle fiber itself which gets weaker and a perception of soreness often occur. It is curious that muscle, structured to absorb and perform mechanical work during eccentric lengthening, sustains muscle damage and while performing a task it appears ideally suited to accomplish. However, muscle damage is not necessarily an obligatory response following high-force eccentric contractions. In fact, the ability to produce high forces with eccentric contractions should perhaps be more properly perceived as a protective muscle adaptation and a stimulus for beneficial muscle (and tendon) responses, rather than as a common cause of damage. Many have called for the use of chronic eccentric exercise in the preventative care or rehabilitation of patients.

Muscles act like shock-absorbing structures and springs when they absorb mechanical work while eccentrically lengthening. The forces resulting from these eccentric muscle contractions produce negative work. While the energy that is absorbed during the muscle and tendon stretch is often dissipated as heat, elastic strain energy can also be stored and recovered if an immediate shortening concentric contraction follows. When muscles are activated eccentrically immediately prior to shortening they no longer act as shock absorbers; rather, they perform more like springs. During a stretch-shorten contraction (SSC), muscles are actively lengthened prior to a subsequent shortening phase. The stretch components of the muscle-tendon unit store elastic recoil potential energy (or elastic strain energy), a portion of which may be subsequently recovered. The storage and recovery of elastic strain energy during a SSC is an important determinant of performance, as the energy stored during a lengthening cycle can substantially amplify, force and power production in the subsequent shortening cycle. Some studies however report that the restitution of elastic strain energy does not provide the increased power output; rather, an increased activation of the muscle enhances shortening work. In all likelihood, the increased power of shortening is a combination of both. The ability to recover elastic strain energy is apparently energetically so advantageous that the most economical stride frequency in running may be set by this property alone.

Apart from the role of tendons and collagen in energy storage, the muscle itself stores and recovers elastic strain energy, as elastic strain energy can occur in the absence of tendons. In a sense, because the muscle is composed of both muscle fibers and tendinous materials, all of these structures must be collectively “tuned” to the spring properties for the muscle-tendon system to store and recover elastic strain energy during locomotion (Lastayo et al., 2003).

It is expected, according to the biomechanics of the technical gesture, and its repetition and all changes in range-of-motion of shoulder girdle and also muscular recruitment that differences exist between shoulder strength of dominant and non-dominant of overhead athletes, especially concerning external and internal rotators, where more changes exist concerning range-of-motion. Donatelli *et al.* (2000), intending to investigate this issue, used a sample of 39 male baseball pitchers without shoulder dysfunction. One blind examiner measured passive external and internal shoulder range-of-motion (without additional pressure) and muscular strength was measured bilaterally with a hand-held dynamometer. Tested muscles were internal and external glenohumeral rotators, with the shoulder at 90º abduction in the scapular plane, supraspinatus muscle at 90º abduction in the scapular plane, middle trapezius, lower trapezius and serratus anterior. After statistical analysis, Donatelli *et al.* (2000) verified a statistical significant difference in shoulder range-of-motion between dominant and non-dominant. According to other mentioned studies (Crockett et al., 2002; Dover et al., 2003; Pieper, 1998; Tokish et al., 2008), dominant limb also presented higher range-of-motion of external rotation and less range-of-motion of internal rotation when comparing dominant and non-dominant limb. Concerning muscular strength, authors verified that dominant limb showed bigger strength in the middle portion of trapezius (dominant = 6.66kg ± 1.66, non-dominant = 5.84kg ± 1.73, $p = 0.003$), in the inferior portion of trapezius muscle (dominant = 6.85kg ± 1.90, non-dominant = 6.08kg ± 1.22, $p = 0.015$) and internal rotators at 90º abduction (dominant = 18.20kg ± 3.96, non-dominant = 17.43kg ± 3.65, $p = 0.029$). On the other hand dominant shoulder also showed a statistical significant decrease of external rotators in the scapular plane (dominant = 13.27kg ± 3.59, non-dominant = 14.50kg ± 3.11, $p = 0.002$) and in 90º abduction (dominant = 15.05kg ± 3.67, non-dominant = 17.14kg ± 4.09, $p <0.001$). The supraspinatus did not show differences in strength between dominant and non-dominant shoulder. Based on these results, Donatelli *et al.* (2000) concluded that there is a decrease in strength of external rotators of the dominant shoulder and a significative increase in strength of the internal rotators and middle and inferior trapezius muscles. The author explained his results based on the biomechanics of overhead throwing motion: the fact that the overhead throwing motion of these athletes recruits more strength in the internal rotators than external rotators can explain this unbalance in muscular strength. Authors highlighted also the importance of trapezius muscles at the final phase of external rotation in the overhead throwing motion, these actuate in the scapula, preventing excessive tension of the glenohumeral joint, protecting the supraspinatus muscle from additional injuries, justifying the fact that this muscle did not show differences in strength between dominant and non-dominant shoulder.

Noffal (2003) on the other hand tried to identify muscular imbalance in dominant and non-dominant shoulders of throwing athletes and non-throwing athletes, being the first to compare functional eccentric to internal concentric ratio in dominant and non-dominant shoulders of throwing athletes and non-throwing athletes. Based on these results, collected in a sample of 59 male subjects (16 throwing athletes and 43 non-throwing athletes), author indicates a statistically significant increase in strength of internal rotators of the dominant shoulder of the throwing athletes when compared with non-throwing athletes, no significant differences was found in the eccentric external rotation strength between groups or extremities. Yildiz *et al.* (2006) with the purpose to evaluate and collect data about terminal range eccentric antagonist/concentric agonist rotator cuff strength in overhead athletes used a sample of 40 asymptomatic military overhead athletes (volleyball, team-handball and tennis) measuring strength of internal and external rotators at 90º abduction using the Cybex NORM isokinetic dynamometer at a speed of 90º/s. Subjects were tested in a supine position, standard stabilization strapping was placed across the distal thigh, waist and chest. Strength was tested through 110º range-of-motion, between 20º of external rotation and 90º of internal rotation from the neutral position. The subjects were tested with a maximum of five repetitions; all participants were tested in concentric internal rotation first, followed by eccentric internal rotation. A 2-min rest interval was given between testing modes to prevent fatigue build up. Yildiz *et al.* (2006) found that in terminal range external rotation, the eccentric strength of internal rotation was significantly higher in the dominant side than the non-dominant ($p<0.01$). On the other side, in terminal range internal rotation the concentric strength of internal of dominant side was significantly higher than the non-dominant side ($p<0.01$). Ratios of terminal range were determined to evaluate the relationship between agonist/antagonist for the terminal range internal rotation (60-90º of internal rotation), the ratio of eccentric/concentric internal rotation of external rotation was of 1.03±0.8 in the dominant side and 1.19±0.8 in the non-dominant side, which means a statistical significant difference ($p<0.01$). Terminal range external rotation (10º de internal rotation until 20º de external rotation) was of 2.09±1.1 for the dominant shoulder and 1.58±0.9 to the non-dominant shoulder, difference also significant ($p<0.01$). Authors concluded that the muscle torque ratios of eccentric antagonist/concentric agonist are different between dominant and non-dominant shoulders of skilled overhead athletes.

Trakis *et al.* (2008) hypothesized that pitchers with a history of throwing-related pain will have weakened dominant-arm posterior shoulder musculature and greater dominant-arm glenohumeral total range-of-motion loss compared with pitchers without throwing-related pain. Initial sample was composed of twenty-three adolescent pitchers; they completed a questionnaire regarding injuries, pain with pitching, and playing statistics for that season. The following information was recorded: (1) the number of games pitched, (2) the number of games pitched during which the player had shoulder or elbow pain, (3) the magnitude of the worst pain the player pitched with during that season, (4) the percentage of practices in which the player had shoulder or elbow pain, (5) whether the player had pain with non-baseball activities, (6) whether the pitcher thought that pain affected performance or mechanics in any game, and (7) if the player sustained any injuries that required medical treatment and resulted in missed time. Two pitchers were excluded from testing because they had a shoulder or elbow injury during the season that required medical treatment and resulted in missed time. Therefore, 23 male pitchers (mean age 15.7 years) underwent postseason strength and ROM testing, three alternating readings of glenohumeral external and internal rotation ROM were made in the supine position without additional pressure by the examiner (with a goniometer) and muscle strength, with a handheld dynamometer. Both examiners were blinded concerning athlete's dominant upper limb and also regarding the questionnaire. Trakis *et al.* (2008) showed that overhead throwing athletes had a decrease in internal rotation ROM (13º±10º, $p<0.0001$) and increase in external rotation ROM (11º±10º, $p<0,0001$) comparing dominant and non-dominant shoulders, without range differences in the full range. They also showed increased muscle strength in the dominant side in inferior and middle trapezius, latissimus dorsi, internal rotators (all $P< .01$) and the external rotators ($P< .05$). There was no significant difference between the dominant and non-dominant sides for strength of the rhomboids and supraspinatus. Twelve of the pitchers reported having throwing-related pain during the previous season; three pitchers thought that pain affected their performance or mechanics. The pitchers with prior pain did not differ from those without prior pain in age or in the number of games pitched that season. Concerning strength, results show that throwing athletes prior to pain had increased strength regarding internal rotation and decreased strength of the external rotators when compared with athletes without history of pain. Trakis *et al.* (2008) suggested that these results showed that pain related to the throwing motion in adolescent pitchers can be due to the inability of weakened posterior shoulder musculature to tolerate stress imparted on it by adaptively strengthened propulsive muscles.

There are few studies studying muscular strength of the overhead throwing athlete, but it seems to exist consensus between authors concerning the relationship of the increased strength in internal rotators and decreased strength in external rotators in the dominant shoulder of the overhead-throwing athlete (Donatelli et al., 2000; Trakis et al., 2008; Yildiz et al., 2006). Noffal (2003) only found statistical significant differences in concentric strength of internal rotators, without finding differences in eccentric contraction of internal rotators neither in external rotation strength when compared with non-dominant shoulder or control group. Yildiz *et al.* (2006) adds the calculation of muscular torque ratios of agonist concentric/ antagonist eccentric and concluded that these are different in their terminal range between dominant and non-dominant shoulders of overhead throwing athletes. These changes in the dominant shoulder of the overhead-athlete, especially the significant decrease in external rotators strength, leave some questions concerning the level of stability of the glenohumeral joint. The rotator cuff is the most important muscular group regarding external rotation, and at same time a crucial paper maintaining stability (anterior) of the joint, can this change induce injury?

Clinical Examination of the Overhead-Throwing Shoulder

Physical examination of the overhead throwing shoulder for some has become somewhat of a lost art because of the difficulty of the examination itself. The subtleties of the normal athletic shoulder that often make comparison to the opposite side unreliable are important aspects to be aware of. Although a classic tenet of physical examination is to compare the symptomatic side with the opposite normal side, this is not always reliable in the overhead athlete. As mentioned before there are a number of morphofunctional adaptations that occur in overhead throwing athletes, which, although asymmetric, are not pathologic. Striving to create symmetry in these athletes may "correct" physiological adaptations that protect the overhead arm and might lead to further problems and dysfunction. The physical examination of the overhead throwing athlete remains a challenging art.

The clinical examination consists of a subjective or interview and a physical section, during which hypothesis formed during the interview may be supported or modified. Further development of hypotheses occurs throughout the treatment process on the basis of response to particular interventions. Knowledge of clinical patterns of the shoulder complex facilitates interpretation of all information received, allowing the physiotherapist to guide the interview to establish supporting or negating features of particular clinical patterns.

Physiotherapist should be aware that this specific shoulder adaptive pattern makes each athlete unique, and the same should occur with the examination and treatment. Changes in humeral retroversion angle will induce rotational ROM alterations, and in the dominant arm these overhead throwing athletes may be prone to present more external rotation (external rotation gain) and an glenohumeral internal rotation deficit (GIRD).

How to measure this rotational range-of-motion during physiotherapy examination should be one important issue during shoulder assessment, as long as these athletes perform their overhead activities standing, performing the whole kinetic chain. Also athletes always use their shoulders in active movement, on the contrary most of the physiotherapy examination is performed passively (McConnell et al., 2012).

Scapula makes part of this kinetic chain, but in most of the studies using the same procedures used during physiotherapy examination, scapula is stabilized and its motion (Boon & Smith, 2000; McConnell et al., 2012; Wilk et al., 2011) or participation is not taken into account. Alterations in static scapular position and dynamic scapular motion, described as scapular dyskinesis have been found in patients with various shoulder pathologies. A reliable method of clinical assessment of these scapular alterations has not been developed. Several problems contribute to this difficulty; first it is challenging to accurately observe the motions of the scapula beneath the muscle and overlying soft tissues. Second, measurements methods must take into account the 3 rotational movements and 2 translations of the scapula. A few of the first clinical assessment methods categorizing or quantifying scapular dyskinesis, such as the lateral scapular test, posterior displacement test and scapular upward rotation measure, used static measures that assessed scapular position in 1 plane or at most, 2 planes. The third challenge is establishing clinical assessment criteria to define scapular dyskinesis.

Clinicians commonly assess scapular function by observing bilateral scapular motion during repeated motions of arm elevation and lowering. Clinically significant scapular dyskinesis is often considered present if symptomatic patients show asymmetric position or motion compared with the opposite side (Uhl, Kibler, Gecewich, & Tripp, 2009). Devices used, such as digital inclinometer and tape measure have been also used to quantify scapular posture asymmetry in patients with abnormalities (Downar &

Sauers, 2005). But these devices only give a 2D image of scapular motion. A 3D image would be important to understand scapular position and orientation helping clinicians to identify scapular behavior.

Scapular dyskinesis is a non-specific response to a painful condition in the shoulder rather than a specific response to certain glenohumeral pathology (Kibler & Sciascia, 2010). In the SICK scapula syndrome, scapular asymmetry is measured statically, but actively produces scapular dyskinesis as the shoulder goes through the throwing cycle. The malpositioned dyskinetic scapula, in turn, dynamically produces altered kinematics of the glenohumeral and acromioclavicular joints and the muscles that insert on the scapula (Burkhart et al., 2003b). However static position and dynamic motion are two separate entities, so when describing the static appearance of the scapula and if an asymmetry is observed, it should be referred to as "*altered scapular resting position*" rather than "*scapular dyskinesis*" (Oyama et al., 2008). Indeed, scapular dyskinesis seems to be a non-specific response to a painful condition in the shoulder rather than a specific response to certain glenohumeral pathology (Kibler & Sciascia, 2010).

CHAPTER 3 - METHODOLOGY

Study Design and Participants

This thesis is compilation of case-control studies. A population of 135 subjects was involved, divided in experimental group; the athletic group (N = 64) and the non-athletic group (N = 70). A match of ages, height and weight was performed, between both groups to ensure comparisons availability. All subjects were recruited on the local community in a voluntary basis. Subjects provided information regarding their arm dominance and retrospective injury history. Injury was regarded as any overuse injury that altered their lives/training for more than a week, and relevant medical history. Subjects were excluded if a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) was recorded.

Subjects were all male and asymptomatic. This assumption was verified due to the fact that subjects underwent a clinical trial performed by an independent clinician, following tests showed in Figure 2.

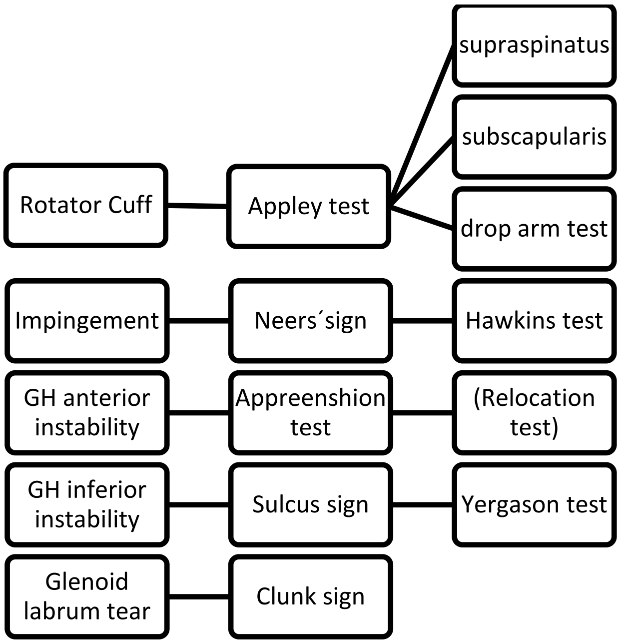


Figure 2: Shoulder clinical tests performed by an independent clinician

Full explanation about the study, in which subjects were involved, and the technique of examination were explained to the participants, and those who agreed to participate signed a free informed consent form according to the recommendations of the declaration of Helsinki. Ethical approval for the study was ratified by The Scientific Board of Human Kinetics Faculty – Technical University of Lisbon.

The non-athletic group was recruited in the local community (age=28±5.5 years; height = 176 ± 7.6 cm; body mass = 76 ± 12.8 kg). All completed a questionnaire concerning their sports activity, ensuring that none had played high level overhead sports.

The athletic group included volleyball players (age = 25.8 ± 6.2 years; height=188±8.8 cm; body mass = 84 ± 10.8 Kg; years of practice = 13.4 ± 5.5 years) and team-handball male players (age = 23 ± 3.5 years; height = 184 ± 5.5 cm; body mass = 84 ± 7.5 kg; years of practice = 17 ± 7.1 years). All reported at least 7 years of practice at high level of competition. An index of sports practice was calculated expressing the number of days, hours and years of training/competition (number hours per week*52 weeks *years of practice/age), normalized by age. On table 1 demographics variables of all studies are presented.

Table 1: Mean (SEM) for demographic variables on each study.

	Experimental group						Control Group					
	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**
N	V:15 H:15	V:6 H:3	V:6 H:6	V:6 H:6	H:13	V:15 H:15	30	9	12	12	13	30
Age	V:27.6 (1.6) H:23.8 (0.8)	V:22 (1.6) H:22 (0.6)	V:22 (1.6) H:22.0 (0.4)	V:22 (0.4) H:22 (0.9)	H:22.3 (3.1)	V:27.6 (1.6) H:23.8 (0.8)	29.6 (1.1)	31.1 (1.7)	23.8 (6.2)	26 (2.9)	26.6 (4.4)	29.6 (1.1)
Height	V:189.4 (2.7) H:185.5 (1.5)	V:181.3 (1.9) H:186.3 (1.5)	V:181.3 (1.9) H:184 (1.5)	V:181 (4.7) H:184 (3.7)	H:186 (3)	V:189.4 (2.7) H:185.5 (1.5)	178.1 (1.2)	166.8 (3.4)	172.7 (8.8)	176 (4.7)	176 (5)	178.1 (1.2)
Bodymass	V:87.5 (3.2) H:87.6 (1.9)	V:74.5 (3.1) H:78.3 (3.8)	V:74.3 (3.1) H:80.7 (2.3)	V:75 (3.2) H:81 (2.3)	H:84.08 (2.6)	V:87.5 (3.2) H:87.6 (1.9)	79.6 (2.7)	70.0 (4.7)	73.3 (13.3)	73 (7.5)	72.8 (7.2)	79.6 (2.7)
Years Practice	V:13.2 (1.6) H:14.7 (0.9)	V:10.2 (1.3) H:10.7 (0.3)	V:10.2 (1.3) H:11.5 (0.5)	V:11.2 (1.1) H:11 (1.0)	H:11.5 (0.5)	V:13.2 (1.6) H:14.7 (0.9)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

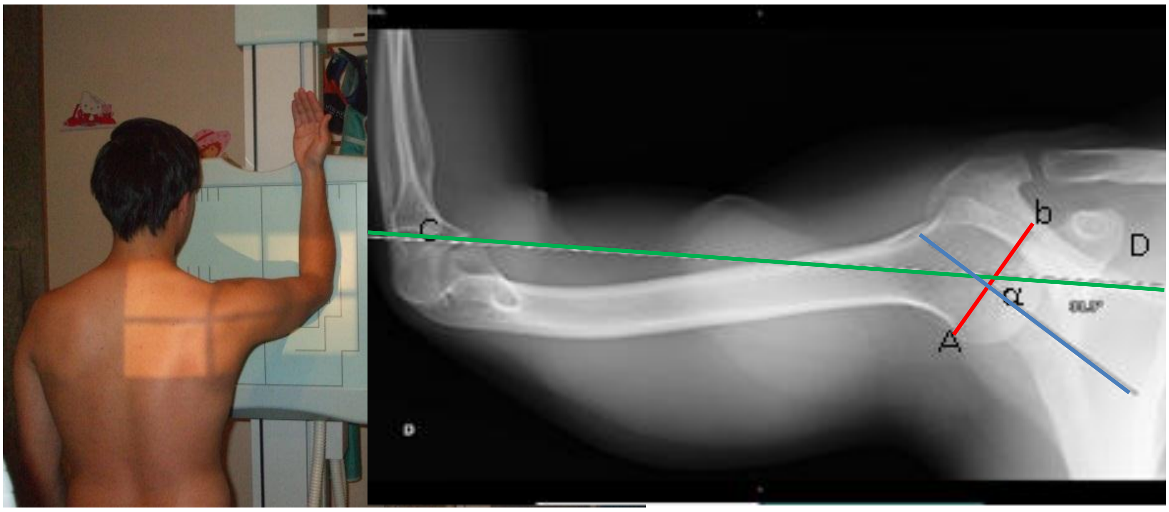
#: Study
V: Volleyball players
H: Team-handball players
n.a.: not applicable

Measurements

This thesis is about the overhead throwing athlete shoulder adaptive pattern. This pattern comprises morphological and kinematic variables. For their study, two different means were used: X-Ray measurements to assess morphological variables; and an electromagnetic tracking device to assess kinematic variables

X-Ray measurements

Posterior-anterior semi-axial radiographs from the dominant shoulder of the subjects were recorded by x-ray equipment (Model: SHIMADZU UD150L-40E; X-Ray ampoule: 40-150 kv and 10 - 630 mA; Focus film distance: 1.5 m; Penetration: 75 keV; Exposure: 60 mA) in order to quantify the humeral retroversion angle. Subjects were standing with the shoulder at 90º flexion and 20 º horizontal abduction, while the forearm was kept fully supinated and elbow flexed to 90º (Figure 3).



A B

Figure 3: Semi-axial radiograph positioning (A) with references used on humeral retroversion angle calculation (B)

The humeral retroversion angle was defined as an angle between the humeral head axis and the distal humeral axis. For humeral head axis estimation the first step consisted of the identification of the limits of the humeral head articular surface. On x-ray images, these limits were defined by the anterior and posterior points where the round articular surface of the humeral head becomes flat (Points A & B; Figure 3). A line could be defined between these two points (Line AB; Figure 3). The humeral head axis corresponds to the perpendicular line to line AB. The distal humeral axis was determined by a line parallel to the anterior articular surface of the distal humerus (Line CD; Figure 3 - B). The humeral retroversion angle was determined by calculating the angle between the intersection of the humeral head axis and the distal humeral axis represented, respectively, by the perpendicular of line AB and by the of line CD (α, Figure 3 - B).

In literature the technique used to describe the humeral head retroversion included direct anatomic radiographic (Cieminski, 2007; Oztuna et al., 2002; Pieper, 1998), ultrasound (R. Whiteley et al., 2006), computed tomography scan (Boileau et al., 2008; Hernigou et al., 2002; Oztuna et al., 2002), MRI (Doyle & Burks, 1998), and computer-assisted methods (DeLude et al., 2007; Robertson, Yuan, Bigliani, Flatow, & Yamaguchi, 2000).

Soderlund *et al.* (1989) were the first to use a semi-axial radiograph method to determine the angle of the humeral head. They used a supine subject position, shoulder at 90º flexion and 10º abduction and elbow at 90º flexion. The authors tested the validity and reliability of the x-ray semi-axial view method and concluded that if the arm is positioned correctly, measurements of humeral head retroversion can be performed with this method with high accuracy. In five healthy volunteers, CT scan images from both shoulders were examined and compared with x-ray semi-axial. The average difference in angle determinations between the methods was 1.5 degrees and the maximum difference was 2 degrees. Concerning intra-reliability, angle determination on radiographs from 22 healthy shoulders was performed by two independent radiologists. The coefficient of variation for intra-observer measurements was 2.8 % and for inter-observer measurements it was 4.6 %. Soderlund *et al.* (1989) reported a standard error of measurement of 1.1º for the standing semi-axial radiograph method.

The original work of Oztuna *et al.* (2002) was the first to propose the standing semi-axial method. In order to determine the validity of this method Oztuna *et al.* (2002) compared x-ray based calculation of the humeral head retroversion of 20 dry humerus placed in this simulated standing position, with measured made directly using a goniometer/jig device. The mean difference reported between both methods was 0.9º with a maximum of 3º. A repeatability coefficient of 98% was also estimated for this method.

In a more recent work, Hoshino *et al.* (2004) compared angles of the humeral head retroversion determined by supine semi-axial x-rays and CT scans. The mean difference between both methods was 1.7º with a maximum of 3º. Based on Soderlund *et al.* (1989), Oztuna *et al.* (2002) and Hoshino *et al.* (2004) it seems that the validity and reliability of the semi-axial radiograph method determining the humeral head retroversion angles, is favorable. However, it must be considered the limited number of subjects involved on those studies, and in some cases the fact that validation as not established directly to CT scans, such as in Oztuna *et al.* (2002).

More recently, Cieminski (2007) investigated the validity of the standing semi-axial method to determine the HRA using CT scan determination as a "*gold-standard*", on five subjects. The x-ray protocol used was similar to Oztuna *et al.* (2002). Results of the study include a high validity index of 0.97 along a low RMS error of 1.4º. The maximal difference between HRA calculated by x-ray method compared to CT was 2.6º with an average of 1.3º. Cieminski (2007) also performed an intrarater reliability analysis. The results of this analysis revealed reliability indices for both the dominant and non-dominant shoulders of 0.97, while the mean difference in HRA between the two measurements was 1.0º. The standard error of measure of the standing semi-axial radiograph method was determined and a value of 1.1º was obtained.

Shoulder Kinematic measurements

Shoulder kinematics were recorded by mean of a 6 degrees-of-freedom electromagnetic tracking device (Hardware: “Flock of Birds”, Ascension Technology, Burlington, Vermont) optimized by a specific software, Motion Monitor software (Innovative Sports Training, Chicago, IL). This system is Ascension’s MotionSTAR cards with an extended range transmitter. The accuracy of our system is 1.8 mm for position and 0.15º for orientation. The static resolution is 0.08cm/0.1 degrees RMS at 1.52 meters from the transmitter and 0.25cm/0.2 degrees RMS at 3.05 meters from the transmitter. Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor.

A sensor setup composed by the thorax sensor firmly attached to the skin by a double-sided tape over T1; the arm sensor attached by means of a cuff just below the deltoid attachment; and the scapular sensor attached to the dominant scapula, on the superior flat surface of the acromion process. In Chapter 6 in study #3 another sensor was attached to the non-dominant scapula. All receivers were secured on the skin using double-sided adhesive disks, pre-wrap, athletic tape, and a hook-and-loop strap to minimize skin-receiver movement. An additional sensor mounted on a hand-held stylus (6.5cm) was used for bony landmark digitalization (Table 2) and posterior kinematic processing according to Wu *et al.* (2005).

Table 2: Bony landmarks used for the definition of the local coordinated system of the thorax, scapula and humerus according to Wu *et al.* (2005).

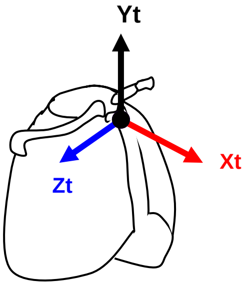
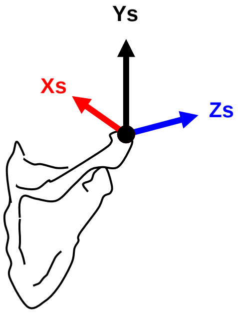
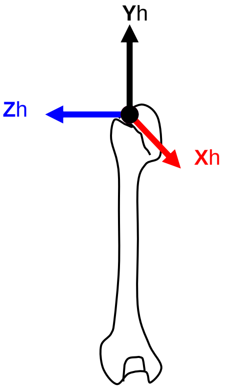
Segment	Bony Landmark	Abbreviations
Thorax	T8 spinous process	T8
	Xiphoid process of the sternum	XP
	C7 spinous process	C7
Scapula	Sternal notch	SN
	Acromial angle	AA
	Root of scapular spine	RS
	Inferior angle	IA
Humerus	Medial epicondyle	ME
	Lateral epicondyle	LE
	Glenohumeral rotation center (*)	GH

(*) Estimated by motion recordings, calculating the pivot point of instantaneous helical axes of GH motion (Stokdijk, Eilers, Nagels, & Rozing, 2003).

Because the glenohumeral joint center cannot be palpated, it was estimated as the point that moves least with respect to the scapula when the humerus is moved passively through several short arcs. The digitized bony landmarks were then used to convert the sensor axes to anatomic axes or local coordinate systems (LCS) (Table 2) on the thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB). Using this procedure, sensors axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion.

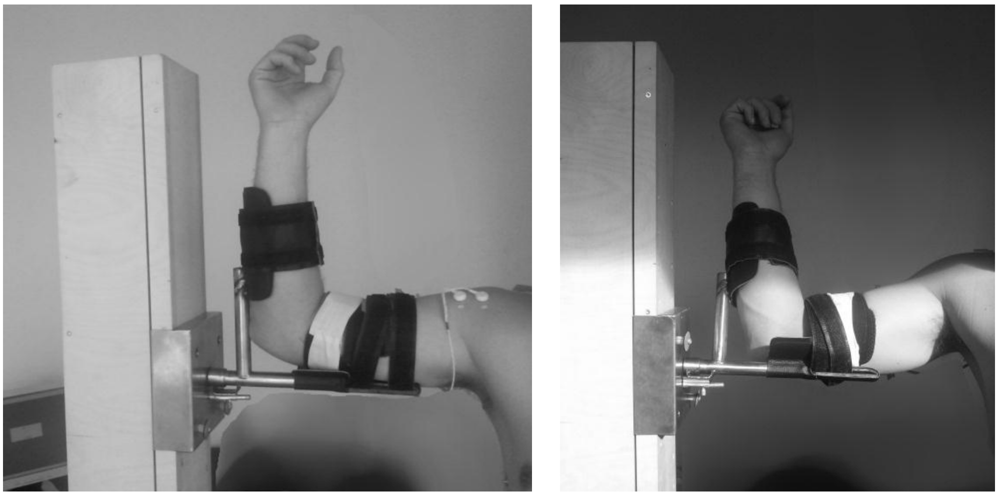
Humeral and scapular motions were described using Euler angles as a sequence of rotations about three anatomical axes following the International Society of Biomechanics (ISB) protocol recommendations (Wu et al., 2005). Humeral motion was described determined using a sequence as (y, x’, y’’): plane of arm elevation, humeral elevation and internal-external rotation. The scapular position was described relative to the thorax using a (y, x’, z’’) sequence as, protraction-retraction, upward-downward rotation and anterior-posterior tilt.

Table 3: Bony landmarks used for the definition of the local coordinated systems of the thorax, scapula and humerus, according to Wu *et al.* (2005).

 **THORAX** *(Right anterolateral view)*	**Yt**: The line connecting the midpoint between XP and T8 and the midpoint between SN and C7 pointing upward **Zt**: The line perpendicular to the plane formed by SN, C7 and the midpoint between XP and T8 pointing to the right **Xt**: The common line perpendicular to Zt and Yt-axis pointing forward The origin coincident with SN
 **RIGHT SCAPULA** *(Posterior view)*	**Ys**: The common line perpendicular to Xs and Zs-axis pointing upward **Zs**: The line connecting RS and AA pointing to AA **Xs**: The line perpendicular to the plane formed by IA, AA and RS, 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 The origin coincident with AA
 **RIGHT HUMERUS** *(Anterior view)*	**Yh** : The line connecting GE and the midpoint of LE and ME, pointing to GH **Zh**: The common line perpendicular to the Yh and Zh-axis pointing to the right **Xh**: The line perpendicular to the plane formed by LE, ME and GH pointing forward The origin coincident with GH

Continuous data were recorded and filtered (Butterworth filter; cut-off = 10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of the humeral external rotation was considered for further analysis.

In this thesis, some exploratory studies were performed in order to solve some methodological issues related with the application of the ISB protocol. Using the proposed ISB protocol was found gimbal lock at the end-range of shoulder axial rotation (external and internal rotation). Gimbal lock describes the situation when the first and third axis of rotation coincide with the second rotation is +90º or -90º (for any order of three different rotation axis) or 0º or 180º (for an order of rotations with the first and third rotation about the same initial axis). Near the gimbal lock position measurement errors will be amplified and large inaccuracies of the first and third rotations will result. Thus, we tried to find a calibration position that would allow the most accurate data collection. In our studies concerning rotational pattern the participants stood in a seated position and with the arm artificially supported in an elevated position (90º), with the elbow flexed (90º) and the forearm perpendicular to the floor. This digitization position was assumed as the initial position for external rotation ROM assessment. Subjects were instructed to slowly reach the end-range of humeral external rotation while holding a dumbbell of 1.5 kg. All subjects repeated task for three times, and after ICC analysis, mean values were used on data reduction using Matlab (R2009a) software. On the basis of our digitization protocol, the zero point (0º) or neutral rotation was defined as the point when the subject´s forearm was perpendicular to the floor.



A **B**

Figure 4: Set-up for humeral external rotation range-of-motion recording. Subject in neutral position (A) and at the end-range of active shoulder external rotation (B)

As found in literature there is a significant main effect of plan for axial rotation (McCully et al., 2005). Due to this fact, and because our subjects had the arm artificially supported in an elevated position, we developed a square drive extension, mounted on a fixed wooden stand, in order to support the weight of the arm, assuring its position in scapular plan (Figure 4). For external rotation the instrument proved to be effective however on internal rotation the shoulder axial rotation axis couldn’t be keep alignment with the instrument axis.

Statistical Procedures

In this thesis, descriptive statistics (mean, standard deviation, standard error of mean) and inferential statistics was used. The Shapiro-Wilk test was used as previous assumption to inferential statistics in order to acquire information about sample normality. No non-parametric statistics were used.

Effect size was also calculated from data, which is a descriptive statistic that conveys the estimated magnitude of a relationship without making any statement about whether the apparent relationship in the data reflects a true relationship in the population. In that way, effect sizes complement inferential statistics such as p-values. Among other uses, effect size measures play an important role in meta-analysis studies that summarize findings from a specific area of research, and in statistical power analyses.

Effect size (ES) analysis and probability scores were reported assuming an ES greater than 0.20, 0.50 and 0.80, respectively, as qualitative score for small, medium or large change/difference (Cohen, 1992).

In all the studies the following statistical tests were used. The independent samples test was applied on Chapter 6 (study #2) to compare the dependent variables, the thoracohumeral and glenohumeral angles and scapular positions (protraction, scapular tilt and lateral rotation) across the two groups of subjects (athletes and non-athletes).

The One-way Analysis of variance (ANOVA) was used on Chapter 4 (study #1) for comparisons of dependent variables (humeral angles and humeral retroversion angles) with the factor "groups of subjects" (volleyball players, team-handball players and the non-athlete control group), This analysis was completed with the Post-Hoc Tukey Honestly Significant Difference (HSD) test, when significant differences were found. In this study, the Pearson coefficient was calculated in order to analyze the relationship between HRA and shoulder external rotation range in both groups and between HRA and the index of sports practice.

In Chapter 5 (studies #1 and #2) the two-way repeated measures ANOVA test was used for comparison of dependent variables (humeral and scapular angles) across groups (athletes and non-athletes). In these studies a mixed-model two-way ANOVA was also used to test the main effect of group (between-group factor) on the five dependent variables: the three scapular rotations (Syt, Sxt and Szt) and the two humeral rotations (HRt and HRs).

In Chapter 6, (study #1) a bivariate correlation test was used to describe the relationships between thoracohumeral angles and scapular variables. Another bivariate correlation test was run order to describe the relationships between scapular spinal tilt (Szt) and shoulder external thoracohumeral and scapulohumeral rotation. Also in Chapter 6 (study #2) bivariate correlations were used to explore the relationship between humeral angles (thoracohumeral angle and glenohumeral angle) and scapular variables.

For all studies and all statistical tests specific software, The Statistical Package for Social Sciences (SPSS) version 20.0 (Chicago Illinois) was used to analyze data. The level of significance was set at 5% and statistical power at 95%.

CHAPTER 4 - OSSEOUS ADAPTATIONS

Humeral Retroversion Angle and Its Relationship with Active Shoulder External Rotation Range-Of-Motion in Volleyball and Team-Handball Players

Andrea Ribeiro; Augusto Gil Pascoal & Paula Ludewig

Abstract

Increased humeral retroversion angle is known as one possible morphological functional adaptation seen in overhead athletes. Based on the literature, volleyball players are expected to show less humeral retroversion angles than team-handball players. However, higher humeral retroversion angle is expected in overhead throwers (volleyball and team-handball players) when compared with a non-throwing group. Most previous studies describe side-to-side differences within groups and a further lack of information exists regarding relationships between humeral retroversion angle and active range of shoulder external rotation in other throwing sports. The total range-of-motion in the dominant shoulders of asymptomatic volleyball and team-handball players would be different from a non-throwing population. Additionally, the measured increase in external rotation occurring between the athlete and control groups would be consistent and directly correlated with an increased angle of humeral retroversion in the dominant upper extremity. The dominant shoulder of 60 subjects (15 volleyball players, 15 team-handball players and 30 non-athletes) was submitted to a shoulder semi-axial radiograph in order to identify the humeral retroversion angle. Maximum shoulder external rotation motion was also measured. These variables were compared between groups and the correlation between retroversion and external rotation range of motion assessed. Both volleyball and team-handball groups showed significantly higher humeral retroversion and humeral external rotation than non-athletes. Retroversion was significantly related to external rotation range of motion. Volleyball and team-handball players showed an increased humeral retroversion angle and external rotation range of motion comparatively to a non-thrower population. This increased range of motion may be explained in part by the increased humeral retroversion angle observed in the athletes group. Knowledge of joint ranges of motion with association to humeral retroversion angle can provide scientific basis for improved preventive and rehabilitative protocols for overhead athletes.

Keywords: humeral retroversion, shoulder external rotation, overhead athletes

Introduction

The humeral retroversion or humeral retroversion angle (HRA) refers to the acute angle, in a medial and posterior direction, between the proximal and distal articular surfaces of the humerus (Hernigou et al., 2002; Yamamoto et al., 2006). The HRA, also referred to as "*humeral torsion*", describes the amount of "twisting" of the longitudinal axis of the humerus and is a measure of the humeral head with respect to the elbow joint (Hernigou et al., 2002; R. Whiteley et al., 2006).

Krahl (1947) was the first to reveal the decrease in HRA values during human development. Using a scatterplot of humeral retroversion and ages, the author was able to verify that the HRA decreases during early development and then ceases to change, in the adult (approximately at 18-20 years). Based on these findings a distinction was suggested between a primary and a secondary humeral torsion. The primary or hereditary equates to be the amount of bony twist that is initially presented in fetal development. Krahl (1947) using a limited number of specimens identified the primary torsion as approximately 48º.

The secondary humeral torsion or acquired torsion is due to the muscular forces exerting a pull via their attachments to various anatomic points on the humerus (Yamamoto et al., 2006). This humeral torsion involves the action of opposite forces exerted by the stronger internal shoulder rotators and weaker external rotators, which set up torsional stresses across the proximal humeral epiphysis. Some authors suggest that this secondary torsion is responsible for the deceleration in the rate of humeral de-rotation (V. E. Krahl, 1947; Yamamoto et al., 2006). The rate of humeral de-rotation can be slowed down to greater extent, resulting in a larger humeral retroversion angle, when the muscular activity increases around the glenohumeral joint, such as during repetitive overhand athletic activities. Edelson´s (1999) work seems to confirm this progression throughout human life.

Pieper *et al.* (1998) were the first to provide evidence about osseous adaptation of the humerus in the form of increased retroversion angle in the throwing arm of Olympic style team-handball players. Since then, other studies provided similar evidence for the throwing arm of baseball players, including professional (Chant et al., 2007; Crockett et al., 2002) and college baseball pitchers (Osbahr et al., 2002), or position players (Reagan et al., 2002), and elite volleyball players. These studies reported differences in the HRA between dominant (throwing) and non-dominant arms and between throwers and non-throwers (control). Most of the information available about HRA refers to differences between dominant and non-dominant arms in baseball players. Crockett *et al.* (2002) found a mean difference of 17º between dominant and non-dominant shoulders, while Reagan *et al.* (2002) found a 10º difference. Later Whiteley *et al.* (2006) found differences ranging from 0º to 29º in baseball players between dominant and non-dominant shoulders while Chant *et al.* (2007) reported an average side-to-side difference of 10.6º in competitive baseball players. In team team-handball players, the average side-to-side difference was reported by Pieper *et al.* (1998) as a 14.4º on average, while Murachovsky *et al.* (2007) presented a value of 3.06º. Schwab *et al* (2009) found in twenty-four elite volleyball players a side-to-side difference of 9.6º.

The augmented or greater retroversion angle seems to increase the available external rotation range-of-motion (ROM).At the same time this is believed to reduce the ability of the rotator cuff to control high forces or velocities through the extremes of shoulder ROM which could lead to excessive humeral head translation and culminate in shoulder pain (Crockett et al., 2002; Ellenbecker et al., 2002). Kronberg *et al.* (1990) found that, in normal shoulders, greater retroversion of the humerus was consistently related with an increased range of external rotation at 90° of shoulder abduction, but no differences were found between subjects' dominant and non-dominant shoulders for each tested range of motion.

Volleyball and team-handball have been referred as "*overhead activities*" (Braun et al., 2009; Pieper, 1998; Seil et al., 1998; Wang & Cochrane, 2001b; Wilk et al., 2009). In Europe, team-handball, which has been an Olympic sport since 1972, is one of the most popular team sports after soccer or basketball. The game is played by two teams consisting of six field players, one goalkeeper, and five substitutes (Seil et al., 1998). In team-handball throwing is the major activity and is used to pass the ball for team members and to score goals. Throwing fast is considered to be an advantage, therefore training is focused on throwing technique (Tillar & Cabri, 2012). This labeling suggests that some assumptions regarding the throwing shoulder adaptation in volleyball and team-handball players could be similar to the adaptation described for baseball players (Braun et al., 2009; Tripp et al., 2007; Warden et al., 2009; Werner et al., 2006; Wilk et al., 2009). Osseous side-to-side adaptations were described in the throwing humerus of volleyball (Schwab & Blanch, 2009) and team-handball players (Pieper, 1998), similar to baseball players, but the nature and implications of them are different and must be analyzed in detail by comparison with a non-throwing population. Volleyball and team-handball are also different with respect to the kinematic and kinetic patterns of the throwing cycle and consequently in the repetitive stress imposed to the shoulder which influences osseous and soft tissue adaptations.

Thus, the purpose of this study was twofold: (1) determine whether a specific sport-related osseous adaptation exists (described by the HRA) in the dominant humerus of volleyball and team-handball players; 2) determine the relationship between HRA and shoulder external rotation ROM. We hypothesized that in a group of asymptomatic volleyball and team-handball players the HRA in the dominant arm would be greater than in a control group of subjects. Additionally, it was hypothesized that a positive correlation exists between the increased HRA and shoulder external rotation ROM.

Materials And Methods

Population and sample

The sample was composed of sixty male volunteers, volleyball and team-handball players, and a control group recruited in the local community. Participants were divided into three groups: volleyball players (n = 15), team-handball players (n = 15) and the control group (n = 30). All the members of the non- athletic group completed a questionnaire concerning their sports activity ensuring that none had played high level overhead sports. Demographic data are presented in Table 4.

Table 4: Mean (standard error of mean) of subject demographic and sport background data by groups

	Volleyball (N = 15)	Team-handball (N = 15)	Control (N = 30)	P - value
Age (years)	27.6 (1.6)	23.8 (0.8)	29.6 (1.1)	0.01 [a][d]
Height (cm)	189.4 (2.7)	185.8 (1.5)	178.1 (1.2)	0.06 [b]
BMI (kg/m2)	24.3 (0.5)	25.4 (0.5)	25.0 (0.7)	0.56 [c]
Age (years) when training commenced	14.4 (0.4)	9.2 (1.3)	not applicable	0.01 *
Sports Index	8422.4 (1258.3)	6726.4 (408.9)	not applicable	0.21 *
Years of Sports Practice	13.2 (1.6)	14.7 (0.9)	not applicable	0.44*

[a] ANOVA results: F (2,57) = 5.42

[b] ANOVA results: F (2,57) = 12.26;

[c] ANOVA results: F (2,57) = 0.55;

[d] Multiple comparisons regarding age: team-handball and control groups are significantly different.

* Independent *t-test* result

These demographic data were compared across the groups using a one-way ANOVA (Table 4). As differences were found between the three groups concerning age and years when training commenced (t-test between the two groups), correlation analyses were performed between these age related demographic variables and the dependent variables of HRA and shoulder ROM. No significant correlation was found between either of these demographic variables (age and age commenced) ($P > 0.05$) and the dependent variables, and as such, these group differences were not of concern as covariates. No differences between groups were found concerning body mass and height.

In the three groups all the subjects were Caucasian except 5 athletes in the volleyball group that were South-American. Because previous studies (V. Krahl & Evans, 1945; V. E. Krahl, 1947) showed that the HRA is race related, a Pearson correlation was performed between HRA in Caucasian subjects and HRA in south-American subjects. No relationship was found (r = 0.234; P = 0.401), so south-American subjects were included in the sample investigated.

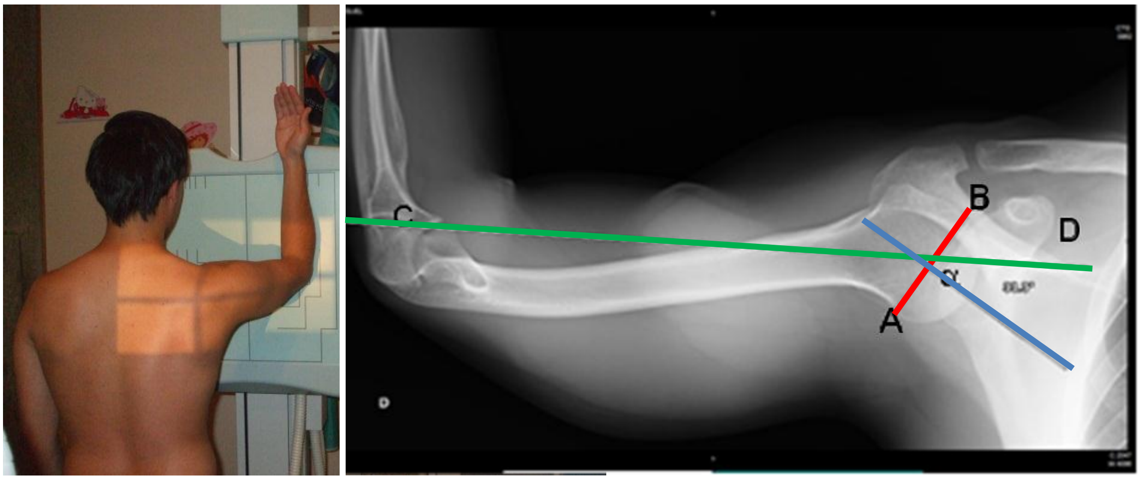
Subjects in either athletic group (volleyball or team-handball players) reported at least 7 years of practice at a high level of competition. An index of sports practice was calculated considering the number of days, hours and years of training/competition (number hours per week * 4 weeks/month * 12 months/year * years of practice). An independent *t-test* was performed to compare the index of sports practice between groups (team-handball and volleyball players). No significant differences were found (Table 4).

Subjects also provided information regarding their arm dominance, retrospective injury history (an injury was regarded as any overuse injury that altered their training for more than a week, and relevant medical history. Subjects were excluded if a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) was recorded. The purposes of the study and the technique of examination were explained to the participants, and those who agreed to participate signed a free informed consent form. This study was approved by the Scientific Board of the Faculty of Human Kinetics, Technical University of Lisbon (Portugal). None of the athletes who met the inclusion criteria declined to participate.

Procedures

Humeral retroversion angles measurements using x-ray recordings

Posterior-anterior semi-axial radiographs from the dominant shoulder of the subjects were recorded by x-ray equipment (Model: SHIMADZU UD150L-40E; X-Ray ampoule: 40-150 kv and 10 - 630 mA; Focus film distance: 1.5 m; Penetration: 75 keV; Exposure: 60 mA). Subjects were standing with the shoulder at 90º flexion and 20º horizontal abduction, while the forearm was kept fully supinated and elbow flexed to 90º (Figure 5). Recordings were made by an examiner blinded to group and arm dominance.



A B

Figure 5: X-Ray Experimental set-up (A) and semi-axial radiograph positioning (B) with reference lines used for the humeral retroversion angle calculation (see text for details)

The humeral retroversion angle was defined as an angle between the humeral head axis and the distal humeral axis. For humeral head axis estimation the first step consisted of the identification of the limits of the humeral head articular surface. On x-ray images, these limits were defined by the anterior and posterior points where the round articular surface of the humeral head becomes flat (Points A and B; Figure 5-B) and a line was drawn between these two points (Line AB; Figure 5-B). The humeral head axis corresponds to the perpendicular line to line AB. The distal humeral axis was determined by a line parallel to the anterior articular surface of the distal humerus (Line CD; Figure 5- B). The humeral retroversion angle was determined by calculating the angle between the intersection of the humeral head axis and the distal humeral axis represented, respectively, by the perpendicular AB line and by the CD line (α, Figure 5-B).

The use of semi-axial radiographs for measurement of HRA as shown in this study, was validated by Soderlund (1989). More recently, Cieminski (2007) investigated the validity of the standing semi-axial method to determine the HRA using CT scan HRA measurement as a "*gold-standard*", on five subjects. The x-ray protocol used was similar to Oztuna *et al.* (2002). Results of the study include an Interclass Correlation Coefficient 0.97 along with a low RMS error (1.4º) between the radiographic and CT measures of HRA.

External rotation range-of-motion recordings

Motion testing was performed with the Flock of Birds electromagnetic tracking sensors (Ascension Technology, Burlington, Vermont) and Motion Monitor software (Innovative Sports Training, Chicago, IL). Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor. The accuracy of our system is 1.8 mm for position and 0.15° for orientation.

A four sensor setup was used: the thorax sensor was firmly attached to the skin by a double-sided tape over T1; the arm sensor was attached by means of a cuff just below the deltoid attachment; and the scapular sensor was attached on the superior flat surface of the acromion process. A 4th sensor mounted on a hand-held stylus (6.5cm) was used for bony landmark digitalization with the participants in a seated position and the arm artificially supported in an elevated position (90º), with the elbow flexed (90º) and the forearm perpendicular to the floor. The arm and forearm were strapped and connected to a square drive extension, mounted on a fixed wooden stand, which supported the weight of the arm. This digitization position was assumed as the initial position for external rotation ROM assessment. Subjects were instructed to slowly reach the end-range of humeral external rotation while holding a dumbbell of 1.5 kg (see Chapter 3, Figure 5). On the basis of our digitization protocol, the zero point (0º) or neutral rotation was defined as the point when the subject´s forearm was perpendicular to the floor.

The digitized bony landmarks were then used to convert the sensor axes to anatomic axes or local coordinate systems (LCS) on the thorax, scapula and humerus segments (see Chapter 3, Table 2), following the recommendations of the International Society of Biomechanics (ISB). Using this procedure, sensor axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCS with tracking sensor motions (see Chapter 3, Table 3).

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB (Wu et al., 2005) recommended rotation sequences (y, x’, y’’): plane of arm elevation, arm elevation and external rotation. Continuous data were recorded and filtered (Butterworth filter; cut-off = 10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of the humeral external rotation was considered for further analysis.

Statistical Analysis

The humeral retroversion angle and the shoulder external rotation end-range relative to the thorax and scapula, respectively the end-range thoracohumeral angles (TH) and the end-range scapulohumeral angles (SH), were used as dependent variables and compared across the groups. All dependent variables were checked for normality (Shapiro & Wilk test) and found to meet criteria for parametric statistics. Data were described as means and standard error of the mean (SE). An independent sample t test was used to compare means between athletes (both groups combined) and the control group. Analysis of variance (ANOVA), followed by the Tukey Honestly Significant Difference (HSD) test, were used for comparisons between the three groups of subjects (volleyball players, team-handball players and the non-athlete control group). Additionally, the Pearson coefficient was calculated in order to analyze the relationship between HRA and shoulder external rotation range in both groups and between HRA and the index of sports practice. Effect size (ES) analysis and probability scores are reported. We used the qualitative assessment of ES where a small, medium or large change/difference is defined by an ES greater than 0.20; 0.50 or 0.80 respectively (Cohen, 1992). The level of significance was set at 5% and statistical power at 95%. The Statistical Package for Social Sciences (SPSS) version17 (Chicago, Illinois) was used to analyze data.

Results

The athletes (volleyball and team-handball) showed significantly higher mean values of humeral retroversion angles than non-athletes (P = 0.000; F (2, 57) = 22.7). The volleyball players had 9.17º more humeral retroversion than the non-athletic group, while the team-handball group demonstrated 7.40º more. No differences were found for the HRA between volleyball and team-handball players (P = 0.572). Concerning external rotation, differences were found between groups for shoulder active external rotation ROM for the thoracohumeral (P = 0.005, F (2, 57) = 0.364) and scapulohumeral (P = 0.002, F (2, 57) = 0.352) angles. Results for active range of thoracohumeral and scapulohumeral external rotation motion are presented in Figure 6.

Multiple comparison test (Tukey HSD) revealed differences on thoracohumeral rotation ROM between non-athletes and the volleyball group (P = 0.018; ES = 0.411) and between non-athletes and the team-handball group (P = 0.042; ES = 0.361). No differences were found between volleyball and team-handball players (P = 0.954; ES = 0.05).

Comparisons of scapulohumeral angles between athletes and non-athletes were made, the team-handball group showed differences when compared with the non-athlete group (P = 0.041; ES = 0.367). No differences were found between volleyball players and the non-athlete group (P = 0.074; ES = 0.33) and between volleyball and team-handball groups (P = 0.974) (Figure 7).

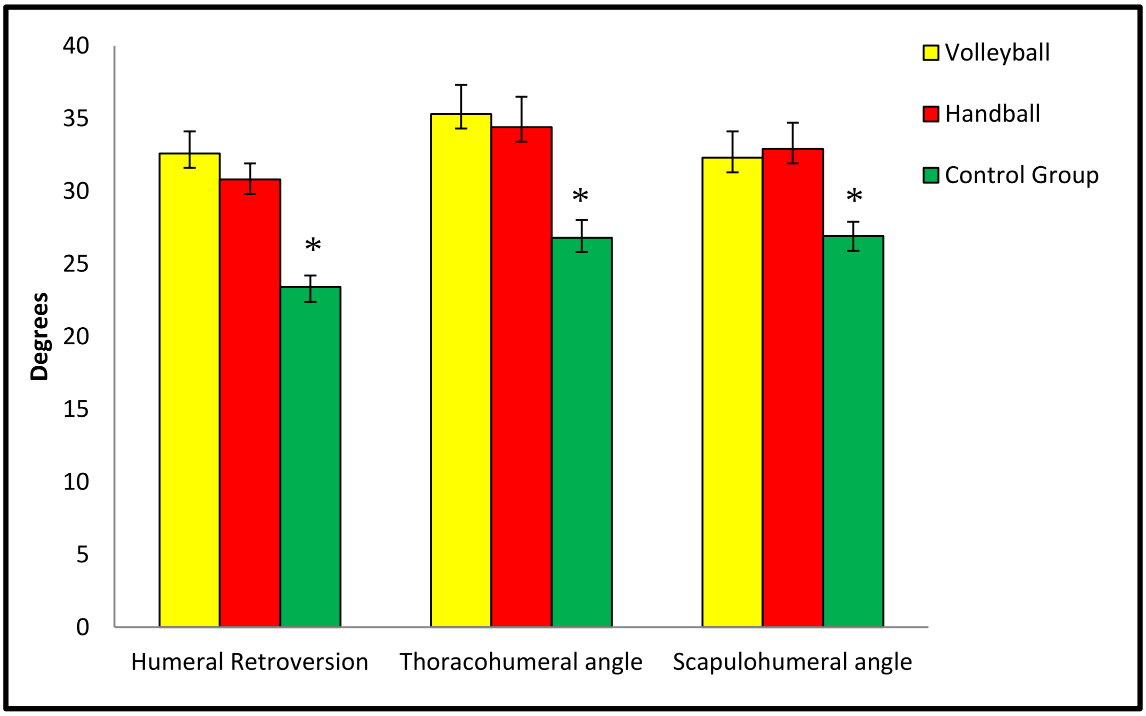


Figure 6: Mean and SEM for the Humeral Retroversion Angle and the Active Shoulder External Rotation ROM (Thoracohumeral and Scapulohumeral angles) in volleyball, team-handball and non-athletic group. (*)- Values significantly different from volleyball and team-handball groups (P < 0.05), except scapulohumeral angles were not different between volleyball players and control group.

Using data from both groups (athletes and non-athletes), a statistically significant positive correlation was found between HRA and both thoracohumeral angles (r = 0.457, P = 0.001) and scapulohumeral angles (r = 0.421; P = 0.000). No correlation was found when both groups were considered separately (Figure 7).

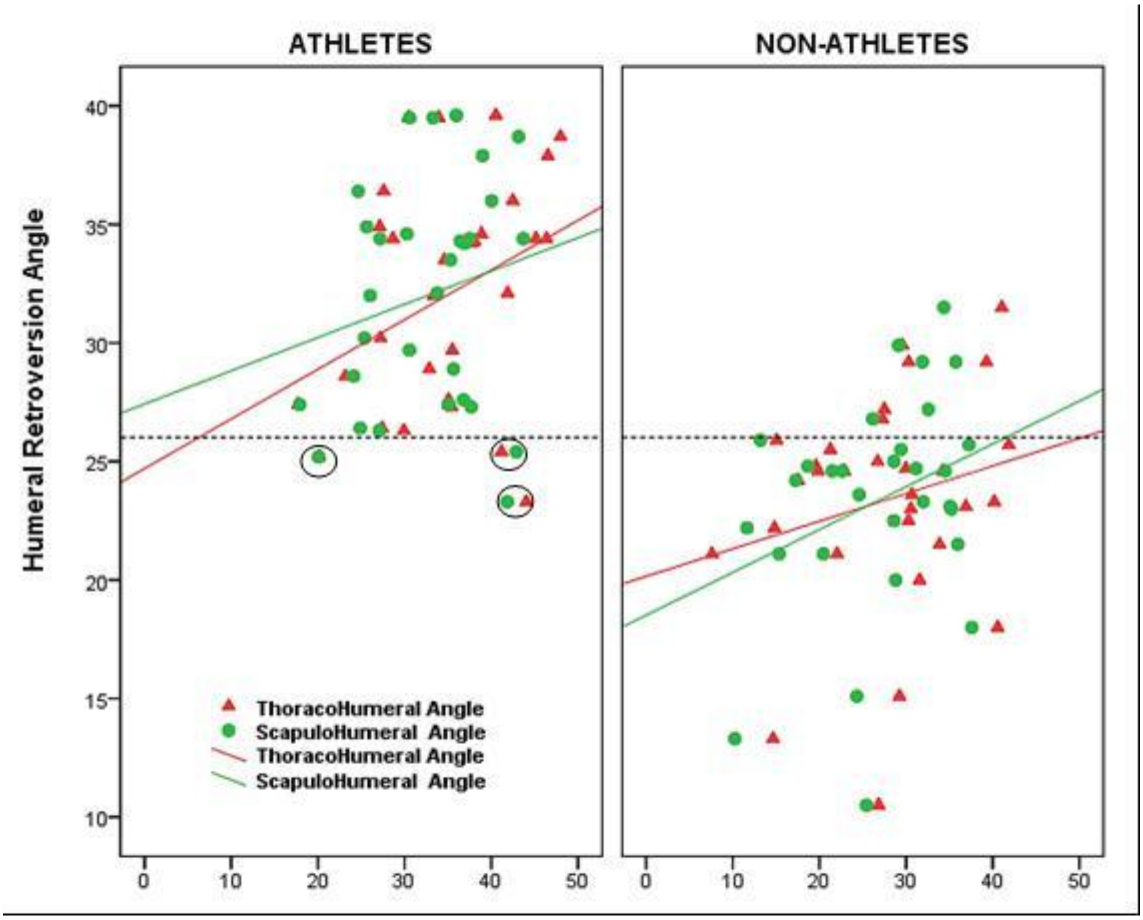


Figure 7: Scatter plots and linear fit lines are shown for the relationship between humeral retroversion angle and thoracohumeral (triangles) and scapulohumeral (dots) angles across the athletes and non-athletic group. The black circles represent the outliers, i.e. athletes with a humeral retroversion angle below 26 degrees (horizontal dotted line).

However, on scatter plots for the athletes group (Figure 8) three outliers were identified, i.e. athletes with a HRA below 26 degrees. These athletes were also the youngest (19 years old) and with few years of sports practice (less than 10 years). After removing these outliers, a statistically significant positive correlation was found between HRA and thoracohumeral angles (r = 0.473; P = 0.00) in the athletes group, but no correlation was found with the scapulohumeral angles (r = 0.370; P = 0.058).

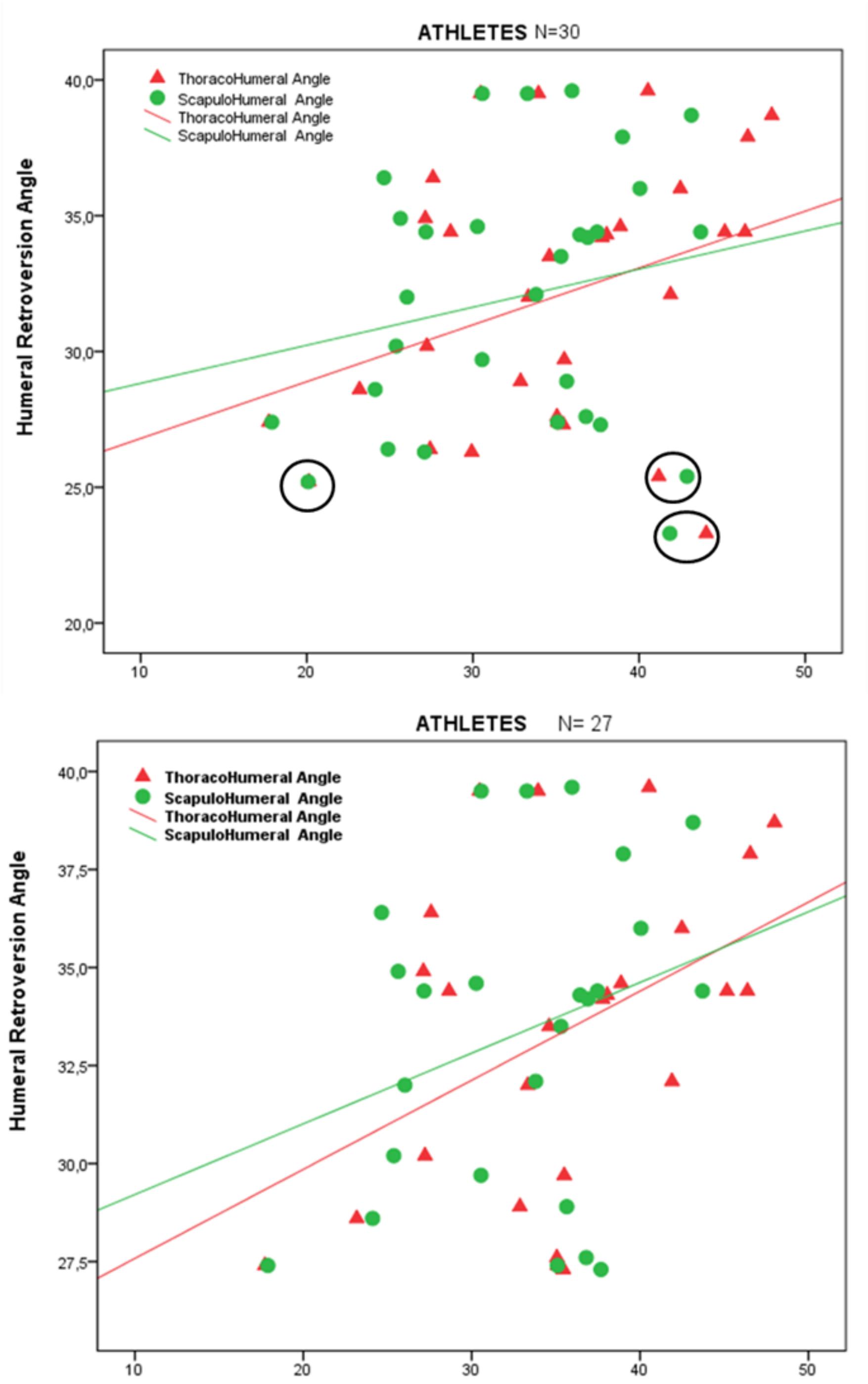


Figure 8: Scatter plots and linear fit lines are shown for the relationship between humeral retroversion angle and thoracohumeral (triangles) and scapulohumeral (dots) angles for the athletes group (N=30) and without (N=27) the 3 outliers (black circles)

On a separated correlation analysis performed for volleyball, team-handball and non-athletes each individually, a positive correlation was found for the team-handball group between HRA and thoracohumeral (r = 0.663; P = 0.007) and scapulohumeral angles (r = 0.534; P = 0.04). A positive correlation was found between humeral retroversion and sports index (r = 0.642; P = 0.000), i.e. the athletes which had more training and practice hours had also more humeral retroversion angles. No correlation was found between HRA and age commenced training either in volleyball players (r = 0.086; P = 0.760) or team-handball players (r = 0.06; P = 0.833) (Figure 9).

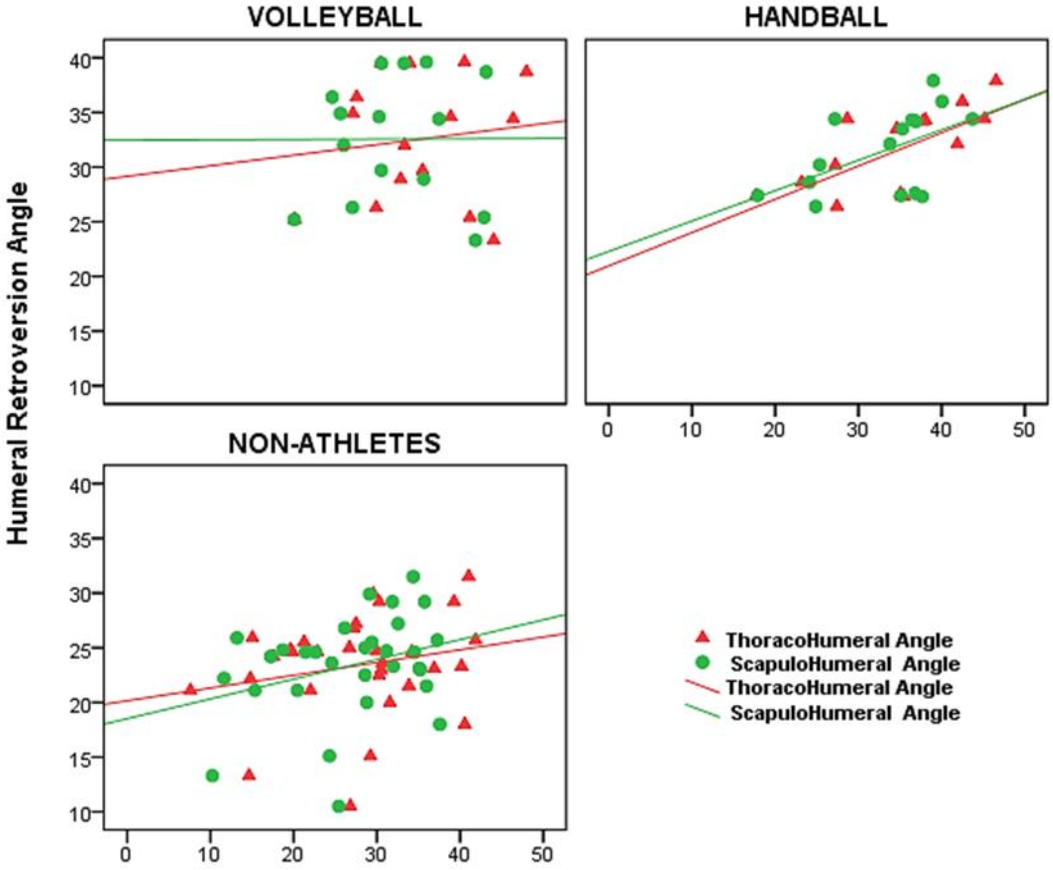


Figure 9: Scatter plots and linear fit lines are shown for the relationship between humeral retroversion angle and thoracohumeral (triangles) and scapulohumeral (dots) angles across the volleyball, team-handball and the non-athletic group

Discussion

Humeral retroversion angle

An increased humeral retroversion angle (HRA) has been reported in the dominant arm of baseball (Crockett et al., 2002), volleyball (Schwab & Blanch, 2009) and team-handball players (Pieper, 1998). In the literature, the information available about the increased HRA comes from side-to-side studies where the dominant throwing shoulder is compared with the non-dominant shoulder (Crockett et al., 2002; Reagan et al., 2002). Our study compares the dominant throwing shoulder between an athletic and non-athletic population. The results showed an increased HRA in the dominant throwing shoulder of volleyball and team-handball players (athletes = 31.7º ± 4.9º; vs. non-athletes = 23.4º ± 4.6º). These results are consistent with previous side-to-side studies in volleyball (Schwab & Blanch, 2009) and team-handball (Pieper, 1998) players. In fact, Schwab *et al.* (2009) found an increase of 9.6º for the HRA of the dominant arm of volleyball players when compared with the non-dominant arm. In our study, the dominant arm of the volleyball players showed an HRA increase of 9.2º when compared with the non-athlete´s dominant shoulder. Concerning team-handball, the previous side-to-side comparisons of Pieper´s (1998) work demonstrated an increased HRA of 9.4º for the dominant arm compared with the non-dominant arm. In our study, the dominant arm of team-handball players showed an HRA increase of 7.4º when compared with the dominant arm of non-athletes.

The cause of the observed asymmetric changes can only be theorized. The proximal humeral epiphysis is responsible for the majority of longitudinal growth of the humerus. This region has also been found to be particularly sensitive to stresses revealed as stress fracture through the growth plate in the skeletally immature thrower (Reagan et al., 2002). Thus, one might conclude that subpathologic loads to the proximal humerus during throwing, although not causing fracture, may cause the measurable changes in retroversion. A pattern of increased humeral retroversion can be expected in the dominant arm of throwing athletes. The increased magnitude of HRA is similar in magnitude for side-to-side and athlete versus non-athlete comparisons. According to the literature, athletes who do not develop this kind of adaptations seem to have more strain on their anterior capsules at less external rotation and may develop chronic shoulder pain because of anterior instability (Pieper, 1998; Reagan et al., 2002; Schwab & Blanch, 2009). One important difference between our study and others (Crockett et al., 2002; Murachovsky et al., 2007; Pieper, 1998; Reagan et al., 2002), is the fact that the dominant shoulder of the athlete´s group was compared with the dominant arm of non-athlete´s instead of comparing dominant and non-dominant shoulders in the same subject. In addition our non-athletes were subjects who were never exposed to any kind of overhead sports.

We expected to find differences between volleyball and team-handball players concerning humeral retroversion. Team-handball is a throwing sport with large demands placed on the shoulder joint, especially on the capsulolabral complex as a joint stabilizer, particularly during the cocking phase of the throw (Pieper, 1998). Volleyball and team-handball are different with respect to kinematic and kinetic patterns of the throwing cycle and consequently in the repetitive stress imposed to the shoulder. In team-handball the weight of the ball at the end-range of the acceleration phase in the cocking phase of the throwing cycle could force the shoulder into more external rotation and increase this range. This extra mass is not present in volleyball spiking. The loss of internal rotation range may also be similarly related to differences in throwing a ball in opposition to striking it. At the time of throwing release, conservation of momentum suggests that the internally rotating arm, after the loss of the extra mass (the ball), would accelerate its motion. Consequently, the throwing arm would require greater deceleration than in the case where at the point of striking a ball (volleyball), energy of the internally rotating arm is dissipated by the ball. Relative tension exerted by the internal and external rotator muscles on the proximal humeral epiphysis seems to be different in the dominant shoulder of volleyball and team-handball players. In both activities, forces towards internal rotation are higher than external rotation. However, in volleyball the magnitude of external forces seems to be even weaker than in team-handball because of the reduced activity of the external rotator muscles in the last phase of the throwing cycle. In fact, during the arm deceleration phase in volleyball striking, shoulder internal rotation energy could be totally or partially dissipated by the inverse motion of the ball.

No correlation was found between the age commenced training and the HRA values for team-handball. The volleyball players started practicing at a mean age of 14 years and presented a mean HRA value of 32.6º. This mean age of commenced training was similar to the one found by Schwab *et al.* (2009), which was 13.3 (2.6) years. The team-handball players in our study initiated their sports practice at a mean age of 9.2 (1.3) years and presented a mean HRA value of 30.8º. Murachovsky *et al.* (2007) in a study involving seventeen European team-handball athletes reported an average retroversion of 36º in players who started practicing early (10 years old) and 26º in others that started later in life. Differences between early and later commenced training in players could be explained by results of Edelson (1999) who verified that the greater part of humeral retroversion osseous adaptation takes place by the age of 8 years (2.12 years). After that age, development continues more slowly until the final adult dimensions are reached confirmed by the appearance of the radial groove at approximately 16 years of age.

Schwab *et al.* (2009) in a study with 24 elite volleyball players found a moderate relationship between the HRA and age of commenced training (r = 0.41; P = 0.045). The authors initially hypothesized a possible correlation between both variables and they explained this result by the small number of players involved in the study (N = 24).

Our investigation of elite volleyball players and team-handball players failed to find a positive correlation between HRA and age commenced training. We assume that the effect of age commenced training on HRA could be stronger in overhead sports such as baseball. Those who start little league baseball usually do it at a younger age (Chant et al., 2007; Crockett et al., 2002; Ellenbecker et al., 2002; Osbahr et al., 2002; Reagan et al., 2002) compared with volleyball players who start at a later age (average 13.3 yrs.). Furthermore, for the definition of a potential elite volleyball player or team-handball player parameters such as height or performance measures such as vertical jump height may be more important than overhead arm motion. Our results are similar to the ones published by (Schwab & Blanch, 2009) but contradicts what has been seen in baseball. Further investigations are required for determining validity of this funding.

In our study a positive correlation was found between HRA and the sports index. This is in accordance with many studies which say that sports practice would induce more HRA (Pieper, 1998; Reagan et al., 2002; Schwab & Blanch, 2009) in athletes.

Humeral external rotation range-of-motion

Significant differences were found between athletes (volleyball and team-handball players) and non-athletes concerning thoracohumeral (TH) and scapulohumeral (SH) active external rotation angles. The athletic group showed higher values of TH and SH external rotation. No differences were found between volleyball and team-handball players concerning TH and SH.

According to several studies (Meister et al., 2005; Tokish et al., 2008), this increase in external rotation seems to be related to overhead sports practice. On the other hand, it was advocated (Crockett et al., 2002; Ellenbecker et al., 1996; Reagan et al., 2002) that the augmented retroversion angle could increase the available external rotation ROM reducing the ability of the rotator cuff to control high forces or velocities through the extremes of shoulder ROM. This could lead to excessive humeral head translation and culminate in shoulder pain (Ellenbecker et al., 2002). Unilateral changes in the glenohumeral joint range of motion of throwing athletes are well documented in the literature (Schwab & Blanch, 2009; Tokish et al., 2008; Torres & Gomes, 2009).

Krahl *et al.* (1947) suggested that retroversion is produced as a result of muscular forces that act in opposition based on the origins and insertions of the muscles that produce the forces and the relative force that is generated by the muscles. One group of the muscles, referred to as infra-epiphyseal rotators, consists of the latissimus dorsi, pectoralis major, and teres major muscles. A second group of muscles, referred to as short lateral rotators, consists of the teres minor, infraspinatus, and supraspinatus muscles. The exception is the subscapularis muscle, a glenohumeral medial rotator, inserts on the epiphysis superior to the epiphyseal line. The forces exerted by the two opposing groups of muscles twist the humerus diaphysis and simultaneously the proximal epiphysis in opposite directions (V. E. Krahl, 1947).

Reagan et al. (2002) suggest that an augmented retroversion leads to an increased ability to externally rotate the shoulder, a motion critical to effective overhand throwing. In our study a positive correlation was found between humeral retroversion and thoracohumeral angles and also between humeral retroversion and scapulohumeral angles, when analyzing the whole sample. So with an augmented humeral retroversion angle we found increased thoracohumeral and glenohumeral angles. In a more detailed analysis a positive correlation was also found between humeral retroversion and thoracohumeral angles in the athletic group, as supported in the literature (Reagan et al., 2002). It is interesting to notice that the three excluded subjects (three outliers found in the athletic group) were the youngest, with less sports practice and also with less humeral retroversion values.

For the volleyball group no correlations were found were found with range of motion. In opposition, for the team-handball group positive correlations were found between humeral retroversion and thoracohumeral angles, and also between humeral retroversion and scapulohumeral angles. Once more, differences between forces and motions between these sports and already mentioned, could be in the basis of this difference.

Conclusion

Volleyball and team-handball players showed an increased humeral retroversion angle comparatively to a non-athletic population. The magnitude of this increase was similar to that found in previous side-to-side comparison studies, 9.17º and 7.40º respectively for the volleyball and the team-handball group. An increased active shoulder external ROM was also found in the athletic group comparatively to the non-athletic group. This change in the active external shoulder rotation ROM was associated with the increased HRA observed in the athletic group.

CHAPTER 5 - SHOULDER ROTATIONAL PATTERN

The Effects of Testing Subject Position (Seated vs. Supine) in Shoulder External Rotation

Andrea Ribeiro & Augusto Gil Pascoal

Abstract

The purpose of this study was twofold: (1) compares the effects of two different testing conditions; seated and supine; (3) compare athletes and non-athletes external rotation range-of-motion and scapular behavior. In 18 healthy subjects (9 athletes and 9 non-athletes), a magnetic tracking device was used to measure active and passive shoulder external motion, in a seated and supine position. Thoracohumeral (TH) and glenohumeral (SH) external range-of-motion were calculated and a 2-way repeated-measures ANOVA was used having the testing as within-subjects factor, and the group (athlete and non-athlete) as a between-subjects factor. No differences were found between groups either for the TH (p=0.564) or for the GH (p=0.907). Both TH and GH showed a significant (p=0.00) main effect with position in a way that the highest values are associated with supine position. At the end-range of the shoulder external rotation, athletes showed a scapula more in external rotation in the seated position. No differences were found between groups regarding the scapular upward-downward rotation and scapular anterior-posterior tilt. An effect was found between position (p=0.001) and Sz with the highest values of spinal tilt recorded in the seated position. For scapular upward-downward rotation no effect was found related with position.

Introduction

Throwing athletes have been shown to have several morphologic changes in their dominant extremities. Among the differences between dominant and non-dominant arms, muscle hypertrophy and increased strength, bone density of the humerus, arm size, and shoulder external rotation have been identified (Awan et al., 2002; Borich et al., 2006; Joseph B. Myers et al., 2006; Pieper, 1998; Safran, Borsa, Lephart, Fu, & Warner, 2001; Yamamoto et al., 2006). These findings have important implications on shoulder athletes' rehabilitation, so physicians and therapists often measure shoulder range-of-motion looking for significant internal rotation deficits (Boon & Smith, 2000) or others.

Previous studies showed that throwing athletes have significantly increased glenohumeral external rotation and decreased internal rotation in the throwing arm, although their overall rotational range-of-motion (external rotation to internal rotation) is kept nearly the same (Bigliani et al., 1997). Those studies, based their results on measures obtained using goniometers or following the goniometry protocol, i.e. testing the subject in a supine position and shoulder external end-range determined by the examiner under passive conditions. It is assumed that in a supine position the scapular contribution is reduced, and glenohumeral motion is facilitated (McConnell et al., 2012). However, a self-determined external rotation end-range (active) with subject in a seated position and the arm in an elevated position seems to have advantages for shoulder functional assessment in throwing athletes.

A widely accepted and reliable method to measure isolated glenohumeral rotational motion does not exist (Boon & Smith, 2000). Several methods currently in use include placing the patient supine with the arm abducted to 90º (as mentioned before), the patient in a seated position and the examiner stabilizing the inferior angle of the scapula, having the patient hold his/her elbow at the side while rotating the forearm around the long axis of the humerus, and having the patient reach superiorly behind his/her back to measure internal rotation (Mallon, Herring, Sallay, Moorman, & Crim, 1996). Due to the possibility of upper limb adaptations due to overuse in overhead throwing activities a valid and reliable indicator is needed.

So, the purpose of this study was twofold: (1) compares the effects of two different testing conditions; seated and supine; (3) compare athletes and non-athletes external rotation range-of-motion and scapular behavior. We hypothesized that the end-range in throwing athletes would be higher when measured in the sitting position.

Materials and Methods

The sample was composed of 18 male volunteers, volleyball and team-handball players, and a control group recruited in the local community. Participants were divided into two groups: non-athletes (N = 9; 31.1 ± 1.7 years; 166.8 ± 3.4 cm; 70.0 ± 4.7 kg) and athletes (6 volleyball and 3 team-handball players; 27.4±2.1 years; 185.8±3.1cm; 86.6±3.3 kg). All the members of the non-athletic group completed a questionnaire concerning their sports activity ensuring that none had played high level overhead sports.

Motion testing was performed with the Flock of Birds electromagnetic tracking sensors (Ascension Technology, Burlington, Vermont) and Motion Monitor software (Innovative Sports Training, Chicago, IL). Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor. The accuracy of our system is 1.8 mm for position and 0.15° for orientation.

A four sensor setup was used: the thorax sensor was firmly attached to the skin by a double-sided tape over T1; the arm sensor was attached by means of a cuff just below the deltoid attachment; and the scapular sensor was attached on the superior flat surface of the acromion process. A 4th sensor mounted on a hand-held stylus (6.5cm) was used for bony landmark digitalization, with the participants in a seated position and the arm artificially supported in an elevated position (90º), with the elbow flexed (90º) and the forearm perpendicular to the floor. This digitization position was assumed as the initial position for external rotation ROM assessment. Subjects were instructed to slowly reach the end-range of humeral external rotation. On the basis of our digitization protocol, the zero point (0º) or neutral rotation was defined as the point when the subject´s forearm was perpendicular to the floor

The digitized bony landmarks were then used to convert the sensor axes to anatomic axes or local coordinate systems (LCS) on the thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB) (Wu et al., 2005). Using this procedure, sensors axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion (see Chapter 3, Table 2 and 3).

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB recommended rotation sequences (y, x’, y’’): plane of arm elevation, arm elevation and axial rotation. The scapular variables were the 3D kinematic values (protraction, upward rotation and tilting) which were analyzed with reference to the trunk using (y, x´, z´´). Continuous data were recorded and filtered (Butterworth filter; cut-off = 10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of the humeral external rotation was considered for further analysis.

Task

Seated position

At scapular plane, in a seated position, subjects were instructed to slowly reach the end-range of humeral external rotation (guided by a metronome). During this trial, the humerus was artificially supported at 90º (without disabling muscle contraction) of shoulder abduction at scapular plane, ensuring position maintenance. The end-range (active shoulder external rotation) was self-determined by the subject (subject was not able to go further on the movement) or when the examiners observed trunk motion.

Passive motion was performed by the examiner until the end-range of shoulder external rotation.

Supine position

In a supine position, with the dominant arm abducted at 90º, subjects were instructed to slowly reach the end-range of humeral external rotation. No allowance for scapular protraction or elevation was permitted. The scapulothoracic joint was stabilized via a posterior directed containment force by the examiner´s hand on the coracoid process, and the anterior aspect of the acromion. This procedure replicated the one used on standard goniometry for shoulder axial rotation (Boon & Smith, 2000).

Statistical analysis

Thoracohumeral (TH) and glenohumeral (SH) external rotation angles were calculated. Additionally, the scapulothoracic contribution on arm rotation was also considered by scapular angles with respect to the thorax, protraction (Sy), lateral rotation (Sx) and spinal tilt (Sz). A 2-way repeated-measures ANOVA was used having one within-subject factors, the testing position and a between-subjects factor: group (athlete and non-athlete).

Results

No differences were found between groups either for the TH (p=0.564) or for the SH (p=0.907). Both TH and SH showed a significant (p=0.00) main effect with position in a way that the highest values are associated with supine position.

Concerning scapular contribution statistical significantly differences (p=0.02) were found between athletes and non-athletes on scapular internal-external rotation (Sy). At the end-range shoulder external rotation athletes show a scapula more in external rotation particularly when a seated position is used for subject testing. No differences were found between groups regarding the scapular upward-downward rotation (Sx) and scapular anterior-posterior tilt (Sz). An effect was found between position (p=0.001 and Sz with the highest values of spinal tilt recorded in the seated position. For Sx no effect was found related with position.

Discussion

Passive shoulder IR and ER ROM is often used as an indicator of shoulder function and athlete´s risk of injury (Dwelly et al., 2009; Ellenbecker et al., 1996; van der Hoeven & Kibler, 2006). Our results showed differences between supine and seated end ROM determination, with higher values associated to supine position. During supine, the scapula is stabilized on the table, but, in a seated position performing active motion, the scapula is free to move with the shoulder girdle muscles, exercising control over the joint and contributing to shoulder ROM. In fact reports are inconsistent with regards to how end range is determined. Some use active positioning while others use passive positioning determined by capsular end feel (Barlow et al., 2002; Reagan et al., 2002), scapular lift-off (Warner et al., 1990) or pain (Andrews AW & RW, 1989).What we were expecting was to find more active motion, in a seated position, among athletes as long as the fast angular velocities during the throwing motion result in much greater IR_ER ROM than what is measured passively (McConnell et al., 2012). Most of the studies in literature assessed shoulder axial rotation ROM at supine position, and the arm at 90º abduction, following this protocol and while testing at supine position. Our findings, concerning external rotation, are similar to other results (Joseph B. Myers et al., 2006), motion in supine position showed highest values among athletes when compared with non-athletes. This could be explained due to shoulder osseous or soft-tissues adaptations that can result from repetitive shoulder motions (Huffman et al., 2006; McCully et al., 2005), which are common among overhead throwing athletes. Stretching of the anterior glenohumeral capsule leads to increased external rotation at the point of cocking and early acceleration and aids in the achievement of higher throwing velocities.

Alterations in scapular coordination have been suggested to cause artrokinematics changes in the glenohumeral joint, increasing the risk of shoulder problems (Borsa et al., 2008; Kibler & Sciascia, 2010; van der Hoeven & Kibler, 2006). Athletes, in our study, showed a scapula in external rotation at the end-range of ER in a seated position. Also highest values of Sz were found at seated position and passive motion. Scapular behavior explains the fact that there are no differences between TH and SH. Athletes seem to replicate with the scapula the humeral movement. So when at supine position the scapula was stabilized allowing the same movement between this bone and the humerus, justifying the highest values during supine position.

Conclusion

Our findings emphasize the importance of end-range determination in a clinical setting particularly on functional assessment of the shoulder of throwing athletes. Shoulder rotational assessment of range-of-motion must be consistent with subject position for end-range determination.

A limitation of this study is that we tested a small number of athletes form a variety of sports. Most were volleyball players and were compared with team-handball players and a control group; this may have influenced the active ROM results. Secondly, a seated position enables us to standardize the throwing technique, but it may have not represented how the athletes use their whole body during the throwing motion, because the whole kinetic chain was not available (lower limbs were eliminated) so the testing protocol may have altered external rotation ROM and scapular motion required at the shoulder.

Shoulder Rotation Range-of-Motion in Throwing Athletes.
The Effect of Active or Passive End-Range Determination

Andrea Ribeiro & Augusto Gil Pascoal

Abstract

The purpose of this study was to compare the effects of active or passive end-range determination (supine position) for external rotation ROM in overhead throwing athletes and verify if athlete's behavior is similar to non-athletes. Kinematic data from dominant shoulder of 24 healthy male subjects, divided into two groups (12 athletes and 12 non-athletes) were recorded at end-range external rotation Thoracohumeral (TH) and glenohumeral (GH) external rotation angles were compared and a 2-way repeated-measures ANOVA was used to calculate the effects of end-range determination (passive *vs.* active) across groups (athlete and non-athlete). A significant main effect ($p<0.001$) on both TH and GH external end-range angles was observed while the highest end-range determination values were associated with passive motion. No differences were observed between the athletes or non-athletes for either TH ($p=0.784$) or GH ($p=0.364$). Results emphasize the importance of end-range determination in a clinical setting particularly on functional assessment of the thrower's shoulder.

Introduction

Throwing athletes have been shown to have several morphologic changes in their dominant extremities when compared to non-dominant (Schwab & Blanch, 2009; Wilk et al., 2011) namely; muscle hypertrophy, increased strength, bone density of the humerus, and/or increased shoulder external rotation, (Safran et al., 2001). These findings have important implications in the assessment and rehabilitation process of athletes with shoulder problems.

Physical examination of the dominant shoulder of overhead throwing athletes consistently demonstrates morphofunctional adaptations, otherwise known as an increased glenohumeral external rotation range-of-motion (ROM), when compared with non-athletes. Based on the results of several studies (Dwelly et al., 2009; Stokdijk et al., 2003; Tokish et al., 2008; Wilk et al., 2011; Wilk et al., 2009) throwers demonstrate significantly increased glenohumeral external rotation and significantly decreased internal rotation ROM in the throwing arm. Nevertheless the total ROM is kept the same (Borsa et al., 2008) A reason for this altered ROM is unclear, but is believed to be an adaptation of the throwing sports demand (Reagan et al., 2002; Wilk et al., 2011). Study these adaptations is important for two main reasons: 1) the available range of internal and external rotation impacts shoulder function, from simple activities of daily living, such as hair combing, to more complex tasks, as the ones used by the athletes during sports activity; and 2), on a less important level, the measurement of internal and external rotation can be used as an indicator of capsular tightness (McCully et al., 2005).

Patient evaluation of glenohumeral internal or external rotation often uses goniometry as a part of shoulder assessment (Ellenbecker & Roetert, 2002). From a biomechanical perspective, these measurements have three key limitations: 1) the end-range is determined by clinical end-feel, as opposed to an objective assessment of torque; 2) goniometers may be designed and used to assess glenohumeral motion but they are really measuring both glenohumeral and scapulothoracic motion; and 3) the effect of the plane of motion has not been well documented (McCully et al., 2005). Supine position with the upper-arm at 90º of abduction is the standard subject position for goniometric measurements. In this position, the humerus is not aligned with the scapular plane, which, on a standard anatomical position, is described around 45º between the frontal and sagittal anatomical planes (Ellenbecker et al., 1996; Tokish et al., 2008; Torres & Gomes, 2009; Wilk et al., 2011). With a standard goniometric position, both the scapula and humerus are aligned to a horizontal plane parallel to the table (lying surface). Some studies demonstrated the reliability (repeatability) of goniometric measurements recorded on these conditions, particularly when scapular motion is constrained (Ellenbecker et al., 1996; Wilk et al., 2011). Others mention that, during passive measurement in supine, the scapula is stabilized on the table, but actively scapula is free to move with the shoulder girdle muscles, exercising control over the joint and contributing to shoulder ROM (McConnell et al., 2012). However, a lack of information exists about validation of the goniometric measurement, i.e., a true comparison with a "*gold standard*". This poses a difficulty for the comparison of results from goniometric based-studies with other measurement approaches (e.g. biomechanical) that do not use the same standards. The available information suggests that shoulder rotation range-of-motion is affected by the plane of the humerus and subject assessment position (McCully et al., 2005).

Measuring maximal external rotation is a common practice in clinics in order to identify shoulder dysfunction due to changes on shoulder rotational pattern with respect to non-dominant side. Non available data exists with respect to changes of rotational pattern in athletes when compared with non-athletes, or even in athletes during passive or active motion. Several procedures are currently used to test humeral rotation these involve placing the patient supine or in a sitting position with the arm abducted to 90º. When the patient is supine, the humerus is totally supported by the table while internal and external rotation occurs. In this patient position, an assumption can be made that the scapular motion is limited by a posterior force applied by the examiner on the coracoids process and clavicle. Application of this posterior force restricts arm motion mostly at the glenohumeral joint. In a sitting position, the examiner has to stabilize the inferior angle of the scapula and, then, while having the patient actively abducts his/her humerus at 90 degrees, rotate the forearm around the long axis of the humerus (Ellenbecker et al., 1996). On both procedures of ROM testing, the end-range is either actively determined by patients with or without (Dwelly et al., 2009) the effects of gravity, or by the examiner, following a standard goniometry procedure by which the patient’s arm is passively positioned and limited by capsular end-feel (Awan et al., 2002; Barlow et al., 2002; Reagan et al., 2002), by scapular liftoff (Nakamizo et al., 2008) or by pain However, no studies to date have specifically investigated how humeral rotational measurements are affected by end-range determination in overhead throwing athletes.

We hypothesize that the end-range of shoulder external rotation would be higher when determined passively as compared to actively in athletes. Examination usually is performed passively, with the assumption that static range of motion measurement is representative of the dynamic range-of-motion during throwing. However, the incidence of shoulder reinjury is high (McConnell et al., 2012). An overhead throwing athlete may be pain free, have restored passive range of motion, and be ready to return sport, but muscle capabilities may be insufficient to control the shoulder girdle during throwing, perhaps resulting in further injury or decreased performance. Thus the purpose of this study was to compare the effects of active or passive end-range determination (supine position) for external rotation ROM in overhead throwing athletes and verify if athlete's behavior is similar to non-athletes.

Materials And Methods

Participants

Twenty-four subjects participated in this study and were divided into two groups, athletes (n=12) and non-athletes (n=12). The athletes were recruited from volleyball and team-handball players. Non-athletes were recruited from the local community. All participants completed a questionnaire concerning their sports activity in order to ensure that none had played high level overhead sports.

Demographic data, with respect to age, height and body mass, were compared across groups using an independent samples t-test (table 5).

Table 5: Mean (standard error of mean) of subject demographic data by groups

	Athletes (N = 12)	**Non-athletes (N = 12)**	**P - value**
Age (years)	25.6 (5.7)	23.8 (6.2)	0.269
Height (cm)	186.0 (7.9)	172.7 (8.8)	0.001
Body mass (kg)	84.6 (8.9)	73.3 (13.3)	0.023

The athletes reported at least 6 years of practice at high level competition. Subjects also provided information regarding their arm dominance, retrospective injury history (an injury regarded as any overuse injury that altered their training for more than a week), and relevant medical history. Subjects were excluded if a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) was recorded. All subjects were recruited on a voluntary basis and signed an informed consent statement. Ethical approval for the study was ratified by the Scientific Board of Human Kinetics Faculty – Technical University of Lisbon.

Task

Passive motion

Shoulder external rotation was assessed at 90º of abduction by Examiner #1 (P.M.R.) while passive external rotation range-of-motion was measured by Examiner #2 (A.M.R.). During the external rotation passive range-of-motion assessment, the scapula was stabilized with one hand by Examiner #1. Then, Examiner #1 passively moved the extremity to end-range (point where end-feel is perceived), and that position was held static as the goniometric data was collected (Figure 10). Passive range was determined by passive weight of the arm and no force or weight was applied by Examiner #1.

Active motion

On active motion assessments, the subject actively moved the extremity to end range (point where end feel is perceived), and that position was held static as the goniometric data was collected. For this assessment, subjects were instructed to actively rotate their arms to maximal external rotation. This position was subjectively defined by the subject based on pain and proprioceptive feeling of soft-tissue stretch, lack of force and/or a subjective feeling about joint integrity, i.e. beyond that extreme position the joint could be at risk of injury (Figure 11). Proper subject arm and scapula position during the trial was monitored by Examiner #1.

Figure 10: Protocol for passive external rotation

Figure 11: Protocol for active external rotation

On passive and active assessments, no allowance for scapular protraction or elevation was permitted. The scapulothoracic joint was stabilized via a posterior directed containment force by Examiner #1's hand on the coracoid process and the anterior aspect of the acromion. This procedure replicates the one used on standard goniometry for shoulder rotation.

Instrumentation

The 3D shoulder kinematics was tracked by an electromagnetic system at 100Hz (Motion Star Flock-of-Birds by Ascension Technology, Burlington, VT) and recorded by specific biomechanics software (*The Motion Monitor* by Innovative Sports Training, Chicago, IL) which allowed registration of the electromagnetic sensors' 3-D position and orientation as long as they were in the range of the electromagnetic field. The reliability of the electromagnetic system is 0.3 mm for the position and 0.15º for orientation, according to the manufacturer. For data collection, a four sensors setup was used: the thorax sensor firmly attach to the skin by a double-glued tape over T1; the arm sensor attached by means of a cuff just below the deltoid attachment; and the scapular sensor firmly glued on the superior flat surface of the acromion process. A 4th sensor mounted on a non-metallic stylus (± 6.5cm) was used on digitalization protocol. The digitized bony landmarks (See Chapter 3, Table 2) were then used to convert the sensor axes to anatomic axes or local coordinate system (LCS) (see Chapter 3, Table 3) on thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB). Using this procedure, sensor axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion.

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB (Wu et al., 2005) recommended rotation sequences (y, x´, y´´): plane of arm elevation, arm elevation and axial rotation. Continuous data were recorded and filtered (Butterworth filter; cut-off=10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of active and passive humeral external rotation was considered for further analysis.

The reliability of the three trials was calculated for each variable using intraclass correlation coefficients, and the standard error of measurement (Thoracohumeral 0.998, P<0.01; Glenohumeral 0.999, P<0.01). After determining trial-to-trial reliability, the values for each subject were averaged across the three trials.

The digitization protocol was performed with the subject in a seated position, arm elevated (± 90º), elbow flexed (± 90º) and forearm parallel to the floor. This position was used as the neutral rotation position and the zero point (0º) for the calculation of the thoracohumeral (TH) and glenohumeral (GH) external rotation.

A 2-way repeated-measures ANOVA was used to compare the effects of the end-range determination (passive or active) across groups (athlete and non-athlete). For all statistical tests, specific software (SPSS Statistics 17.0) was used and results were considered significant at P values < 0.05. Effect size (ES) analysis and probability scores were reported. We used the qualitative assessment of ES whereby a small, medium or large change/difference is defined by an ES greater than 0.20, 0.50 or 0.80 respectively (Cohen, 1992).

Results

Active vs. passive comparisons

Comparing active and passive end-range determination, a significant main effect was found on TH and SH angles with the highest values associated with the passive approach.

External rotation; athlete´s vs. non-athlete´s comparisons

No differences were found between athletes and non-athletes groups either for the TH (p = 0.784) or the SH (p = 0.364) angles. On athletes the SH angles showed a mean differences between active (athletes = 103.4 ± 3.1; non-athletes = 100.6 ± 3.1; ES = 0.41) and passive motion (athletes = 109.2 ± 2.9; non-athletes = 104.3 ± 2.9; ES = 0.645) when compared with non-athletes.

The same behavior on thoracohumeral angles for athletes showed mean differences between active (athletes = 101.5 ± 3.7; non-athletes = 104.3 ± 3.7; ES = -0.35) and passive motion (athletes = 105.7 ± 3.9; non-athletes = 105.9 ± 3.9; ES = -0.02), however none of these differences were statistically significantly (Figures 12 and 13).

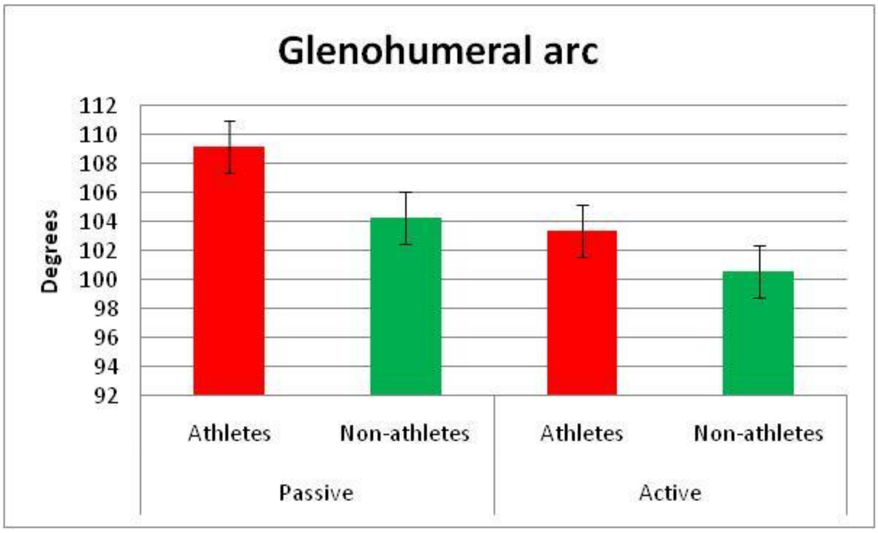


Figure 12: Mean values of shoulder external rotation (glenohumeral arc of ROM determined passively and actively across groups)

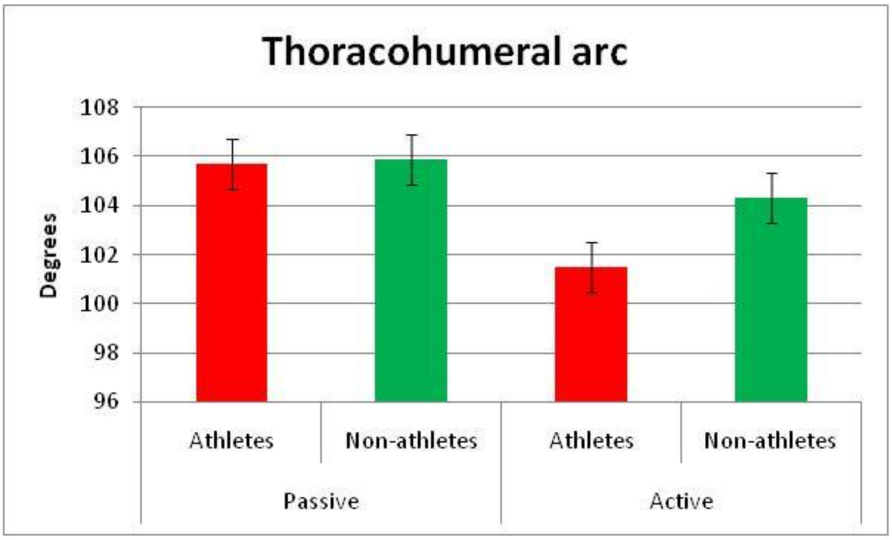


Figure 13: Mean values of shoulder external rotation (thoracohumeral arc of ROM determined passively and actively across groups)

Discussion

Differences were found between active vs. passive end-range determination on both thoracohumeral and glenohumeral angles. These results showed that shoulder external rotation range was higher when the end-range was passively determined by the examiner.

In literature the effect of end-range determination (passive vs. active) on shoulder range assessment is not clear. While some authors use an active end-range approach (Dover et al., 2003; Laudner et al., 2006; Nakamizo et al., 2008) others reported the use of a passive one (Dwelly et al., 2009; Meister et al., 2005; Torres & Gomes, 2009). This end-range was determined by capsular end-feel (Awan et al., 2002; Barlow et al., 2002; Reagan et al., 2002), by scapular liftoff (Warner et al., 1990) or by pain (Andrews AW & RW, 1989). This aspect is crucial to understand the results from other studies that showed higher values of ROM associated to passive condition with the proposed goniometric procedure (Osbahr et al., 2002). In most of the studies, a supine position with the arm at 90° abduction was used to assess the shoulder rotational ROM (Awan et al., 2002; Barlow et al., 2002; Lajtai et al., 2009; Reagan et al., 2002).

Despite shoulder internal rotation being considered an important component on the throwing mechanism, two main reasons explain why the present study was focused only on external rotation range-of-motion. The first reason was strictly methodological and refers to the use of an electromagnetic sensor on the scapula (scapula’s sensor), located on the superior flat surface of the acromion. This sensor’s physical location reduces the examiner’s ability to manually constrain scapular motion. In fact, during shoulder internal rotation the acromion and clavicle move anteriorly and require an additional examiner to keep the posterior aspect of the scapula in contact with the table, inducing artifacts on the scapula’s sensor recordings. During shoulder external rotation, this is not the case as the examiner´s attention is more directed towards monitoring scapular motion, instead of an effective scapular motion restriction. As was demonstrated by Boon et al. (Boon & Smith, 2000) during external rotation in a lying position, the scapula is limited mechanically by the ribcage, whereas in shoulder internal rotation the scapula can tilt anteriorly and “wing off” the chest wall. Thus, manual scapular stabilization is less critical during external rotation measurements but is necessary during shoulder internal rotation to minimize scapulothoracic motion and restrict motion to the GH joint. With an electromagnetic sensor on the scapula, it was possible to follow the scapular motion in real-time and exclude those trials where the scapula moves above a certain level. This information was refined by the examiner’s manual perception with the hand that was positioned over the shoulder. The second reason that explains why focusing on external rotation refers to the purpose of the study: describe the effect of passive vs. active end-range determination on shoulder rotation range-of-motion assessment. For that purpose external or internal shoulder rotation could be used. According to our findings, the mean range-of-motion in passive shoulder external rotation is higher among athletes when compared to a non-athletes population. This seems to indicate that athletes probably do not develop any kind of adaptation that could induce differences between active and passive shoulder range-of-motion.

Conclusions

Results emphasize the importance of end-range determination in a clinical setting particularly on functional assessment of the thrower’s shoulder. Examination usually is performed passively, with the assumption that static and active ROM are similar (McConnell et al., 2012). In fact, the throwers on our study seem to demonstrate this. We were expecting to find, in the athletes group, less active external rotation because athletes could not use scapular motion, due to stabilization, although they showed similar behavior while compared to non-athletes. With this approach, the recorded shoulder motion was mostly around the GH joint and could be correlated with goniometric measurements even when an effective scapular motion restriction is not applied. Goniometric data collected with a kinematic tracking system needs to be compared with other sources of goniometric data collection.

CHAPTER 6 - SCAPULAR ADAPTATIONS

The Scapular Contribution to the Amplitude of Shoulder External Rotation on Throwing Athletes

Andrea Ribeiro, Augusto Gil Pascoal & Nuno Morais

Abstract

Traditional clinical testing of the shoulder ER imposes a fixed scapula in order to assess the glenohumeral joint, despite the recognized importance of the scapular mobility and stability on shoulder function. Here the scapular contribution to the amplitude of humeral axial rotation (internal and external) was tested on the dominant shoulder of two groups of twelve subjects, the thrower athletes and the non-athletes group. The scapular 3D position recorded at the end-range of SH and TH IR and ER rotations were compared across groups using a mixed-model two-way ANOVA. At the end-range of humeral ER, throwers showed less SH and TH amplitude and a scapula more in retraction. A positive correlation was found between scapular spinal tilt and TH and SH angles at the end-range of ER. The throwers group showed a scapula more in retraction in maximal external rotation of the humerus, and less external rotation in active motion. On volleyball players, the scapula assumed a position of posterior spinal tilt when the humerus was positioned more in external rotation. No such correlation was found in the control group or the team-handball players group, possibly due to sports adaptation.

Introduction

Overhead throwers are a population at risk of developing shoulder injuries. The mechanics of the throwing action, where a ball is released or stroked at maximum speed when the hand is placed over the head, puts an enormous stress on shoulder structures. Fortunately, musculoskeletal system has the ability to adapt to the high load activities in order to achieve the best performance and avoid injury. Not all the adaptations are considered beneficial and some of them have been involved in the pathomechanics of shoulder pain and disability. The throwing shoulder poses major challenges to clinicians. It is a complex of great mobility in which static and dynamic stability depends on the synchronized position and motion between scapula and humerus. Understanding the role of the scapula in shoulder function and dysfunction is one of the recent directions in the scientific community. It is accepted that changes in scapular kinematics are related to shoulder pathology however clinical procedures to assess scapular contribution to total shoulder motion have been poorly developed. Here is presented the contribution of the scapula to one of the most acknowledged functional adaptations of the throwing shoulder – the external rotation gain.

Shoulder structure and function

Glenohumeral joint structure and function

The glenohumeral joint is composed by static and dynamic stabilizers. The dynamic stabilizers of the glenohumeral joint include the rotator cuff, the scapulothoracic muscles, and the long head of the biceps tendon, while the static stabilizers include the osseous anatomy, the fibrocartilaginous labrum, and the glenohumeral joint capsule (Lee, Kim, O'Driscoll, Morrey, & An, 2000; Matsen, Chebli, & Lippitt, 2006; Veeger & van der Helm, 2007). The stability demands on these structures are even higher during the practice of overhead sports such as tennis (Torres & Gomes, 2009), volleyball , handball (Murachovsky et al., 2007; Pieper, 1998), baseball (Oyama, 2006; Tokish et al., 2008; Tripp et al., 2007; Warden et al., 2009), water polo (Webster, Morris, & Galna, 2009) and swimming (Oyama, 2006; Torres & Gomes, 2009).

The mobility of the shoulder joint is the result of motion in both the glenohumeral joint and scapulothoracic-gliding plane. Most of the thoracohumeral motion takes place in the glenohumeral joint, which itself allows for glenohumeral elevation up to 120º and in addition the humerus is able to axially rotate about 135º relative to the scapula (Magermans, Chadwick, Veeger, & van der Helm, 2005; van der Helm & Pronk, 1995; Veeger & van der Helm, 2007).

Alterations in either the anatomy of the joint, e.g. glenoid version (Nyffeler et al., 2006), or deficiencies in the intrinsic biomechanical properties of the ligamentous and/or capsular components can cause motion abnormalities and focal contact stresses or even develop instability (Kelkar et al., 2001; Lee et al., 2000). Depending on the injured structures involved, the direction of instability may be primarily anterior, inferior or posterior, or a combination of these. The degree of instability may range from mild subluxation to dislocation, with associated injuries to the bony (e.g. Hill Sachs lesion), capsulolabral structures (e.g. Bankart and SLAP lesions), or both, and surrounding musculature (e.g. rotator cuff tears and impingement). Isolated injuries are not very common and usually one problem may lead to other (Burkhart et al., 2003c; Meister, 2000a).

The shoulder girdle structure and function

The shoulder girdle is a morphofunctional unit composed by the scapula and the clavicle bones, resting on the thorax. Scapula and clavicle are connected via acromioclavicular joint. Both bones are linked to the thorax via sternoclavicular joint and the functional scapulothoracic joint. In this context, the thorax acts as a stable base for the movements of the upper limb. Together the thorax and the shoulder girdle form a closed kinematic chain mechanism with some degree of inter-dependence. As consequence, the shoulder girdle moves with respect to the thorax at the same time that is used as a stable base for muscles acting on the humerus.

Overhead-throwing athletes

Thrower athletes also called overhead-throwing athletes include throwers (e.g. baseball pitchers), swimmers, and water-polo, handball, and volleyball players. From a functional standpoint, these sports require repetitive overhead motions, which are discontinuous and ballistic in nature, and where the throwing arm is forced forward from maximal external to near maximal internal rotation, while the arm is kept in an elevated position.

Kinematics of the throwing arm motion (with ball) is frequently described as a particular sequence of phases, the "*throwing cycle*" (Werner et al., 2006), that includes the initial and late cocking phases, where the arm assumes an elevated-external rotated position, followed by an acceleration and a follow-through (deceleration) phases. At the end of the acceleration phase the object (ball) is released or stroked. On throwers, during the deceleration phase, the posterior rotator cuff musculature acts eccentrically in order to decelerate or "*brake*" the internal and horizontal adduction arm motion, generated during the acceleration phase. The act of throwing requires a coordinated motion that progresses from the toes to the fingertips. This sequence of events has been described conceptually as a kinetic chain. For the kinetic chain to work effectively, sequential muscle activity is required so that the energy that is generated in the lower body can be transmitted to the upper body through the arm, hand, and fingers, and finally to the ball. The speed of the ball is then determined by the efficiency of this process. Body rotation, timing and positioning of the scapula are key elements in the kinetic chain. Any physical condition that alters the components of the kinetic chain, especially one that affects the so called "*core*" (trunk, back and proximal parts of the lower limbs), will alter more distal segments and may result in the development of a dysfunctional shoulder .

The inherent contradiction for overhead athletes is the fact that the shoulder must be loose enough to perform overhead activity and yet stable enough to prevent the joint from "*giving way*" or sub-luxation. In elite-level throwers, there is a delicate balance between shoulder mobility and stability. The shoulder needs to be mobile enough to reach extreme positions of rotation so that velocity can be imparted to the ball, but at the same time the shoulder needs to remain stable so that the humeral head remains within the glenoid socket, creating a stable fulcrum for rotation; this is known as the "*thrower´s paradox*". With each pitch, the soft-tissue envelope that surrounds the shoulder is loaded at levels that approach the ultimate failure loads of the tissues, which are thus quite vulnerable to injury.

The "throwing shoulder"

Numerous studies have documented motion adaptations on the dominant shoulder of throwers either by comparing shoulders bilaterally or with the dominant shoulder of non-athletes (Dwelly et al., 2009; Oyama et al., 2008; Torres & Gomes, 2009; Warden et al., 2009). One of the most visible and highlighted adaptations, imposed by the repetitive throwing cycle at high velocities over time, includes changes on shoulder rotational ROM pattern with increased external rotation (external rotation gain) and limited internal rotation (glenohumeral internal rotation deficit), while the range of the total arc of motion (external arc *plus* internal arc) is kept unchanged.

In general, the shoulder rotational adaptation on the asymptomatic dominant throwing shoulder of an elite-level athlete was described as an increased external rotation arc and a correspondent decrease in the internal rotation arc, while the amplitude of the total arc is kept unchanged, in a condition called the "*posterior shift*" (Borich et al., 2006; McCully et al., 2005; Tokish et al., 2008; Wilk et al., 2009). This adaptive pattern was mostly described through goniometric studies (Barlow et al., 2002; Downar & Sauers, 2005; Ellenbecker et al., 1996) where the athletes were assessed in a supine or a sitting position with the arm placed at 90º of abduction. The arm is then passively rotated from the extreme position (end-range) internal rotation until the end-range of external rotation, or vice-versa. Following this standard goniometry procedure, the shoulder rotation end-range is determined by the examiner according to the sensation of capsular end-feel, the scapular liftoff momentum or perceived pain. A few studies described the changes on the rotational pattern using an active end-range determination (Ellenbecker & Roetert, 2002; Hayes et al., 2001) and no studies to date have specifically investigated how humeral rotational pattern is affected by active or passive end-range determination in overhead throwing athletes.

The posterior shift in the total arc of motion is considered to be a physiological adaptation of the shoulder joint to throwing. According to Wilk *et al.* (2009) most throwers exhibit an obvious motion disparity, whereby shoulder external rotation (ER) is excessive and internal rotation (IR) is limited when measured at 90º of abduction. This loss of IR on the throwing shoulder, referred to as "*glenohumeral internal rotation deficit*" (GIRD) (Nakamizo et al., 2008; Pieper, 1998), is suggested to be caused by the retraction of the posterior capsule induced due to the increased amplitude of external rotation in the late cocking phase. This allows hyper-external rotation as the posterior capsule reaches maximum length while the anterior capsule still allows for additional external rotation. Burkhart *et al.* (2003a) described the GIRD as an alternative mechanism for primary progression of "*internal impingement-like*" changes in the shoulder. The glenohumeral internal rotation deficit model is based on the high prevalence of posterior capsular contractures and contractures of the posterior band of the inferior glenohumeral ligament in thrower shoulders. When a posterior capsular contracture develops, the center of rotation of the humerus, or the contact point of the humerus on the glenoid, is shifted postero-superiorly. This shift functionally increases the length of the anterior aspect of the capsule, which provides more clearance for the greater tuberosity, diminishing the glenohumeral contact point of the anterior-inferior aspect of the capsule with proximal part of the humerus. As a result, the biceps anchor is peeled back under tension, causing injury to the postero-superior structures, especially the postero-superior aspect of the labrum (SLAP lesion). The so-called peel-back progression mechanism permits further laxity of the anterior aspect of the capsule (Burkhart et al., 2003a, 2003b). With the glenohumeral internal rotation deficit model, one attempts to identify throwers at risk for shoulder injury by quantifying the internal rotation deficit individuals are considered to have a clinically relevant glenohumeral internal rotation deficit when there is a loss of internal rotation of the throwing shoulder as compared with the non-throwing side. Such deficits are commonly found in overhead throwers, when compared with measurements on the contralateral side, as well as concomitant increases in external rotation.

Some studies suggested an osseous adaptation as a possible explanation for the increased external rotation observed on the throwing arm, namely an increase on the angle of the humeral head retroversion, or humeral torsion (Crockett et al., 2002;

Reagan et al., 2002). More external rotation range in the dominant arm could be seen as a strategy to improve performance, allowing increased cocking of the throwing arm which leads to higher ability to generate power and speed or release (Wang & Cochrane, 2001b). Other authors though do not look at these adaptations as single benefits but as abnormal stresses at the joints and the surrounding tissues which may cause shoulder pain, decreased performance or some unspecific shoulder disorders (P. McClure et al., 2009; Tsai, McClure, & Karduna, 2003). Pieper *et al.* (1998) found an augmented angle of retroversion (up to 15°) in the dominant shoulder of 51 team-handball players, when compared with the non-dominant shoulder. This retroversion seems to increase the available external rotation range-of-motion (ROM) but at the same time reduced the ability of the rotator cuff to control high forces or velocities through the extremes to shoulder ROM which could lead to excessive humeral head translation and culminate in shoulder pain (Ellenbecker et al., 2002). Thus, it remains unclear whether there are benefits or disadvantages associated to changes in humeral torsion.

Humeral torsion may not be the only mechanism that explains the external rotation gain in throwers. It seems that the looseness of the connective that surrounds and stabilizes the glenohumeral joint may also play a role. The inferior glenohumeral ligament complex (IGHLC) is considered to be the most restraining structure at the late cocking position (Kuhn et al., 2000; Turkel et al., 1981) followed by the coracohumeral ligament (Kuhn et al., 2000). It is likely that with the continuous excessive external rotation in throwing mechanics, the anterior capsule and the anterior band of the IGHLC may become looser than normal subjects (Herrington, 1998; Mihata et al., 2004). The link between looseness of the anterior band of the IGHLC, increased anterior and inferior humerus head translations and humeral external rotation was demonstrated in cadaveric models (Mihata et al., 2004).

Problem

Despite advances in diagnostic and treatment interventions, shoulder injuries continue to plague throwing athletes. These athletes are prone to shoulder injuries as a result of the high forces placed on the shoulder during the throwing motion. Overhead athletes require a delicate balance between shoulder mobility and stability in order to meet the functional demands of their respective sport. Altered mobility patterns, concerning rotational movement, as mentioned before, have been consistently reported in the dominant shoulder of throwers such as elite baseball pitchers (Werner et al., 2006), volleyball players or team-handball players (J. B. Myers et al., 2005).

Commonly, clinical ROM testing includes the measurement of maximal external and internal rotation using a goniometric approach, i.e., placing patient in a supine or a sitting position, with the arm abducted to 90º and totally supported by the table. In this position, the examiner passively rotates the arm until the extreme position of internal or external rotation (end-range). In a seated position the examiner has to stabilize the inferior angle of the scapula, having the patient hold his/her elbow at a side while rotating the forearm around the long axis of the humerus (Ellenbecker et al., 2002). On both procedures the examiner passively sets the arm according to the capsular end-feel (Awan et al., 2002; Barlow et al., 2002; Reagan et al., 2002), or by scapular liftoff (Warner et al., 1990) or even by pain. On the other hand, the goniometric protocol imposes that the scapular motion must be limited by a posterior force applied by the examiner on the coracoids process and clavicle, restricting arm motion to the glenohumeral joint.

From a biomechanical perspective the goniometric protocol has three key limitations: 1) the end-range is determined by clinical end-feel, as opposed to an objective assessment of torque; 2) goniometers were designed to assess glenohumeral motion, but they are really measuring both glenohumeral and scapulothoracic motion and scapula can have a significant effect on both goniometric and vertebral level measurements. Isolating glenohumeral motion typically requires a fixation technique to prevent unwanted scapular motion, but this approach is difficult to perform and may induce unwanted artifact into the measurement. Third, the effect of the plane of motion has not been well documented (McCully et al., 2005).

Purpose of the study

The main purpose of the study was to clarify the scapular contribution to the amplitude of shoulder external rotation on thrower athletes. The assessment of internal and external rotation ROM is a standard part of a shoulder clinical examination. However, the contribution of shoulder girdle in the rotational motion pattern often is frequently not considered by clinicians. Additionally, the study looks to quantify the effects of the end-range determination and the speed of motion on the external rotation ROM. To date, no studies have specifically investigated how humeral rotational pattern is affected by active or passive end-range determination in overhead throwing athletes.

Materials And Methods

Sample

Twenty-four subjects (n = 24) divided in two groups were studied: the throwers group with 6 volleyball players (height = 181± 4,7 cm; age = 22 ± 4,0 years; body mass: 75 ± 7,6 kg) and 6 team-handball players (height = 184 ± 3,7cm; age = 22 ± 0,9 years; body mass = 81 ± 5,6kg); and the non-thrower group with 12 non-thrower athletes (height = 176 ± 4,7 cm; age = 26 ± 2,9 years; body mass= 73 ± 7,5 kg).

Kinematic proceedings

Humeral and scapular 3D positions were recorded by means of a 6DOF electromagnetic tracking device (Hardware: "*Flock of Birds system*" Ascension Technology; Software: Motion Monitor v 7.0) which allowed simultaneous tracking of four sensors at a sampling rate of 100 Hz per sensor. This system allows the registration of the position and orientation of the sensors in space always when they are inserted in an extended electromagnetic field. The static accuracy of these sensors with an Extended Range Transmitter is up to 0.76cm RMS/0.5 degrees RMS at a 1.52 meter distance from the transmitter. The static resolution is 0.08cm/0.1 degrees RMS at 1.52 meters from the transmitter. On data collection a four sensors setup was used. Thorax sensor was attached over T1 using double faced tape assuring its fixation. The arm sensor, placed just below the deltoid attachment, by mean of a cuff firmly adjusted to the arm. Finally the scapular sensor was attached to the superior flat surface of the acromion process, using the same kind of tape.

A 4th sensor mounted on a hand-held acrylic stylus (± 6,5cm) was used on bony landmarks digitalization in order to link sensors position to the local anatomical coordinate systems (LCS) (See Chapter 3, Table 2 and 3) and subsequently calculated segments and joint rotations by combining the LCSs with the sensor motions. Segments LCSs and joint rotations definition, expressed in Euler angles, were made according to the shoulder ISB standardization protocol (Wu et al., 2005).

Task

The subject was in a seated position, with supported feet, keeping the hips and knees at 90º flexion. The shoulder evaluated was at 90º of humeral elevation and in the scapular plane supported by the researcher. The subjects performed one task in two specific conditions concerning velocity: 1) slow axial rotation; 2) fast axial rotation (Figure A). Subjects performed total axial rotation since maximal external (Figure 14A) rotation until maximal internal rotation (Figure 14B).

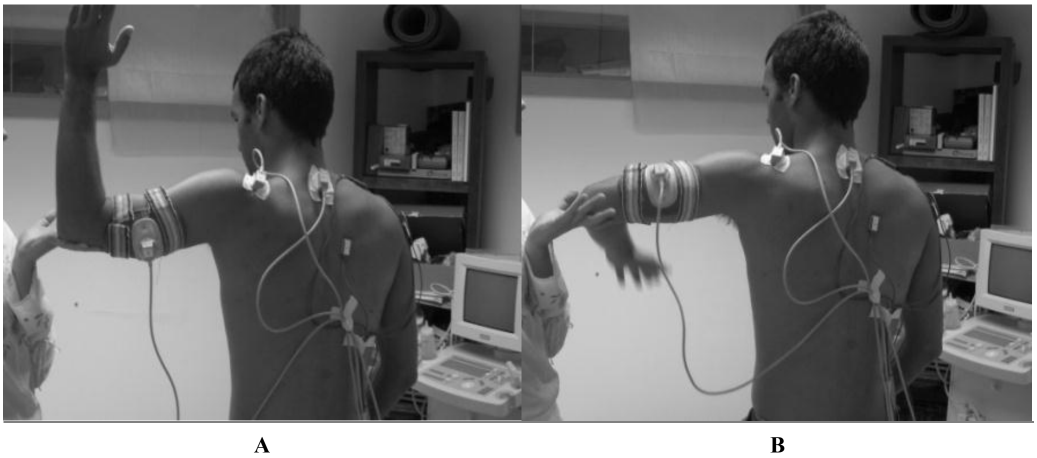


Figure 14: (A) Subjects performing external and (B) internal rotation

At the first condition, subjects were asked to perform slow motion, keeping the scapula stable. At the second condition, they performed the movement reproducing a ballistic one. Both conditions were repeated for 3 times each. Humeral axial rotation was described with respect to the scapula, the glenohumeral (HRs) angles, and with respect to thorax, the thoracohumeral (HRt). Scapular position was described with respect to the thorax as protraction (Syt), lateral rotation (Sxt) and spinal tilt (Szt). These angles were recorded at end-range of active fast and slow (subject self-selected end-of-range).

Statistics

A mixed-model two-way ANOVA was used to test the main effect of group (between-group factor) on the three scapular (Syt, Sxt and Szt) and the two humeral (HRt and HRs) dependent variables, as well as test for an interaction of group and speed motion (slow *vs.* fast; within-subjects factor). A bivariate correlation test was used to describe the relationships between HRt and scapular variables. Another bivariate correlation test was run order to describe the relationships between scapular spinal tilt (Szt) and shoulder external thoracohumeral and scapulohumeral rotation.

Results

No significant interaction was found between group and speed motion for any of the three scapular and the two humeral dependent variables. On both groups, the increment of arm velocity imposed a decrease on the amplitude of the humeral external rotation. The throwers group showed at the end-range of the humeral external rotation, significantly less amplitude of HRs (23º difference; P = 0.04) and a scapula more in retraction (15º difference; P = 0.00). Considering the influence of the fast arm condition, amplitude of HRs was lower at the end-range of external rotation (13, 6º difference; P = 0.04). Also on throwers, scapula was also kept more in retraction at the end-range of ER (Table 6).

Table 6: Humeral and scapular 3D position at the end-range of external rotation on both groups (throwers and non-throwers) during the fast condition (Mean ± standard deviation)

	Non-throwers	Throwers
Humeral external rotation w.r.t. Thorax	-96.3 ± 26.8	-77.5 ± 19.2
Humeral external rotation w.r.t. Scapula	-90.4 ± 29.2	-65.6 ± 19.5
Scapular protraction *(Syt)* (at end-range of humeral external rotation)	32.5 ± 14.0	17.4 ± 5.6
Scapular lateral rotation *(Sxt)* (at end-range of humeral external rotation)	42.1 ± 9.8	39.4 ±12.1
Scapular spinal tilt *(Szt)* (at end-range of humeral external rotation)	8.3 ± 7.1	9.9 ± 6.5

w.r.t. = with respect to

Considering fast shoulder external rotation between spinal tilt (Szt) and thoracohumeral (TH) and glenohumeral (GH) arc a positive correlation was found on the control group.

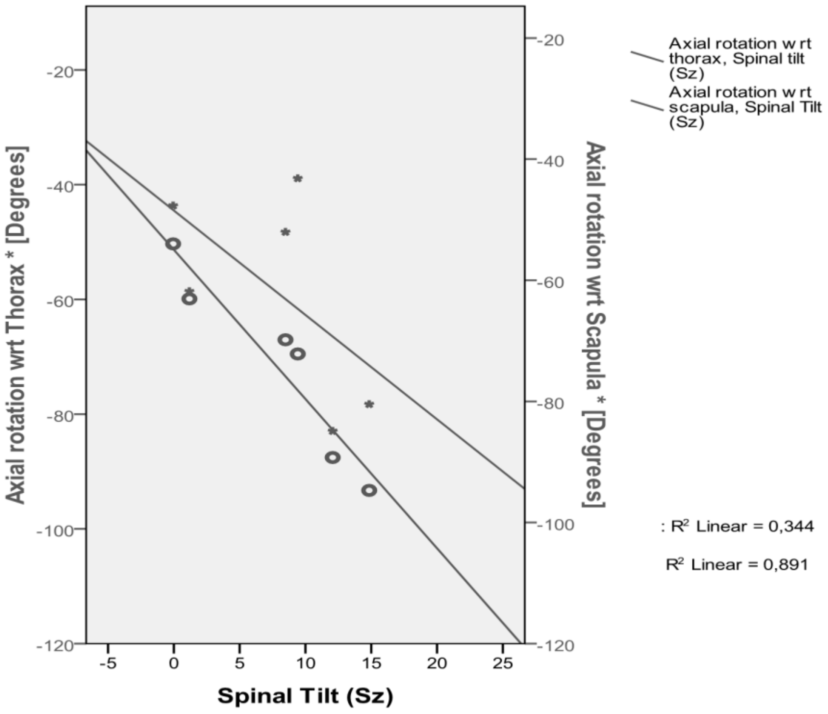


Figure 15: Volleyball athletes: Correlation between spinal tilt (Szt) and shoulder axial rotation w.r.t. thorax (TH) and w.r.t. scapula (GH) in fast condition. All values are in degrees.

Concerning volleyball players a negative correlation was found between Szt and TH and no correlation on team-handball players was realized. In the control group we found a linear relation, so, with higher external rotation, less scapular tilt is shown. At the non-throwers group movement occurs more in the GH while in volleyball movement is in GH and scapula. At fast condition on volleyball players a negative correlation was shown (Figure 15). On volleyball players, scapula assumes a position on posterior spinal tilt (acromion backwards) when humerus is positioned more in external rotation. No correlation was found between volleyball players and the slow arm condition.

Discussion

Several studies had identified several morphologic and functional adaptations on the dominant shoulder of overhead athletes, such as volleyball players (Wang, Macfarlane, & Cochrane, 2000), water polo players (Pascoal & Tainha, 2006), baseball players (J. B. Myers et al., 2005; Osbahr et al., 2002; Reagan et al., 2002; Safran et al., 2001), swimmers (Oyama, 2006) and body building (Barlow et al., 2002).

In our study, throwers also showed a significant increase on glenohumeral external rotation and loss of internal rotation, while the rotational arch was maintained (External Rotation + Internal Rotation) as previously reported (Barlow et al., 2002; Burkhart et al., 2003a, 2003c; Laudner et al., 2006; Reagan et al., 2002; Safran et al., 2001).

In opposition to our study and considering glenohumeral rotational range of motion variation in overhead-athletes Dwelly *et al* (2009) demonstrated using a sample of 29 baseball male athletes and 19 softball female athletes, that there is a significant gain of shoulder external rotation amplitude at the dominant arm, and a significant raise of the total arch of motion. No changes were found at the amplitude of internal rotation during the season. The analysis of the morphofunctional adaptations of the thrower athlete cannot be circumscribed to the glenohumeral joint, and should be extended to the other joints of the shoulder complex, particularly the scapulothoracic joint.

During the throwing cycle it is suppose that athletes, such as volleyball or team-handball players, keep their scapula stable while the arm is fastly moved from a full external position to a full internal position. Scapular stabilization could be challanged when the arm motion is to fast. Therefore, an innadequate scapular position at the end-range of glenohumeral motion will lead to shoulder dysfunction and pathology (Werner et al., 2006).

The results showed that throwers demonstrated a scapula more in retraction (acromion backwards) when compared with non-throwers. This seems to work as a protective mechanism for the glenohumeral joint. In fact, the inability to retract the scapula, appears to impart several negative biomechanical effects on the shoulder, including narrowing of the subacromial space, increased strain on the anterior-inferior glenohumeral ligament, reduced impingement-free arc of upper limb elevation, reduced isometric elevation strength tested in the sagittal plane. Concerning this, throwers on our study seem to have developed an adaptation towards stability.

While in clinical trial these kinds of patterns are important to evaluate, to allow a better rehabilitation, with the traditional methods this does not seem possible. Using 3D kinematic analysis, scapular positioning could be recorded and morphofunctional adaptations could be identified, and also the specific movement of throwers. While using traditional goniometry this cannot be possible.

Concerning axial shoulder rotation, scapular contribution is crucial as it is well recognized that the external rotation needed to perform the throwing motion occurs not only at the glenohumeral joint but also with the participation of the scapula (Werner et al., 2006).

Excessive motion is required at the shoulder joint during throwing, yet the glenohumeral joint must remain stable to resist injury. We found that volleyball players show a more posterior tilted scapula when arm is positioned more in external rotation, while the control group showed less posterior scapula tilt. This seems to demonstrate that shoulder adaptation on volleyball players, while throwing, does not occur only at the glenohumeral joint, as it is commonly assumed in clinical practice, but instead it is supported by the trunk where the scapula in retraction and posterior tilt gives the necessary stability to achieve best performance. This seems the reason why proper 3D position of the scapula relative to the humerus and trunk is so relevant for muscle function. The scapula acts as the common point of attachment of the rotator cuff and primary humeral movers such as the biceps, deltoid and triceps, as well as several scapular stabilizers. Poor position of the scapula can lead to alterations to the relationship between length and tension of each muscle, thus adversely affecting muscle force generation (J. B. Myers et al., 2005). An imbalance in external rotators will lead to alterations in scapular tilt. Concerning the movement, clinical trials use passive and active motion. But the active motion used is usually a slow motion (McCully et al., 2005), and not simulating the sports practice. Our study looked for active motion. We have used an elevated arm position as the testing position, however the calibration one, was the same proposed in the ISB protocol as mentioned in methods, with the arm at a side. While testing we hoped that when raising the arm to the elevated position (arm at 90º flexion and abduction) the zero stayed the same, we did not expect to have any complementary rotation, and it happened that way. So the main reason to find more external rotation at non-throwers is possibly the fact that we were evaluating active motion and not passive one. Knowledge of joint ROM and speeds of movement along with joint forces and moments will provide a scientific basis for improved and rehabilitative protocols for throwers.

Conclusions

Speed was not an interaction factor between groups. At the end-range of arm external rotation the volleyball players group showed a scapula more in retraction and in posterior tilt (acromion backwards). No such correlation was found in the control group or the team-handball players, possibly due to sports adaptation. This group also showed less amplitude of external rotation in active motion.

As a limitation of this study we would include possible skin artifacts, especially at the arm sensor. To avoid this situation a sensor mounted on a cuff tiny adjusted to the arm just below the deltoid attachment was used, trying to ensure the position of the sensor towards the skin.

Scapular Contribution for the End-Range of Shoulder Axial Rotation.

Scapular Behavior in Over-Head Athletes

Andrea Ribeiro & Augusto Gil Pascoal

Abstract

The aim of this study was to analyze the relative contribution of the scapular motion on the extreme range of motion of shoulder external and internal rotation, in overhead athletes. An electromagnetic tracking device (Flock of Birds) was used to record humeral and scapular kinematic positions. The dominant arm of 26 male subjects (13 athletes and 13 non-athletes) was studied while subjects actively reached end-range of internal and external rotation. Humeral and scapular angles were calculated and compared across groups by means of a t-test for independent samples. A bivariate correlation approach was used to describe the relationship between humeral angles and scapular variables. The range of motion of the thoracohumeral angles, during shoulder external rotation was significantly less ($p<.05$) on the athletes group, athletes also positioned their dominant scapula more retracted and posteriorly tilted. A positive correlation was found between glenohumeral angles and scapular tilt ($r=0.6777$; $p<.05$). Concerning internal rotation; athletes showed significantly highest thoracohumeral angles ($p<.05$). Scapula assumed a position more in retraction and anterior tilt. Based on these findings, it is suggested that differences found in athletes seem to reveal an eventual shoulder adaptation.

Keywords: throwing-shoulder, overhead-athletes, axial rotation, scapula.

Introduction

Scapula plays an important role in normal shoulder function. In sports in which demands placed on the shoulder are extremely high, the quality of movements depends on the interaction between scapular and glenohumeral kinematics. How does scapula behave or how much scapula contributes for the axial rotation is not clear yet. The answer to these questions adds important information to understanding the overhead throwing athletes and how to behave during clinical trials and rehabilitation.

The physical examination of the dominant shoulder of overhead throwing athletes consistently shows changes on rotational range-of-motion (ROM), namely on external rotation (ER), when compared with non-athletes (Osbahr et al., 2002; Oyama et al., 2008). Most overhead athletes exhibit an obvious motion disparity, whereby ER is excessive and shoulder internal rotation (IR) is limited when measured at 90º of abduction (Crockett et al., 2002; Meister, 2000b; Pieper, 1998; Reagan et al., 2002). According to Seroyer et al. (2009) the total ROM in the dominant arm is preserved. Any gain of ER should be offset by a comparable decrease in IR, resulting in the same total rotational ROM.

An adequate scapular positioning is believed to be necessary for ideal muscle lengths, force production and assisting with glenohumeral joint stability (Borich et al., 2006; Burkhart et al., 2003a; J. B. Myers et al., 2005). Imbalances in scapular force couples action may result in scapular dyskinesis, glenohumeral translation or rotator cuff overload; scapular muscle actions allow proper positioning and stability of the scapula while maintaining the glenohumeral center of rotation throughout arm motion (McMullen & Uhl, 2000). Deviating patterns of ER or the inability to externally rotate the humerus sufficiently may change the scapular kinematics leading to several impairments such as, shoulder impingement, internal rotation deficit among others (Stokdijk et al., 2003).

A few studies (Borich et al., 2006; Oyama et al., 2008) reported asymmetries in the resting scapular position of overhead athletes when comparing the dominant with the non-dominant arm. At rest, the dominant scapula of overhead athletes is positioned more in scapular IR (protraction) and anterior tilt (Borich et al., 2006; Seroyer et al., 2009). It is believed that this anterior tilted position is positively related with the glenohumeral internal rotation deficit, found on most overhead athletes (Borich et al., 2006).

The loss of internal rotation of the throwing shoulder has been referred to as glenohumeral internal rotation deficit (GIRD). The posterior shift in the total arc of motion is considered to be a physiological adaptation of the shoulder joint to throwing. (Burkhart et al., 2003a, 2003b, 2003c) described glenohumeral internal rotation deficit as an alternative mechanism for primary progression of “internal impingement-like” changes in the shoulder. Additionally, it is also known that the injury mechanism on overhead athletes is mostly related to the throwing motion and the extreme ROM of ER (Borsa et al., 2006; Downar & Sauers, 2005).

However, little is known about the relative contribution of scapular position on the range of motion of shoulder external rotation. Changes in scapular position, both dynamic and static, play critical roles in pathologic processes of overhead athletes. Currently, the scapulothoracic motion’s to throwing is one of the least studied and understood entities in the overhead athlete. Thus, the purpose of this cross-sectional observational study was to determine the change in the relative contribution of the scapular motion at the end-range of active shoulder rotation (ER and IR), in throwing athletes compared with non-athletes. We hypothesized that at the end-range of shoulder axial rotation, athletes would present a different scapular motion than non-athletes. This would be more advantageous for the overhead athlete, allowing a more stable glenohumeral joint. The movement with the scapula participation could increase the displacement of the hand range of motion, with benefits to hit or spike the ball. This should be seen in athletes but not in non-athletes, if this is seen as an adaptation due to sports practice. This is important in athletes shoulder rehabilitation because, if it presents an adaptation, when restoring the function after an injury, it has to be preserved.

Materials and Methods

Participants

Twenty six male subjects were recruited from the community in a voluntary basis and were divided into two study groups. The athletes group was composed by 13 elite handball players (first division), (height = 1.86 ± 3 m; body mass = 84.08 ± 7.6 kg; age = 22.3 ± 3.1 years) and the non-athletes or control group with 13 subjects (height = 1.76 ± 5 m; body mass = 72.8 ± 7.2 kg; age = 26.6 ± 4.4 years). Data about each subject was collected and those with a previous history of shoulder surgery or traumatic injury (e.g. dislocation, subluxation) or elbow pain in the last 6 months and athletes with less than 6 years of high level of sports practice (training for at least 5 times a week) were excluded from the study. In addition participants with shoulder or elbow pain in the last 6 months and athletes with less than 6 years of high level of sports practice (training for at least 5 times a week) were excluded from the study.

Prior to the participation, the purpose of the study and the experimental protocol was explained and subjects signed an informed consent document according to the recommendations of the declaration of Helsinki. Ethical approval for the study was ratified by The Scientific Board of Human Kinetics Faculty – Technical University of Lisbon.

Procedures

Motion testing was performed with the Flock of Birds electromagnetic tracking sensors (Ascension Technology, Burlington, Vermont) and Motion Monitor software (Innovative Sports Training, Chicago, IL. Simultaneous tracking of 4 sensors occurred at a sampling rate of 100 Hz per sensor. The accuracy of our system is 1.8 mm for position and 0.15º for orientation. A four sensor setup was used: the thorax sensor firmly attached to the skin by a double-sided tape over T1; the arm sensor attached by means of a cuff just below the deltoid attachment; and the scapular sensor firmly adjusted on the superior flat surface of the acromion process. A 4th sensor mounted on a hand-held stylus (6.5cm) was used for bony landmark digitalization (see Chapter 3, Table 2), with the participants in a seated position and the arm artificially supported in an elevated position (90º), with the elbow flexed (90º) and the forearm perpendicular to the floor. The arm and forearm were strapped and connected to a square drive extension, mounted on a fixed wooden stand, which supported the weight of the arm. This digitization position was assumed as the initial position for axial rotation ROM assessment. Subjects were instructed to slowing reach the end-range of humeral external rotation followed by extreme internal rotation. On the basis of our digitization protocol, the zero point (0º) or neutral rotation was defined as the point when the subject´s forearm was perpendicular to the floor.

The digitized bony landmarks (see Chapter 3, Table 3) were then used to convert the sensor axes to anatomic axes or local coordinate system (LCS) on thorax, scapula and humerus segments, following the recommendations of the International Society of Biomechanics (ISB) (Wu et al., 2005). Using this procedure, sensors axes were linked to LCS and subsequently segment and joint rotations were calculated by combining the LCSs with tracking sensor motion.

Angular values, expressed in Euler angles, for the humeral motion relative to the thorax (thoracohumeral angles) and to the scapula (scapulohumeral angles) were determined using the ISB (Wu et al., 2005) recommended rotation sequences (y, x’, y’’): plane of arm elevation, arm elevation and axial rotation. Continuous data were recorded and filtered (Butterworth filter; cut-off = 10Hz) for the thoracohumeral and glenohumeral axial rotation. The end-range position of the humeral external and internal rotation was considered for further analysis.

Data Analysis

In this study the dependent variables were humeral and scapular positions of thoracohumeral, glenohumeral angles and protraction, tilt and lateral rotation. All variables were checked for normality (Shapiro & Wilk test) and found to meet criteria for parametric statistics. These were compared between groups using a t-test for independent samples. Effect size (ES) analysis and probability scores are reported. We used the qualitative assessment of ES where a small, medium or large change/difference is defined by an ES greater than 0.20, 0.50 or 0.80 respectively (Cohen, 1992).

Relationship between thoracohumeral angle and glenohumeral angle and scapular variables were also analyzed by means of bivariate correlations. The level of significance was set at 5% and statistical power at 95%. The Statistical Package for Social Sciences (SPSS) version 20 (Chicago, Illinois) was used to analyze data.

Results

The 3D scapular position and the axial rotational range of motion at the end-range of shoulder external and internal rotation are presented in Table 7 and Table 8, respectively. The thoracohumeral angles at the extreme range of motion of shoulder ER was significantly less on the athletes group. At the end-range of ER, athletes positioned their dominant scapula more in retraction and posterior tilt. In the athletes group a positive correlation ($r = 0.677$, $p<0.01$) was found between thoracohumeral angle and scapular spinal tilt. A negative correlation ($r = - 0.619$, $p = 0.001$) was found between scapular protraction and humeral axial rotation with respect to thorax.

Table 7: Scapular (protraction (+) | retraction (-); lateral rotation; anterior spinal tilt (-) | posterior spinal tilt (+) and humeral rotations (degrees) at the end-range of shoulder external rotation

	Scapular rotations						***Humeral rotations***			
	Protraction (Syt)		**Lateral Rotation (Sxt)**		**Spinal Tilt (Szt)**		**Axial rotation w.r.t. Thorax (HRt)**		**Axial rotation w.r.t. Scapula (HRs)**	
Group	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**
Mean	21,4(1.7)	33,4(4.3)	35,6(2.7)	39(2.8)	10,0(1.7)	5,8(2.6)	92,3(1.8)	113,4(2.0)	90,2(4.9)	104,1(8.3)
ES	-0,453		-0,166		0,260		-0,836		-0,272	
P	**<0.05**		0.14		**<0.05**		**<0.05**		0.16	

SEM: Standard Error of Mean; **ES:** Effect size; **w.r.t:** with respect to thorax; **Bold** values are significant (p<0.05)

Table 8: Scapular (protraction (+) | retraction (-); lateral rotation: anterior spinal tilt (-) | posterior spinal tilt (+) and humeral rotations (degrees) at the end-range of shoulder internal rotation.

	Scapular rotations						***Humeral rotations***			
	Protraction (Syt)		**Lateral Rotation (Sxt)**		**Spinal Tilt (Szt)**		**Axial rotation w.r.t. Thorax (HRt)**		**Axial rotation w.r.t. Scapula (HRs)**	
Group	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**Non-Athletes**	**Athletes**	**No-Athletes**
Mean	32,6(2.2)	48(1.5)	9,0(2.6)	12,5(2.0)	-15,5(1.9)	-2,9(0.9)	37,7(2.8)	10,2(3.6)	30,8(3.4)	28,7(4.8)
ES	-0,749		-0,205		-0.757		0,762		0,069	
P	**<0.05**		0.30		**<0.05**		**<0.05**		0.73	

SEM: Standard Error of Mean; **ES:** Effect size; **w.r.t:** with respect to thorax; **Bold** values are significant (p<0.05)

Concerning the extreme range of motion of shoulder IR, the athletes group showed significantly highest range of motion of thoracohumeral angles. At end-range of IR athletes, while compared with non-athletes, positioned their dominant scapula more in retraction and anterior tilt. Also in internal rotation a negative correlation between lateral rotation of the scapula and thoracohumeral angles (r = -0.499, p = 0.009) was found. This means that for higher values of thoracohumeral angles less lateral scapular rotation is found. A negative correlation between spinal tilt and thoracohumeral angle (r = -0.467, p = 0.016) was also observed, which means that for higher values of thoracohumeral angles less spinal tilt were found.

Discussion

Shoulder external rotation

During overhead activities, the shoulder, besides having an adequate rotation must also have a synchronized motion between humerus, scapula, clavicle and thorax to a proper function (P. M. Ludewig, Cook, & Nawoczenski, 1996; Tokish et al., 2008). In our study, and concerning, ER ROM, athletes showed less thoracohumeral range-of-motion than non-overhead athletes. As found in literature (Braun et al., 2009; Wilk et al., 2011) athletes tend to develop chronic adaptations which contribute to, or have their origins in the throwing motion. It is hard to conclude if these adaptations are related to a better performance or injury prevention or even if they are responsible for inducing shoulder impairment. In this study, athletes did not show the external rotation increase found in literature (Tokish et al., 2008; Torres & Gomes, 2009; Wilk et al., 2011) but an external rotation decrease. It is important to notice that these measurements were taken under active condition instead of the usual measurement based on passive condition.

The results in external rotation showed also that throwers demonstrated a scapula more in retraction (acromion backwards) when compared with non-throwers. According to literature (Paula M. Ludewig & Reynolds, 2009; Lukasiewicz et al., 1999; J. B. Myers et al., 2005), this seems to be protective for the glenohumeral joint. In fact, the inability to retract the scapula, appears to impart several negative biomechanical effects on shoulder, including a narrow subacromial space, increased strain on the anterior-inferior glenohumeral ligament, reduced impingement-free arc of upper limb elevation, reduced isometric elevation strength tested in the sagittal plane (Braun et al., 2009). Concerning this, throwers on our study seem to have developed an adaptation towards stability (Borich et al., 2006; Forthomme et al., 2008; Lukasiewicz et al., 1999).

During the throwing cycle it is supposed that athletes, such as team handball, keep their scapula stable while the arm is fastly moved from a full external position to a full internal position. Scapular stabilization could be challenged when the arm motion is too fast. Therefore, an inadequate scapular position at the end-range of glenohumeral motion will lead to shoulder dysfunction and pathology (Werner et al., 2006), such as impingement or dyskinesis.

Excessive motion is required at the shoulder joint during throwing, yet the glenohumeral joint must remain stable to avoid injury. We found that the athletes group showed a more posterior tilted scapula when arm is positioned at the end-range of shoulder external rotation, while the control group showed an anterior tilted scapula. This seems to demonstrate that shoulder adaptation on athletes, while throwing, does not occur only at the glenohumeral joint, as it is evaluated in sports clinical trial. It is supported by the trunk, where a scapula in retraction and posterior tilt, gives the necessary stability to achieve best performance (Boon & Smith, 2000). This is probably the reason why scapular position relative to humerus and trunk, is so relevant for muscle function. The scapula acts as the common point of attachment of the rotator cuff and primary humeral movers such as the biceps, deltoid and triceps, as well as several scapular stabilizers. Poor position of the scapula can lead to alterations to the relationship between length and tension of each muscle, thus adversely affecting muscle force generation (J. B. Myers et al., 2005). An imbalance in shoulder external rotators will lead to alterations in scapular tilt (P.M. Ludewig & Cook, 2000; Lukasiewicz et al., 1999).

Concerning the movement origin, clinical trials use passive or active motion. Active motion used is usually a slow motion (McCully et al., 2005), and not simulating the sports practice. Our study used active motion protocol. Although the calibration positioning used was the same proposed by the ISB (Wu et al., 2005) protocol (arm at a side), the testing position was with the arm in an elevated position. The main reason to find more external rotation at non-athletes is possibly the fact that we were evaluating active motion and not passive one (McConnell et al., 2012).

There was positive correlation seen in the athletes group between the thoracohumeral angles and scapular spinal tilt rotation at the extreme position of shoulder external rotation. This seems to show that the posterior scapular tilt follows the raise of the thoracohumeral angle, demonstrating advantages not only towards stability of the shoulder girdle but also for the force-length relationship of the scapulohumeral muscles (Borsa, Timmons, & Sauers, 2003). Concerning this, overhead athletes in our study seem to have developed an adaptation towards stability.

Shoulder internal rotation

At the extreme of shoulder internal rotation, athletes demonstrated a scapula and a humerus that behave as a block when they spin around the diaphysis. The range of motion of shoulder axial rotation of the humerus, with respect to the scapula, does not show differences when comparing athletes group and non-athletes. In the athletes group the thoracohumeral IR ROM was higher. No differences were found in glenohumeral angle. So, higher values of IR range of motion seen in athletes seem to be due to an evident scapular contribution. In a more detailed analysis, considering the eventual contribution of the shoulder girdle (in the range of motion of IR), athletes seemed to show a scapula in retraction and anterior tilt. Looking for scapular positioning some authors (Borich et al., 2006) found that there is a relationship between glenohumeral internal rotation deficit and abnormal scapular positioning, particularly increased anterior tilt. Also Myers et al (2005) showed in a study with 21 overhead athletes, that at the scapular plane these athletes presented a scapula in upward rotation, protraction and anterior tilt. This protraction pattern accentuates impingement; the situation can be increased with the arm in IR (Borich et al., 2006; P. M. Ludewig et al., 1996; Paula M. Ludewig & Reynolds, 2009).

In our study, differences found in the shoulder girdle seem to reveal an eventual shoulder adaptation in overhead athletes (team handball). In these athletes shoulder axial rotation is followed by scapular retraction. This positioning seems to have advantages to glenohumeral joint stability, particularly at the ER end-range. In IR the scapular positioning in retraction and anterior spinal tilt amplifies the shoulder axial rotation motion. This seems why overhead athletes keep stability, achieving more range of motion on behalf of the scapula, without losing stability (Borich et al., 2006; J. B. Myers et al., 2005; Oyama et al., 2008).

As mentioned before, and when considering shoulder joint adaptations seen in literature concerning internal rotation (Dwelly et al., 2009; Torres & Gomes, 2009), we cannot be sure they are exactly towards less internal rotation. These studies use goniometry where the scapula is fixed not allowing the subject to complete the total range of motion (Boon & Smith, 2000). As seen previously, scapular contribution is crucial for a complete motion. Blocking the scapular movement will affect total ROM. If the scapular movement is blocked, the total range of motion will be affected. This is why, knowledge of joint ROM and speeds of movement along with joint forces and moments will provide a scientific basis for improved and rehabilitative protocols for throwers.

Conclusions

Concerning shoulder external rotation the athletes group showed less thoracohumeral range-of-motion than non-overhead athletes. Athletes also presented a scapula in retraction and posterior tilt. Considering internal rotation, athletes group demonstrated higher thoracohumeral range of motion, when compared with non-athletes, but no differences were found in scapulohumeral range-of-motion, which means that higher values of internal rotation seen in athletes seem to be due to an evident scapular contribution. Also in internal rotation, athletes seemed to show a scapula in retraction and anterior tilt. This scapular position amplifies the shoulder axial rotation motion, (Borich et al., 2006) and could be the reason why overhead athletes seem to keep stability, achieving more range of motion.

Taking into account these results, differences found in athletes (team handball) concerning shoulder girdle behavior seem to reveal an eventual shoulder adaptation.

Current study provides clinicians with an understanding of the effects of sport related adaptations on healthy athletes throwing shoulder. A specific scapular positioning seems to be related to sports practice and also protective to the throwing shoulder, which is a fundamental outcome to the throwers evaluation at clinic.

As a limitation of this study we would include possible skin artifacts, especially at the arm sensor. To avoid this situation a sensor mounted on a tiny cuff adjusted to the arm just below the deltoid attachment was used, trying to ensure the sensor position towards the skin.

Resting Scapular Posture in Healthy Overhead Throwing Athletes

Andrea Ribeiro & Augusto Gil Pascoal

Abstract

Clinical trials often observe the asymmetry in scapular posture, and these asymmetries are often associated with abnormalities. However these asymmetries may be a shoulder adaptation to sports practice due to the overuse of the dominant limb.

The purpose of the study was to quantify the differences in resting scapular posture between dominant and non-dominant sides in 3 groups of healthy subjects (volleyball players, team-handball players and a control group). Quantify also differences between athletes and non-athletes using an electromagnetic tracking device.

Bilateral 3D scapular kinematics with the arm at rest was measured using an electromagnetic tracking device.

In handball athletes, the scapula was more in internal rotation and anteriorly tilted than in volleyball players, in the dominant side. Scapula was more anteriorly tilted in athletes than non-athletes, also in the dominant side.

Clinicians must recognize that some degree of scapular asymmetry could be found, at resting position, and it should not be considered like a pathological sign, instead an adaptation due to sports practice and upper limb arm overuse.

Introduction

While undergoing a clinical trial, scapular position and orientation are one of the most important components (Kibler, 1998; Uhl et al., 2009) of this trial. Alterations in scapular motion have been found in athletes (Ellenbecker et al., 1996; Torres & Gomes, 2009; Wilk et al., 2011). These alterations have been thought to affect normal scapulohumeral rhythm and shoulder artrokinematics leading to several kinds of impairments (Burkhart et al., 2003a; Uhl et al., 2009). It is still not clear how much these scapular postural asymmetries may be related with abnormalities (Burkhart et al., 2003a, 2003b; Meister, 2000b) or it should be considered as a sport adaptation.

Devices used, such as digital inclinometer and tape measure have been used to quantify scapular posture asymmetry in patients with abnormalities (Downar & Sauers, 2005). But these devices inly give a two dimensional image of scapular motion. A 3D image would be important to understand scapular position and orientation. This could help researchers to identify the behavior of specific scapular kinematic variables that could contribute to scapular posture asymmetries.

So, it would be important to describe and characterize scapular posture 3-dimensionally in subjects without pathology and also in athletes. Electromagnetic tracking devices allow calculation of 3D scapular positions and orientations (Wu et al., 2005).

The purpose of our study was to quantify the resting scapular posture in 3 groups of healthy subjects. Two groups of overhead athletes (volleyball players and team-handball players), and a third group composed by non-athletes, by using an electromagnetic tracking device and to determine whether these groups of overhead athletes displayed asymmetry in resting scapular posture. We hypothesized that the asymmetry would be present in all 2 groups of healthy overhead athletes from the repetitive use of the dominant shoulder. Identifying scapular asymmetry in healthy overhead athletes is important because it provides a basis for comparison with injured overhead athletes.

Materials and Methods

Participants

Fifteen volleyball players (27.6± 1.6 years, 189.4 ± 2.7 cm, 24.3 ± 0.5 kg/m2; 15 right-hand dominant), 15 competitive team-handball players (23.8 ± 0.8 years, 185.8 ± 1.5 cm, 25.4 ± 0.5 kg/m2; all right hand dominant), and 30 non-athletes (29.6± 1.1 years, 178.1 ± 1.2 cm, 25.0 ± 0.7 kg/m2; 30 right-hand dominant) participated in this study. The dominant limb was identified as the arm that would be used to throw a ball or to wright. Only men were recruited for this study to control for possible sex differences. Those with a previous history of shoulder surgery or traumatic injury (dislocation, subluxation, or acromioclavicular joint sprain) were excluded from this study. Participants with shoulder or elbow pain within 6 months of testing also were excluded from the study.

Instrumentation

We used the Motion Monitor electromagnetic tracking device (Innovative Sports Training, Inc., Chicago, IL) to assess 3-dimentional scapular resting position. The device consists of a transmitter that creates an electromagnetic field and receivers that detect the electromagnetic field emitted by the transmitter. The receivers were attached to specific body segments as described in the previous literature. The electromagnetic tracking device recorded the position and orientation of the receivers about the x-axis, y-axis, and z-axis relative to the transmitter (global coordinate system). By digitizing the anatomical landmarks with a stylus, the orientation of one body segment was calculated with respect to another. The data were collected at 100 Hz. All kinematic assessments were performed with the participants in a seated position with their arms along the body.

Procedures

All testing in the current study was performed in a biomechanics research laboratory. The purposes of the study and the technique of examination were explained to the participants, and those who agreed to participate signed a free informed consent form. This study was approved by the Scientific Board of the Faculty of Human Kinetics, Technical University of Lisbon (Portugal). None of the athletes who met the inclusion criteria declined to participate.

We used 5 receivers for bilateral scapular resting position assessment, attached as follows: the spinous process of the seventh cervical vertebra, the flat portion of the acromion processes bilaterally, and the midshaft of the posterior dominant humerus. All receivers were secured on the skin using double-sided adhesive disks, prewrap, athletic tape, and a hook-and-loop strap to minimize skin-receiver movement. The fifth receiver was attached to the stylus that was used to palpate and digitize the anatomical landmarks on the upper arm, scapula, and thorax. The anatomical landmarks digitized included the eighth thoracic vertebra, xiphoid process, seventh cervical vertebrae, jugular notch, sternoclavicular joint, acromioclavicular joint, medial scapular border where it intersects with the scapular spine, inferior scapular angle, medial epicondyle, lateral epicondyle, and glenohumeral joint center. Landmarks on the humerus and the scapula were digitized bilaterally. Because the glenohumeral joint center cannot be palpated, it was estimated as the point that moves least with respect to the scapula when the humerus is moved passively through several short arcs. Digitizing these anatomical landmarks on each segment allowed construction of the local coordinate system for each body segment (thorax, scapula, and humerus). Using local coordinate systems, position and orientation of the scapula with respect to the thorax were calculated. Each participant performed 3 continuous repetitions of bilateral full-shoulder elevation in the scapular plane (45º anterior to the frontal plane). The volunteer elevated the arm in 3 seconds and lowered the arm in 3 seconds, guided by the metronome. The participants were instructed to bring their arms to rest by their sides at the end of each repetition. This procedure allowed the volunteers to be distracted from the postural assessment, which may have helped to capture their natural posture. Bilateral resting scapular posture was measured as the scapular position and orientation when the arms were at the sides between the 3 repetitions of the elevation task. The averages of the 3 recordings for both limbs were used for analysis.

Data Reduction

Raw scapular kinematic data were filtered with a low-pass, 10-Hz Butterworth filter. The position and orientation data of the receivers and the digitized anatomical landmarks were used to construct local coordinate systems for the thorax, scapula, and humerus. The coordinate systems used were in accordance with recommendations from the International Shoulder Group of the International Society of Biomechanics (Wu et al., 2005). When the participant stood in an anatomical position, the coordinate system for each segment was vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis).

Scapular orientation was determined as rotation about the y-axis of the scapula (internal-external rotation), rotation about the z-axis of the scapula (upward-downward rotation), and rotation about the x-axis of the scapula (anterior-posterior tilt). Euler angle decompositions were used to determine scapular and humeral orientation with respect to the thorax. The rotation sequence of the Euler angles was chosen based on the recommendation of the International Shoulder Group (Wu et al., 2005).

Data Analysis

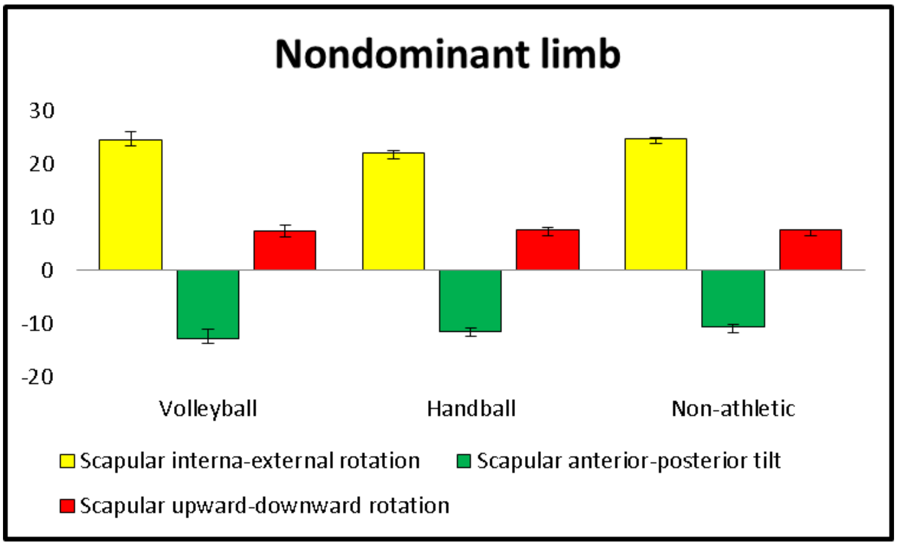
Between-limbs and between-groups differences in each variable (upward-downward rotation, internal-external rotation, anterior-posterior tilt, protraction-retraction, and elevation-depression) were analyzed using separate within-subjects, between-subjects factor analyses of variance. Tukey HSD post hoc analysis was conducted when the interaction was significant. Statistical analysis was performed using SPSS (version 20; SPSS Inc., Chicago, IL). The level of significance was set a priori at .05.

Results

Comparing athletes and non-athletic group differences were found in scapular anterior posterior tilt concerning dominant limb (P=0.002) and non-dominant limb (P=0.04).

Three-dimensional scapular position assessment demonstrated limb-by-group interaction for protraction-retraction (P<0.001), for scapular anterior-posterior tilt (P=0.04) and scapular upward-downward rotation (p<0.01). The post hoc analysis showed a difference between volleyball and handball groups concerning scapular internal-external rotation (P=0.043). Concerning scapular anterior-posterior tilt differences were found between volleyball and control group (P=0.031) and between handball and control group (P=0.029) (Figure 16).

The post hoc analysis showed a difference between dominant and non-dominant shoulders in volleyball players (P=0.04) concerning scapular anterior-posterior tilt and also for scapular upward-downward rotation (P<0.001). In the handball group differences between dominant and non-dominant limb were found for scapular upward-downward rotation (P<0.001) and scapular internal-external rotation (P<0.001). For the control group differences between dominant and non-dominant limb were found for all scapular variables studied (P<0.001).



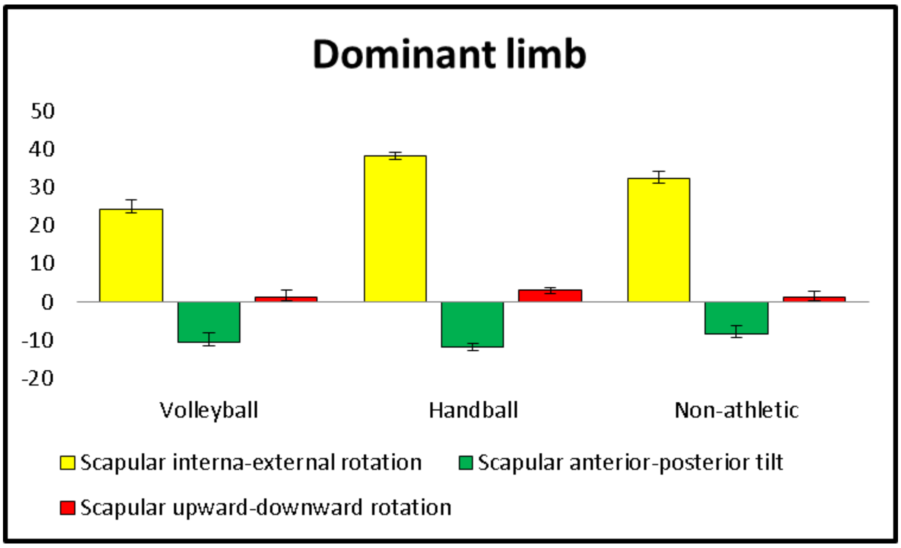


Figure 16: Mean (SEM) for scapular internal-external rotation; Scapular posterior tilt and scapular upward-downward rotation for dominant and non-dominant limbs

Discussion

Our goal was to quantify resting scapular posture in 3 groups of healthy subjects; volleyball players, team-handball players and non-athletes. Indeed, we found resting scapular posture asymmetry between dominant and non-dominant sides in healthy overhead athletes. The dominant shoulder of team-handball players was more anteriorly tilted and internally rotated than volleyball players or even than non-athletic group.

Because the demands placed on shoulders of volleyball or team-handball players are different, we expected to see differences in scapular posture among groups. Increased moment of inertia of the upper extremity from holding a ball may result in greater stress at the shoulder, for the team-handball group.

All athletes who participated in this study were asymptomatic, the presence of this postural asymmetry may be normal in the population of overhead athletes. Therefore our results confirm that during clinical trial the assumption, which symmetry will be found, could induce reasoning problems. In fact, clinician should be aware, that this asymmetry may exist and it is not necessarily a problem.

Borich *et al* (2006) reported a significant relationship between glenohumeral internal rotation deficit and abnormal scapular positioning, particularly anterior tilt. Also Burkhart *et al* (2003b) reported that injured overhead athletes typically present with asymmetrically shoulder on the affected side, caused by increased scapular protraction, anterior tilting and internal rotation. This could lead to a conclusion that this asymmetry is associated with pathology. However like in our study, also Oyama *et al* (2008) found a scapula more internally rotated and anteriorly tilted, in a study with 43 athletes (15 baseball pitchers, 15 volleyball players and 13 tennis players). These results suggest that asymmetry found may not be related to abnormality, and there should be a threshold for scapular asymmetry at which this becomes a problem.

In fact, we compared athletes with non-athletes while other studies compared only athletes or even injured subjects (Borich et al., 2006; Joseph B. Myers et al., 2006; Oyama et al., 2008). Furthermore, results seem to indicate, that probably athletes develop some kind of sports adaptation. Considering the asymmetric characteristics of overhead throwing athlete´s shoulders, such as humeral retroversion (Pieper, 1998; Reagan et al., 2002; Ribeiro & Pascoal, 2012; Tokish et al., 2008; Yamamoto et al., 2006), range of motion (Torres & Gomes, 2009; Wilk et al., 2011) among others, asymmetry at resting position seems to be expected.

Despite differences found, non-athletic group demonstrated a similar scapular orientation (also internally rotated and anteriorly tilted), this could be due to hand dominance, and if so, this is not unique to overhead throwing athletes. How much these asymmetries are due to sports is not understood yet, so athletes and non-athletes should be further analyzed. Clinicians must recognize that some degree of scapular asymmetry could be found, at resting position, and it should not be considered like a pathological sign, instead an adaptation due to sports practice and upper arm overuse.

CHAPTER 7 - GENERAL DISCUSSION

Overview

Overhead-throwing activities seem to develop a variety of adaptations within and around the tissues of the dominant throwing shoulder. These changes result from the extreme physiological demands of the overhead-throwing activity, which are sport-related and configure an unique pattern on the dominant overhead-throwing shoulder, the **overhead throwing shoulder adaptive pattern** (OTSAP). The OTSAP represents the shoulder attempt to maintain balance and the necessary stability for the throwing motion. This adaptive pattern comprises osseous adaptations on humerus and scapula, soft-tissues adaptations on glenohumeral capsuloligamentous structures, and functional adaptations on glenohumeral and scapulothoracic joints.

In literature most of the studies about this OTSAP are concerned with the dominant shoulder of baseball players while comparing with non-dominant shoulder (Crockett et al., 2002; Reagan et al., 2002; Tokish et al., 2008). This thesis explored the assumption that overhead-throwing activities involved in volleyball and team-handball could induce sport-related adaptations similar to those described in baseball players. Another concern was the physiotherapy examination of the overhead-throwing athlete. This has become somewhat of a lost art because of the difficulty of the examination itself. In fact, comparing the dominant side with the opposite side of these athletes is not always reliable due to the above mentioned adaptations.

In Chapter 4 a study is presented about a specific sports osseous adaptation in the dominant humerus of volleyball and team-handball players, expressed by an augmented humeral retroversion angle (HRA). Additionally, the study also address to the relationship between the augmented HRA and augmented shoulder external rotation ROM, the external rotation gain (ERG). Previous side-to-side studies were able to demonstrate the presence of a certain degree of osseous adaptations on the dominant shoulder of baseball players (Crockett et al., 2002; Reagan et al., 2002), team-handball players (Pieper, 1998) when compared with the non-dominant shoulder. However, lack information exists in literature concerning osseous adaptation on volleyball players or even baseball or team-handball players about the characterization of changes in the dominant shoulder by comparison with a non-athletic population.

The study presented in Chapter 4 compares the dominant shoulder of an athletic population (volleyball and team-handball player) with the dominant shoulder of a non-athletic population with respect to the HRA and the rotational pattern. The results showed an increased HRA in the dominant throwing shoulder of volleyball and team-handball players (athletes = 31.7º ± 4.9º; vs. non-athletes = 23.4º ± 4.6º). These results are consistent with previous side-to-side studies in volleyball (Schwab & Blanch, 2009) and team-handball (Pieper, 1998) players. In fact, Schwab *et al.* (2009) found an increase of 9.6º for the HRA of the dominant arm of volleyball players when compared with the non-dominant arm. In our study, the dominant arm of the volleyball players showed an HRA increase of 9.2º when compared with the non-athlete´s dominant shoulder. Concerning team-handball, the previous side-to-side comparisons of Pieper´s (1998) work demonstrated an increased HRA of 9.4º for the dominant arm compared with the non-dominant arm. In our study, the dominant arm of team-handball players showed an HRA increase of 7.4º when compared with the dominant arm of non-athletes. Thus, a pattern of increased humeral retroversion can be expected in the dominant arm of overhead throwing athletes. Furthermore, the magnitude of the found increase is similar for side-to-side comparisons while in this study we performed athlete vs. non-athlete. According to the literature, athletes who do not develop this kind of adaptations seem to have more strain on their anterior capsules at less external rotation and may develop chronic shoulder pain because of anterior instability (Pieper, 1998; Reagan et al., 2002; Schwab & Blanch, 2009).

We expected to find differences between volleyball and team-handball players concerning humeral retroversion. These sports have different sports gestures, for example, volleyball does not have to exactly throw the ball as it happens with team-handball, which has a permanent extra mass (ball), and due to this requires greater deceleration. So, relative tension exerted by the internal and external rotator muscles on the proximal humeral epiphysis seems to be different in the dominant shoulder of volleyball and team-handball players. Our investigation failed to find a positive correlation between HRA and age commenced training, so we assume that the effect of age commenced training on HRA could be stronger in baseball for example (Chant et al., 2007; Ellenbecker et al., 2002). On the other hand, a positive correlation between HRA and sports index was found. This is in accordance with many studies which say that sports practice would induce more HRA (Pieper, 1998; Reagan et al., 2002; Schwab & Blanch, 2009) in athletes. Results also showed a positive correlation between humeral retroversion angle and sports practice in accordance to scientific knowledge which says that sports practice would induce more HRA. This augmented HRA seems to have increased the available external rotation ROM as long as a positive correlation between HRA and TH angles in the athletic group was found.

The athletes' who participated in our studies also presented an increase in external rotation when compared to the non-athletic group. According to several studies (Meister et al., 2005; Tokish et al., 2008), this increase in external rotation seems to be related to overhead sports practice. In fact, it was advocated (Crockett et al., 2002; Ellenbecker et al., 1996; Reagan et al., 2002) that the augmented retroversion angle could increase the available external rotation ROM reducing the ability of the rotator cuff to control high forces or velocities through the extremes of shoulder ROM. This could lead to excessive humeral head translation and culminate in shoulder pain (Ellenbecker et al., 2002). Unilateral changes in the glenohumeral joint range of motion of throwing athletes are well documented in the literature (Schwab & Blanch, 2009; Tokish et al., 2008; Torres & Gomes, 2009). For the volley ball group no correlations were found were found with range of motion. In opposition, for the team-handball group positive correlations were found between humeral retroversion and thoracohumeral angles, and also between humeral retroversion and scapulohumeral angles. Once more, differences between forces and motions between these sports and already mentioned, could be in the basis of this difference.

The experimental protocol for this study (Chapter 4), regarding kinematic measurements athletes were in a seated position while performing active motion. However, physical examination of the overhead athlete shoulder is usually performed passively in a lying position (Dwelly et al., 2009; Ellenbecker et al., 1996). Often the increased external rotation found in the dominant shoulder, tested in this condition, is used as an indicator of shoulder dysfunction and/or risk factor to injury, assuming that static ROM measurements are representative of the dynamic ROM during throwing (McConnell et al., 2012).

Additionally, a goniometric protocol is used with patient in a supine position with the scapula stabilized. From a biomechanical perspective, these measurements have three key limitations: 1) the end-range is determined by clinical end-feel, as opposed to an objective assessment of torque; 2) goniometers may be designed and used to assess glenohumeral motion but they are really measuring both glenohumeral and scapulothoracic motion; and 3) the effect of the plane of motion has not been well documented (McCully et al., 2005).This fact raised some methodological issues: 1) which should be the subject position during shoulder ROM examination, seated or supine; 2) shoulder ROM end-range should be tested actively or passively? Indeed in Chapter 4, athletes performed the shoulder motion in a seated position, but should this be the correct position to evaluate shoulder?

On Chapter 5 two studies are presented aiming to clarify the above mentioned methodological issues. Studies are presented about changes on the rotational pattern in the dominant shoulder of volleyball and team-handball players and glenohumeral end-range determination. One of the studies explores the influence of subject test-position on end-range determination. In supine condition the goniometry protocol was exactly the same followed by physiotherapists during shoulder assessment. In this protocol one physiotherapist positioned the arm, and a second therapist measured and recorded the angle without informing the positioning therapist. The first therapist moved the arm through the full range of external rotation. The end point for passive motion was determined by the positioning therapist, both by patient comfort and by capsular end-feel (Boon & Smith, 2000). The other study presented in Chapter 5 explores the effect of the active vs. passive end-range determination on the recorded amplitude of glenohumeral rotational ROM.

Newsworthy is to see that in both groups (athletes and non-athletes) similar scapular behavior under different conditions (seated vs. supine, active vs. passive) were found. Also highest values of shoulder external rotation were found under passive and supine conditions for both groups. Nevertheless, it is important to add that in these trials athletes (while in a seated position) were not able to perform the whole kinetic chain. These subjects are accustomed to use feet, legs, trunk, shoulder, elbow and hand during the throwing motion which was not allowed in this task. This could explain the fact that athletes could not achieve higher values of external rotation, as we expected. If during the physical examination, motion is measured passively and in a supine position, scapular contribution seems to be neglected during it. An adequate scapular positioning is believed to be necessary for ideal muscle lengths, force production and assisting with glenohumeral joint stability (Borich et al., 2006; Burkhart et al., 2003b; J. B. Myers et al., 2005). Imbalances in scapular force couples action may result in scapular dyskinesis, glenohumeral translation or rotator cuff overload; scapular muscle actions allow proper positioning and stability of the scapula while maintaining the glenohumeral center of rotation throughout arm motion (McMullen & Uhl, 2000).

However, little is known about the relative contribution of scapular position on the range of motion of shoulder external rotation. Changes in scapular position, both dynamic and static, play critical roles in pathologic processes of overhead athletes. Currently, the scapulothoracic motion’s to throwing is one of the least studied and understood entities in the overhead athlete.

Chapter 6 intended to clarify these doubts and lack of knowledge. Athletes demonstrated a different scapular behavior during axial rotation. Indeed, they presented a scapula more in retraction and posterior tilt when compared with a non-athletic population. In a more detailed analysis results seem to suggest that at the end-range of shoulder external rotation athletes presented a scapula in retraction during active motion. Likewise, scapula was positioned in posterior tilt in athletes group, while in non-athletes it was in anterior tilt.

Regarding shoulder internal rotation, athletes showed a scapula in retraction and anterior tilt. The positive correlation found between thoracohumeral angles and scapular spinal tilt at extreme position of shoulder external rotation, seems to demonstrate that the posterior scapular tilt follows the increase of thoracohumeral angle indicating advantages towards stability of shoulder girdle but also for the force-length relationship of the scapulohumeral muscles (Borsa et al., 2008). Scapular positioning appears to be related to sports practice and also protective to the throwing shoulder. This is a fundamental outcome to the overhead throwing athlete evaluation at clinic and adds important information for characterization of OTSAP.

As mentioned before, while undergoing a clinical trial, scapular position and orientation is one of the most important components (Kibler, 1998; Uhl et al., 2009) of this trial. Alterations in scapular motion have been found in athletes (Ellenbecker et al., 1996; Torres & Gomes, 2009; Wilk et al., 2011). These alterations have been thought to affect normal scapulohumeral rhythm and shoulder artrokinematics leading to several kinds of impairments (Burkhart et al., 2003b; Uhl et al., 2009). It is still not clear how much these scapular postural asymmetries may be related with abnormalities (Burkhart et al., 2003b, 2003c; Meister, 2000b) or it should be considered as a sport adaptation.

In study entitled "*Resting Scapular Posture in Healthy Overhead Athletes*" we compared asymptomatic athletes and non-athletes. Results indicate a scapula protracted and anteriorly tilted, in the athletes group (concerning resting position). These results suggest that asymmetry found may not be related to abnormality, and there should be a threshold for scapular asymmetry at which this becomes a problem. In fact, we compared athletes with non-athletes while other studies compared only athletes or even injured subjects (Borich et al., 2006; Joseph B. Myers et al., 2006; Oyama et al., 2008). Furthermore, results seem to indicate, that probably athletes develop some kind of sports adaptation due to the overhead-throwing motion. Considering the asymmetric characteristics of overhead throwing athlete´s shoulders, such as humeral retroversion (Pieper, 1998; Reagan et al., 2002; Ribeiro & Pascoal, 2012; Tokish et al., 2008; Yamamoto et al., 2006), range of motion (Torres & Gomes, 2009; Wilk et al., 2011) among others, asymmetry at resting position seems to be expected. These changes should not be considered like a pathological sign, instead an adaptation due to sports practice and upper arm overuse.

Main research findings

The studies included in this thesis were able to identify an unique adaptive pattern, the overhead-throwing shoulder adaptive pattern (OTSAP), on the dominant shoulder of volleyball and team-handball players. This pattern was characterized in comparison with a non-athletic population and includes an augmented humeral retroversion angle (structural adaptation) and changes on the glenohumeral rotational amplitude, expressed by an external rotation gain (functional adaptations). These adaptations are similar to those described on other overhead-throwing sports (e.g. baseball) but some components of this adaptive pattern include changes that are related with the specificity of sport activity, i.e. they are sport-related. The OTSAP characterization was extended in this thesis to the scapulothoracic joint with studies about scapular contribution on glenohumeral rotational pattern and asymmetry on scapula's resting position. A few studies in literature analyze this issue, and all of them about baseball players (Borich et al., 2006). The results of our studies revealed that in external rotation, athletes showed a scapula which is positioned in retraction and posterior tilt. It seemed to demonstrate that the posterior scapular tilt followed the increase of thoracohumeral angle indicating advantages towards stability of shoulder girdle but also for the force-length relationship of the scapulohumeral muscles (Borsa et al., 2008). Concerning resting position athletes demonstrated a scapula protracted and anteriorly tilted, in the athletes group. These results suggest that asymmetry found may not be related to abnormality, and there should be a threshold for scapular asymmetry at which this becomes a problem. In fact, we compared athletes with non-athletes while other studies compared only athletes or even injured subjects (Borich et al., 2006; J. B. Myers et al., 2005; Oyama et al., 2008). Thus, according with our results, volleyball and team-handball athletes, despite being considered overhead-throwing athletes, develop different adaptive patterns, even when compared with baseball players. Indubitably these are sport-related changes, and should be considered in shoulder examination by physiotherapists or other clinicians. Physiotherapists should also take into account, that active motion and seated position should be used during the clinical trial. These positions allow for scapular intervention during the shoulder motion, which meets the movement performed during the sports gesture. Physiotherapists must recognize also that some degree of scapular asymmetry could be found at resting position, in addition a specific scapular and humeral positioning during throwing motion seems to be present. The overhead throwing adaptation pattern should be considered by the physiotherapist and the adaptations comprised in it should be seen due to sports practice and upper arm overuse.

Implications and future directions

Further investigation is needed to completely characterize this **overhead throwing shoulder adaptive pattern** in order to develop a shoulder functional evaluation protocol as accurate as possible for these athletes. It is also important to understand which differences occur between the so called overhead throwing sports, and how specific the physical examination should be.

Humeral retroversion has to be further analyzed in volleyball and handball players. This could be done using ultrasound, which would allow a large sample and more accurate conclusions about this theme, and how this humeral retroversion angle interferes with external rotation range-of-motion. Whitley et al (2010; 2006) measured humeral retroversion, in shoulders of baseball players, bilaterally using ultrasound. The method involves placing the subject supine with the arm abducted to 90º and elbow flexed at 90º. With the assistance of diagnostic ultrasound the examiner visualizes the bicipital groove at the point where the adjacent greater and lesser tubercules are of maximum and equal height and rotates the arm until this point is uppermost. The inclination of the forearm is then measured with an inclinometer placed against the distal ulna (R. Whiteley et al., 2010; R. Whiteley et al., 2006).

Internal rotation should also be considered in the overhead throwing shoulder pattern adaptation. First an accurate strategy to collect these data has to be developed, in order to avoid skin artifacts. After that would be important to evaluate total axial rotation range of motion in these athletes to understand if they also present a glenohumeral internal rotation deficit, or if their total range-of-motion is different from other athletes (bigger) or even different from non-athletes.

Scapula should not be neglected, understand its behavior in volleyball and handball athletes is important and also clarify scapular dyskinesis in these athletes, and how much this could be considered an adaptation or a pathology. This could be done, comparing arm elevation of volleyball and team-handball athletes with a non-athletic population. At same time, cross these data with scapular resting position of the above mentioned three groups.

Limitations

Some limitations were identified in our study: 1) possible skin artifacts due to the humerus sensor; 2) the subject position used for kinematic data collection; 3) accuracy of X-Ray measurements; 4) lack of data concerning shoulder internal rotation.

Some procedures were followed in order to reduce these limitations.

Possible skin artifacts exist related with arm sensor location, as a result of slippage between the sensor and the skin and/or muscular contraction. To avoid these artifacts the sensor was mounted on a cuff, tiny adjusted to the arm, below the deltoid attachment and close to the epicondyles. In addition, the location of the cuff was at a comfortable distance from the muscle arm movers, limiting muscle contraction artifacts. Recent data showed that these skin artifacts persist on shoulder axial rotation recordings, even when a tiny cuff is used (Hamming, Braman, Phadke, LaPrade, & Ludewig, 2012). However, those skin artifacts are bigger for shoulder internal rotation than for external rotation.

Another limitation concerned with the subject position to acquire kinematic data. A seated position enables us to standardize the throwing technique. Although may have not represented how the athletes use their whole body during the throwing motion. In this position the whole kinetic chain was not available (lower limbs were eliminated) so the testing protocol may have altered external rotation ROM and scapular motion required at the shoulder. Another advantage on seated position is the fact that gravity does not influence arm movement, while in supine position the overarm is completely outside of the table, where gravity acts towards external rotation.

Another limitation refers to X-Ray recordings. Radiation exposure limits the number of subjects and trials reducing the option for a side-to-side study about the HRA. The future use of ultrasound, similar as used by (R. Whiteley et al., 2010; R. Whiteley et al., 2006), could be a possible solution for this limitation.

Despite shoulder internal rotation being considered an important component on the throwing mechanism, the main reason to explain why the present study was focused on external rotation range-of-motion was strictly methodological and refers to the use of an electromagnetic sensor on the scapula (scapula’s sensor), located on the superior flat surface of the acromion. This sensor’s physical location reduces the examiner’s ability to manually constrain scapular motion. In fact, during shoulder internal rotation the acromion and clavicle move anteriorly and require an additional examiner to keep the posterior aspect of the scapula in contact with the table, inducing artifacts on the scapula’s sensor recordings. During shoulder external rotation, this is not the case as the examiner´s attention is more directed towards monitoring scapular motion, instead of an effective scapular motion restriction. As was demonstrated by Boon *et al.* (2000) during external rotation in a lying position, the scapula is limited mechanically by the ribcage, whereas in shoulder internal rotation the scapula can tilt anteriorly and “wing off” the chest wall. Thus, manual scapular stabilization is less critical during external rotation measurements but is necessary during shoulder internal rotation to minimize scapulothoracic motion and restrict motion to the GH joint. With an electromagnetic sensor on the scapula, it was possible to follow the scapular motion in real-time and exclude those trials where the scapula moves above a certain level. This information was refined by the examiner’s manual perception with the hand that was positioned over the shoulder.

CHAPTER 8 - REFERENCES

Ambrosio, L., Netti, P. A., & Nicolais, L. (2002). Soft tissue. In R. Barbucci (Ed.), *Integrated Biomaterials Science* (pp. 347-365). New York: Kluwer Academic/Plenum Publishers.

Andrews AW, & RW, B. (1989). Decreased shoulder range of motion on paretic side after stroke. *Physical Therapy, 69*(9), 768-772.

Awan, R., Smith, J., & Boon, A. J. (2002). Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. *Arch Phys Med Rehabil, 83*(9), 1229-1234.

Baeyens, J., Van Roy, P., De Schepper, A., Declercq, G., & Clarijs, J. (2001). Glenohumeral joint kinematics related to minor anterior instability of the shoulder at the end of the late preparatory phase of throwing. [doi: DOI: 10.1016/S0268-0033(01)00068-7]. *Clin Biomech 16*(9), 752-757.

Baeyens, J. P., Van Roy, P., & Clarys, J. O. (2000). Intra-articular kinematics of the normal glenohumeral joint the late preparatory phase of throwing: Kaltenborn's rule revisited. *Ergonomics, 43*(10), 1726-1737.

Barlow, J. C., Benjamin, B. W., Birt, P., & Hughes, C. J. (2002). Shoulder strength and range-of-motion characteristics in bodybuilders. *J Strength Cond Res, 16*(3), 367-372.

Bigliani, L. U., Codd, T. P., Connor, P. M., Levine, W. N., Littlefield, M. A., & Hershon, S. J. (1997). Shoulder motion and laxity in the professional baseball player. *Am J Sports Med, 25*(5), 609-613.

Boileau, P., Bicknell, R. T., Mazzoleni, N., Walch, G., & Urien, J. P. (2008). CT scan method accurately assesses humeral head retroversion. *Clin Orthop Relat Res, 466*(3), 661-669.

Boon, A. J., & Smith, J. (2000). Manual scapular stabilization: Its effect on shoulder rotational range of motion. *Arch Phys Med Rehabil, 81*(7), 978-983.

Borich, M. R., DPT., Bright, J. M., DPT., Lorello, D., Cieminski, C. J., PT, MS, ATC, CSCS., & Buisman, T., PT. (2006). Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther, 36*(12), 926-934.

Borsa, P. A., Dover, G. C., Wilk, K. E., & Reinold, M. M. (2006). Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc, 38*(1), 21-26.

Borsa, P. A., Jacobson, J. A., Scibek, J. S., & Dover, G. C. (2005). Comparison of dynamic sonography to stress radiography for assessing glenohumeral laxity in asymptomatic shoulders. *Am J Sports Med, 33*(5), 734-741.

Borsa, P. A., Laudner, K. G., & Sauers, E. L. (2008). Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. [Review]. *Sports Med, 38*(1), 17-36.

Borsa, P. A., Timmons, M. K., & Sauers, E. L. (2003). Scapular-Positioning Patterns During Humeral Elevation in Unimpaired Shoulders. *J Athl Train, 38*(1), 12-17.

Borsa, P. A., Wilk, K. E., Jacobson, J. A., Scibek, J. S., Dover, G. C., Reinold, M. M., et al. (2005). Correlation of range of motion and glenohumeral translation in professional baseball pitchers. *Am J Sports Med, 33*(9), 1392-1399.

Braun, S., Kokmeyer, D., & Millett, P. J. (2009). Shoulder injuries in the throwing athlete. [Review]. *J Bone Joint Surg Am, 91*(4), 966-978.

Brown, L. P., Niehues, S. L., Harrah, A., Yavorsky, P., & Hirshman, H. P. (1988). Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *Am J Sports Med, 16*(6), 577-585.

Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003a). The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy, 19*(4), 404-420.

Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003b). The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy, 19*(6), 641-661.

Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003c). The disabled throwing shoulder: spectrum of pathology. Part II: evaluation and treatment of SLAP lesions in throwers. *Arthroscopy, 19*(5), 531-539.

Cassagnaud, X., Maynou, C., Petroff, E., Dujardin, C., & Mestdagh, H. (2003). A study of reproducibility of an original method of CT measurement of the lateralization of the intertubercular groove and humeral retroversion. *Surg Radiol Anat, 25*(2), 145-151.

Chagneau, F., Delamarche, P., & Levasseur, M. (1992). Stroboscopic computerized determination of humeral rotation in overarm throwing. *Br J Sports Med, 26*(1), 59-62.

Chant, C. B., Litchfield, R., Griffin, S., & Thain, L. M. (2007). Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. *J Orthop Sports Phys Ther, 37*(9), 514-520.

Cieminski, C. J. (2007). *Humeral retroversion: Its measurement and effect on scapular kinematicas in competitive baseball players lacking shoulder rotation range of motion.* University of Minnesota, Minneapolis.

Cohen, J. (1992). Quantitative methods in Psichology. *Physiological Bulletin, 112*(1), 155-159.

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Danneels, L. A., & Cambier, D. C. (2003). Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. *Am J Sports Med, 31*(4), 542-549.

Cools, A. M., Witvrouw, E. E., Mahieu, N. N., & Danneels, L. A. (2005). Isokinetic Scapular Muscle Performance in Overhead Athletes With and Without Impingement Symptoms. *J Athl Train, 40*(2), 104-110.

Crockett, H. C., Gross, L. B., Wilk, K. E., Schwartz, M. L., Reed, J., O'Mara, J., et al. (2002). Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med, 30*(1), 20-26.

DeLude, J. A., Bicknell, R. T., MacKenzie, G. A., Ferreira, L. M., Dunning, C. E., King, G. J., et al. (2007). An anthropometric study of the bilateral anatomy of the humerus. *J Shoulder Elbow Surg, 16*(4), 477-483.

Dillman, C. J., Fleisig, G. S., & Andrews, J. R. (1993). Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther, 18*(2), 402-408.

Donatelli, R., Ellenbecker, T., Ekedahl, S. R., Wilkes, J., Kocher, K., & Adam, J. (2000). Assessment of Shoulder Strength in Professional Baseball Pitchers. *J Orthop Sports Phys Ther, 30*(9), 544-551.

Dover, G. C., Kaminski, T. W., Meister, K., Powers, M. E., & Horodyski, M. (2003). Assessment of shoulder proprioception in the female softball athlete. *Am J Sports Med, 31*(3), 431-437.

Downar, J. M., & Sauers, E. L. (2005). Clinical Measures of Shoulder Mobility in the Professional Baseball Player. *J Athl Train, 40*(1), 23-29.

Doyle, A. J., & Burks, R. T. (1998). Comparison of humeral head retroversion with the humeral axis/biceps groove relationship: a study in live subjects and cadavers. *J Shoulder Elbow Surg, 7*(5), 453-457.

Dwelly, P. M., Tripp, B. L., Tripp, P. A., Eberman, L. E., & Gorin, S. (2009). Glenohumeral rotational range of motion in collegiate overhead-throwing athletes during an athletic season. *J Athl Train, 44*(6), 611-616.

Edelson, G. (1999). Variations in the retroversion of the humeral head. *J Shouder Elbow Surg, 8*, 142-145.

Ellenbecker, T. S., Bailie, D. S., Mattalino, A. J., Carfagno, D. G., Wolff, M. W., Brown, S. W., et al. (2002). Intrarater and interrater reliability of a manual technique to assess anterior humeral head translation of the glenohumeral joint. *J Shoulder Elbow Surg, 11*(5), 470-475.

Ellenbecker, T. S., & Roetert, E. P. (2002). Effects of a 4-month season on glenohumeral joint rotational strength and range of motion in female collegiate tennis players. *J Strength Cond Res, 16*(1), 92-96.

Ellenbecker, T. S., Roetert, E. P., Piorkowski, P. A., & Schulz, D. A. (1996). Glenohumeral joint internal and external rotation range of motion in elite junior tennis players. *J Orthop Sports Phys Ther, 24*(6), 336-341.

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995). Kinetics of Baseball Pitching with Implications About Injury Mechanisms. *Am J Sports Med, 23*(2), 233-239.

Forthomme, B., Crielaard, J. M., & Croisier, J. L. (2008). Scapular positioning in athlete's shoulder : particularities, clinical measurements and implications. [Review]. *Sports Med, 38*(5), 369-386.

Fradet, L., Botcazou, M., Durocher, C., Cretual, A., Multon, F., Prioux, J., et al. (2004). Do handball throws always exhibit a proximal-to-distal segmental sequence? *J Sports Sci, 22*(5), 439-447.

Fradet, L., Kulpa, R., Multon, F., & Delamarche, P. (2002). *Kinematic analysis of handball throwing.* Paper presented at the ISBS 2002, Caceres Extremadura Spain.

Gardener, G. (1998). *Anatomia* (R. Benevento, Trans. 4ª ed. Vol. 1): Guanabara Koogan.

Grossman, M. G., Tibone, J. E., McGarry, M. H., Schneider, D. J., Veneziani, S., & Lee, T. Q. (2005). A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. *J Bone Joint Surg Am, 87*(4), 824-831.

Gumina, S., Carbone, S., & Postacchini, F. (2009). Scapular Dyskinesis and SICK Scapula Syndrome in Patients With Chronic Type III Acromioclavicular Dislocation. *Arthroscopy, 25*(1), 40-45.

Hamill, J., & Knutzen, K. (2009). *Biomechanical basis of human movement* (3rd ed.). Philadelphia: Wolters Kluwer Health/Lippincott Williams and Wilkins.

Hamming, D., Braman, J. P., Phadke, V., LaPrade, R. F., & Ludewig, P. M. (2012). The accuracy of measuring glenohumeral motion with a surface humeral cuff. [Research Support, N.I.H., Extramural]. *J Biomech, 45*(7), 1161-1168.

Harryman, D. T., Sidles, J. A., Clark, J. M., McQuade, K. J., Gibb, T. D., & Matsen, F. A. (1990). Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am, 72*(9), 1334-1343.

Hayes, K., Walton, J. R., Szomor, Z. R., & Murrell, G. A. (2001). Reliability of five methods for assessing shoulder range of motion. *Aust J Physiother, 47*(4), 289-294.

Hebert, L. J., Moffet, H., McFadyen, B. J., & Dionne, C. E. (2002). Scapular behavior in shoulder impingement syndrome. *Arch Phys Med Rehabil, 83*(1), 60-69.

Hernigou, P., Duparc, F., & Hernigou, A. (2002). Determining humeral retroversion with computed tomography. *J Bone Joint Surg Am, 84-A*(10), 1753-1762.

Herrington, L. (1998). Glenohumeral joint: internal and external rotation range of motion in javelin throwers. *Br J Sports Med, 32*(3), 226-228.

Hoshino, Y., Igarashi, H., Sutou, T., Higuchi, H., Kubota, H., & Matsubara, K. (2004). [Measurement of the humeral retroversion angle using a simple X-ray pictorial image]. *Nippon Hoshasen Gijutsu Gakkai Zasshi, 60*(10), 1452-1458.

Howell, S. M., Galinat, B. J., Renzi, A. J., & Marone, P. J. (1988). Normal and abnormal mechanics of the glenohumeral joint in the horizontal plane. *J Bone Joint Surg, 70*(A2), 227-232.

Huffman, G. R., Tibone, J. E., McGarry, M. H., Phipps, B. M., Lee, Y. S., & Lee, T. Q. (2006). Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med, 34*(10), 1662-1669.

Jobe, F. W., Kvitne, R. S., & Giangarra, C. E. (1989). Shoulder pain in the overhand or throwing athlete. The relationship of anterior instability and rotator cuff impingement. *Orthop Rev, 18*(9), 963-975.

Kebaetse, M., McClure, P., & Pratt, N. A. (1999). Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil, 80*(8), 945-950.

Kelkar, R., Wang, V. M., Flatow, E. L., Newton, P. M., Ateshian, G. A., Bigliani, L. U., et al. (2001). Glenohumeral mechanics: a study of articular geometry, contact, and kinematics. [Research Support, Non-U.S. Gov't]. *J Shoulder Elbow Surg, 10*(1), 73-84.

Kibler, W. B. (1998). The role of the scapula in athletic shoulder function. *Am J Sports Med, 26*(2), 325-337.

Kibler, W. B., & Sciascia, A. (2010). Current concepts: scapular dyskinesis. *Br J Sports Med, 44*(5), 300-305.

Kibler, W. B., Uhl, T. L., Maddux, J. W., Brooks, P. V., Zeller, B., & McMullen, J. (2002). Qualitative clinical evaluation of scapular dysfunction: a reliability study. [Comparative Study]. *J Shoulder Elbow Surg, 11*(6), 550-556.

Krahl, V., & Evans, F. (1945). Humeral torsion in man. *Am J Phys Anthropol, 3*, 229-253.

Krahl, V. E. (1947). The torsion of the humerus; its localization, cause and duration in man. *Am J ANAT, 80*(3), 275-319.

Kronberg, M., Brostrom, L., & Soderlund, V. (1990). Retroversion of the head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop Relat Res, 253*, 113-120.

Kuhn, J. E., Bey, M. J., Huston, L. J., Blasier, R. B., & Soslowsky, L. J. (2000). Ligamentous Restraints to External Rotation of the Humerus in the Late-Cocking Phase of Throwing: A Cadaveric Biomechanical Investigation. *Am J Sports Med, 28*(2), 200-205.

Labriola, J. E., Lee, T. Q., Debski, R. E., & McMahon, P. J. (2005). Stability and instability of the glenohumeral joint: the role of shoulder muscles. *J Shoulder Elbow Surg, 14*(1 Suppl S), 32S-38S.

Lajtai, G., Pfirrmann, C. W., Aitzetmuller, G., Pirkl, C., Gerber, C., & Jost, B. (2009). The shoulders of professional beach volleyball players: high prevalence of infraspinatus muscle atrophy. *Am J Sports Med, 37*(7), 1375-1383.

Lastayo, P. C., M., W. J., Lewek, M. D., Snyder-Mackler, L., Trude-Reich, B., & Lindstedt, S. L. (2003). Eccenctric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. *J Orthop Sports Phys Ther, 33*, 557-571.

Laudner, K. G., Myers, J. B., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2006). Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther, 36*(7), 485-494.

Laudner, K. G., Stanek, J. M., & Meister, K. (2007). Differences in scapular upward rotation between baseball pitchers and position players. [Comparative Study

Research Support, Non-U.S. Gov't]. *Am J Sports Med, 35*(12), 2091-2095.

Lazarus, M. D., Sidles, J. A., Harryman Ii, D. T., & Matsen Iii, F. A. (1996). Effect of a Chondral-Labral Defect on Glenoid Concavity and Glenohumeral Stability. A Cadaveric Model. *J Bone Joint Surg Am, 78*(1), 94-102.

Lee, S.-B., Kim, K.-J., O'Driscoll, S. W., Morrey, B. F., & An, K.-N. (2000). Dynamic Glenohumeral Stability Provided by the Rotator Cuff Muscles in the Mid-Range and End-Range of Motion : A Study in Cadavera. *J Bone Joint Surg Am, 82*(6), 849-.

Levangie, P. K., & Norkin, C. C. (2011). *Joint structure and function : a comprehensive analysis* (5th ed.). Philadelphia: F.A. Davis Co.

Levine, W. N., Brandon, M. L., Stein, B. S., Gardner, T. R., Bigliani, L. U., & Ahmad, C. S. (2006). Shoulder adaptive changes in youth baseball players. *J Shoulder Elbow Surg, 15*(5), 562-566.

Lewis, J. S., Green, A., & Wright, C. (2005). Subacromial impingement syndrome: the role of posture and muscle imbalance. *J Shoulder Elbow Surg, 14*(4), 385-392.

Lintner, D., Mayol, M., Uzodinma, O., Jones, R., & Labossiere, D. (2007). Glenohumeral Internal Rotation Deficits in Professional Pitchers Enrolled in an Internal Rotation Stretching Program. *Am J Sports Med*.

Ludewig, P. M., & Cook, T. M. (2000). Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther, 80*(3), 276-291.

Ludewig, P. M., Cook, T. M., & Nawoczenski, D. A. (1996). Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. [Review]. *J Orthop Sports Phys Ther, 24*(2), 57-65.

Ludewig, P. M., & Reynolds, J. F. (2009). The Association of Scapular Kinematics and Glenohumeral Joint Pathologies *J Orthop Sports Phys Ther., 39*(2), 90-104.

Lukasiewicz, A. C., McClure, P., Michener, L., Pratt, N., & Sennett, B. (1999). Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. [Comparative Study]. *J Orthop Sports Phys Ther, 29*(10), 574-583; discussion 584-576.

Magermans, D. J., Chadwick, E. K., Veeger, H. E., & van der Helm, F. C. (2005). Requirements for upper extremity motions during activities of daily living. *Clin Biomech (Bristol, Avon), 20*(6), 591-599.

Mair, S. D., Uhl, T. L., Robbe, R. G., & Brindle, K. A. (2004). Physeal changes and range-of-motion differences in the dominant shoulders of skeletally immature baseball players. *J Shoulder Elbow Surg, 13*(5), 487-491.

Mallon, W. J., Herring, C. L., Sallay, P. I., Moorman, C. T., & Crim, J. R. (1996). Use of vertebral levels to measure presumed internal rotation at the shoulder: a radiographic analysis. *J Shoulder Elbow Surg, 5*(4), 299-306.

Matias, R., & Pascoal, A. G. (2006). The unstable shoulder in arm elevation: a three-dimensional and electromyographic study in subjects with glenohumeral instability. *Clin Biomech (Bristol, Avon), 21 Suppl 1*, S52-58.

Matsen, F. A., 3rd, Chebli, C., & Lippitt, S. (2006). Principles for the evaluation and management of shoulder instability. [Lectures]. *J Bone Joint Surg Am, 88*(3), 648-659.

McClure, P., Tate, A. R., Kareha, S., Irwin, D., & Zlupko, E. (2009). A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train, 44*(2), 160-164.

McClure, P. W., Michener, L. A., & Karduna, A. R. (2006). Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. *Phys Ther, 86*(8), 1075-1090.

McClure, P. W., Michener, L. A., Sennett, B. J., & Karduna, A. R. (2001). Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg, 10*(3), 269-277.

McConnell, J., Donnelly, C., Hamner, S., Dunne, J., & Besier, T. (2012). Passive and dynamic shoulder rotation range in uninjured and previously injured overhead throwing athletes and the effect of shoulder taping. [Research Support, Non-U.S. Gov't]. *PM R, 4*(2), 111-116.

McCully, S. P., Kumar, N., Lazarus, M. D., & Karduna, A. R. (2005). Internal and external rotation of the shoulder: Effects of plane, end-range determination, and scapular motion. *J Shoulder Elbow Surg, 14*(6), 602-610.

McMullen, J., & Uhl, T. L. (2000). A kinetic chain approach for shoulder rehabilitation. *J Athl Train, 35*(3), 329-337.

Meister, K. (2000a). Injuries to the shoulder in the throwing athlete. Part one: Biomechanics/pathophysiology/classification of injury. *Am J Sports Med, 28*(2), 265-275.

Meister, K. (2000b). Injuries to the shoulder in the throwing athlete. Part two: evaluation/treatment. *Am J Sports Med, 28*(4), 587-601.

Meister, K., Day, T., Horodyski, M., Kaminski, T. W., Wasik, M. P., & Tillman, S. (2005). Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med, 33*(5), 693-698.

Mihata, T., Lee, Y., McGarry, M. H., Abe, M., & Lee, T. Q. (2004). Excessive humeral external rotation results in increased shoulder laxity. *Am J Sports Med, 32*(5), 1278-1285.

Murachovsky, J., Ikemoto, R. Y., Nascimento, L., Bueno, R., Strose, E., & Almeida, A. (2008). Does the presence of proximal humerus growth plate changes in young baseball pitchers happen only in symptomatic athletes? A X-ray evaluation of 21 young baseball pitchers. *Br.J.Sports Med.*

Murachovsky, J., Ikemoto, R. Y., Nascimento, L. G., Bueno, A., Coelho, J., Komeçu, M. T., et al. (2007). Evaluation of humeral head retroversion in handball players. *Acta Orthop. Bras., 15*(5), 258-261.

Myers, J. B., Laudner, K. G., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2005). Scapular position and orientation in throwing athletes. [Research Support, Non-U.S. Gov't]. *Am J Sports Med, 33*(2), 263-271.

Myers, J. B., Laudner, K. G., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2006). Glenohumeral Range of Motion Deficits and Posterior Shoulder Tightness in Throwers With Pathologic Internal Impingement. *Am J Sports Med, 34*(3), 385-391.

Nakamizo, H., Nakamura, Y., Nobuhara, K., & Yamamoto, T. (2008). Loss of glenohumeral internal rotation in little league pitchers: a biomechanical study. *J Shoulder Elbow Surg, 17*(5), 795-801.

Noffal, G. J. (2003). Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. *Am J Sports Med, 31*(4), 537-541.

Nyffeler, R. W., Sheikh, R., Atkinson, T. S., Jacob, H. A., Favre, P., & Gerber, C. (2006). Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. *J Shoulder Elbow Surg, 15*(5), 625-629.

Osbahr, D. C., Cannon, D. L., & Speer, K. P. (2002). Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med, 30*(3), 347-353.

Oyama, S. (2006). *Profiling physical characteristics of the swimmer´s shoulder:comparison to baseball pitchers and non-overhead athletes.* Oregon State University, Oregon.

Oyama, S., Myers, J. B., Wassinger, C. A., Daniel Ricci, R., & Lephart, S. M. (2008). Asymmetric resting scapular posture in healthy overhead athletes. *J Athl Train, 43*(6), 565-570.

Oztuna, V., Ozturk, H., Eskandari, M. M., & Kuyurtar, F. (2002). Measurement of the humeral head retroversion angle. A new radiographic method. *Arch Orthop Trauma Surg, 122*(7), 406-409.

Pascoal, A. G., & Tainha, C. (2006). Alterações no padrão de rotação externa e abdução horizontal do braço em jogadoras de pólo aquático. *Re(habilitar) - Revista da ESSA, 1*(2), 3-21.

Pieper, H. G. (1998). Humeral torsion in the throwing arm of handball players. *Am J Sports Med, 26*(2), 247-253.

Pritchett, J. W. (1991). Growth plate activity in the upper extremity. *Clin Orthop Relat Res*(268), 235-242.

Reagan, K. M., Meister, K., Horodyski, M. B., Werner, D. W., Carruthers, C., & Wilk, K. (2002). Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med, 30*(3), 354-360.

Ribeiro, A., & Pascoal, A. G. (2012). The relationship between the humeral retroversion angle and the active shoulder rotation in volleyball players. *J Biomech, 45(S1), S626*.

Robertson, D. D., Yuan, J., Bigliani, L. U., Flatow, E. L., & Yamaguchi, K. (2000). Three-dimensional analysis of the proximal part of the humerus: relevance to arthroplasty. *J Bone Joint Surg Am, 82-A*(11), 1594-1602.

Sabick, M. B., Kim, Y. K., Torry, M. R., Keirns, M. A., & Hawkins, R. J. (2005). Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *Am J Sports Med, 33*(11), 1716-1722.

Safran, M. R., Borsa, P. A., Lephart, S. M., Fu, F. H., & Warner, J. J. (2001). Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg, 10*(5), 438-444.

Schwab, L. M., & Blanch, P. (2009). Humeral torsion and passive shoulder range in elite volleyball players. *Phys Ther Sport, 10*(2), 51-56.

Seil, R., Rupp, S., Tempelhof, S., & Kohn, D. (1998). Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *Am J Sports Med, 26*(5), 681-687.

Seroyer, S. T., Bach, B., Bush-Joseph, C., A.,, Nicholson, G., P.,, & Romeo, A. A. (2009). Shoulder pain in the overhead throwing athlete. *Sports Health*.

Sethi, P. M., Tibone, J. E., & Lee, T. Q. (2004). Quantitative assessment of glenohumeral translation in baseball players: a comparison of pitchers versus nonpitching athletes. *Am J Sports Med, 32*(7), 1711-1715.

Soderlund, V., Kronberg, M., & Brostrom, L. (1989). Radiologic assessment of humeral head retroversion. Description of a new method. *Acta Radiol, 30*(5), 501-505.

Stefko, J. M., Tibone, J. E., Cawley, P. W., ElAttrache, N. E., & McMahon, P. J. (1997). Strain of the anterior band of the inferior glenohumeral ligament during capsule failure. *J Shoulder Elbow Surg, 6*(5), 473-479.

Stokdijk, M., Eilers, P. H., Nagels, J., & Rozing, P. M. (2003). External rotation in the glenohumeral joint during elevation of the arm. *Clin Biomech (Bristol, Avon), 18*(4), 296-302.

Tate, A. R., McClure, P., Kareha, S., Irwin, D., & Barbe, M. F. (2009). A clinical method for identifying scapular dyskinesis, part 2: validity. [Comparative Study

Research Support, Non-U.S. Gov't

Validation Studies]. *J Athl Train, 44*(2), 165-173.

Terry, G. C., & Chopp, T. M. (2000). Functional anatomy of the shoulder. *J Athl Train, 35*(3), 248-255.

Tillar, R., & Cabri, J. (2012). Gender differences in the kinematics and ball velocity of overarm throwing in elite team handball players. *J.Sports Sci, 30*(8), 807-813.

Tokish, J. M., Curtin, M. S., Kim, Y. K., Hawkins, R. J., & Torry, M. R. (2008). Glenohumeral internal rotation deficit in the asymptomatic professional pitcher and its relationship to humeral retroversion. *J. Sports Sci. Med., 7*(1), 78-83.

Torres, R. R., & Gomes, J. L. (2009). Measurement of glenohumeral internal rotation in asymptomatic tennis players and swimmers. *Am J Sports Med, 37*(5), 1017-1023.

Trakis, J. E., McHugh, M. P., Caracciolo, P. A., Busciacco, L., Mullaney, M., & Nicholas, S. J. (2008). Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med, 36*(11), 2173-2178.

Tripp, B. L., Yochem, E. M., & Uhl, T. L. (2007). Functional fatigue and upper extremity sensorimotor system acuity in baseball athletes. *J Athl Train, 42*(1), 90-98.

Tsai, N. T., McClure, P. W., & Karduna, A. R. (2003). Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil, 84*(7), 1000-1005.

Turkel, S. J., Panio, M. W., Marshall, J. L., & Girgis, F. G. (1981). Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. *J Bone Joint Surg Am, 63*(8), 1208-1217.

Uhl, T. L., Kibler, W. B., Gecewich, B., & Tripp, B. L. (2009). Evaluation of clinical assessment methods for scapular dyskinesis. *Arthroscopy, 25*(11), 1240-1248.

van der Helm, F. C. T., & Pronk, G. M. (1995). Three dimensional recording and description of motions of the shoulder mechanism. *J Biomech Eng, 177*, 27-40.

van der Hoeven, H., & Kibler, W. B. (2006). Shoulder injuries in tennis players. *Br J Sports Med, 40*(5), 435-440; discussion 440.

Veeger, H. E. J., & van der Helm, F. C. T. (2007). Shoulder Function: The perfect compromise between mobility and stability. *J Biomech, 40*(10), 2119-2129.

Wagner, H., & Muller, E. (2008). The effects of differential and variable training on the quality parameters of a handball throw. *Sports Biomech, 7*(1), 54-71.

Wagner, H., Pfusterschmied, J., Tilp, M., Landlinger, J., von Duvillard, S. P., & Muller, E. (2012). Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scand J Med Sci Sports*.

Walch, G., Liotard, J. P., Boileau, P., & Noel, E. (1991). [Postero-superior glenoid impingement. Another shoulder impingement]. [Case Reports]. *Rev Chir Orthop Reparatrice Appar Mot, 77*(8), 571-574.

Wang, H. K., & Cochrane, T. (2001a). A descriptive epidemiological study of shoulder injury in top level English male volleyball players. *Int J Sports Med, 22*(2), 159-163.

Wang, H. K., & Cochrane, T. (2001b). Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fitness, 41*(3), 403-410.

Wang, H. K., Macfarlane, A., & Cochrane, T. (2000). Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med, 34*(1), 39-43.

Warden, S. J., Bogenschutz, E. D., Smith, H. D., & Gutierrez, A. R. (2009). Throwing induces substantial torsional adaptation within the midshaft humerus of male baseball players. *Bone, 45*(5), 931-941.

Warner, J. J., Micheli, L. J., Arslanian, L. E., Kennedy, J., & Kennedy, R. (1990). Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med, 18*(4), 366-375.

Webster, M. J., Morris, M. E., & Galna, B. (2009). Shoulder pain in water polo: a systematic review of the literature. *J Sci Med Sport, 12*(1), 3-11.

Werner, S. L., Gill, T. J., Murray, T. A., Cook, T. D., & Hawkins, R. J. (2001). Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. *Am J Sports Med, 29*(3), 354-358.

Werner, S. L., Guido, J. A., Jr., Stewart, G. W., McNeice, R. P., Vandyke, T., & Jones, D. G. (2006). Relationships between throwing mechanics and shoulder distraction in collegiate baseball pitchers. *J Shoulder Elbow Surg*.

Whiteley, R., Adams, R., Nicholson, L., & Ginn, K. (2010). Reduced humeral torsion predicts throwing-related injury in adolescent baseballers. *J Sci Med Sport, 13*(4), 392-396.

Whiteley, R., Ginn, K., Nicholson, L., & Adams, R. (2006). Indirect Ultrasound Measurement of humeral torsion in adolescent baseball players and non-athletic adults: Reliability and significance. *J Sci Med Sport, 9*(4), 310-318.

Whiteley, R. J., Ginn, K. A., Nicholson, L. L., & Adams, R. D. (2009). Sports participation and humeral torsion. *J Orthop Sports Phys Ther, 39*(4), 256-263.

Wilk, K. E., Arrigo, C. A., & Andrews, J. R. (1997). Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther, 25*(6), 364-379.

Wilk, K. E., Macrina, L. C., Fleisig, G. S., Porterfield, R., Simpson, C. D., 2nd, Harker, P., et al. (2011). Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med, 39*(2), 329-335.

Wilk, K. E., Obma, P., Simpson, C. D., Cain, E. L., Dugas, J. R., & Andrews, J. R. (2009). Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther, 39*(2), 38-54.

Wortler, K. (2010). Shoulder injuries in overhead sports. *Radiologe, 50*(5), 453-459.

Wu, G., van der Helm, F. C., Veeger, H. E., Makhsous, M., Van Roy, P., Anglin, C., et al. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. [Consensus Development Conference Guideline Review]. *J Biomech, 38*(5), 981-992.

Wyland, D. J., Pill, S. G., Shanley, E., Clark, J. C., Hawkins, R. J., Noonan, T. J., et al. (2012). Bony adaptation of the proximal humerus and glenoid correlate within the throwing shoulder of professional baseball pitchers. *Am J Sports Med, 40*(8), 1858-1862.

Yamamoto, N., Itoi, E., Minagawa, H., Urayama, M., Saito, H., Seki, N., et al. (2006). Why is the humeral retroversion of throwing athletes greater in dominant shoulders than in nondominant shoulders? *J Shoulder Elbow Surg, 15*(5), 571-575.

Yildiz, Y., Aydin, T., Sekir, U., Kiralp, M. Z., Hazneci, B., & Kalyon, T. A. (2006). Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. *Scand J Med Sci Sports, 16*(3), 174-180.

Zatsiorsky, V. M. (1998). *Kinematics of Human Motion*. Champaign: Human Kinetics.

CHAPTER 9 - APPENDICES

Shoulder clinical tests description

Rotator cuff integrity tests

1. **Empty-can (supraspinatus test):** a test designed to identify a tear in the supraspinatus tendon. The patient is either seated or standing. The patient´s upper limbs are positioned horizontally at 30º anterior to the frontal plane, abducted to 90º and internally rotated (empty-can position). The examiner applies a downward force on the patient´s limbs. The test is positive if pain and weakness are present.
2. **Subscapularis (Gerber Lift-off sign):** a test used to rule out a rupture of the subscapularis tendon. The patient is seated or standing with the test arm behind their back; hand resting on their flank. The examiner stabilizes the patient´s scapula while moving the resting arm away from the body. Apprehension, muscle guarding or pain localized to the anterior shoulder may indicate rupture.
3. **Drop arm test (Codman´s test):** a test designed to determine the presence of a torn rotator cuff. With the patient seated, the examiner abducts the patient´s shoulder to 90º. The patient is then asked to slowly lower the test extremity to their side. The test is positive if the patient is unable to lower the arm slowly to their side in the same arc of movement or has severe pain when attempting to do so. This is a highly provocative test because it requires eccentric contraction of the supraspinatus.

Impingement

1. **Neers ´sign:** a test to identify impingement of the supraspinatus tendon or long head of the biceps in the coracoacromial arch. While stabilizing the scapula, the

examiner internally rotates the shoulder and then brings the shoulder into flexion. Pain reproduced over the coracoacromial arch indicates positive test.

   a. **Hawkins test (Kennedy-Hawkins’s test):** the examiner brings the patient´s arm into 90º of flexion with the elbow bent to 90º. The arm is then forced into internal rotation. Pain over the coracoacromial arch would indicate a positive test for impingement.

Glenohumeral anterior instability

1. **Apprehension test (Crank):** a test designed to determine whether a patient has a history of anterior dislocations. With the patient supine, the examiner slowly abducts and externally rotates the patient´s arm. The test is positive if the patient becomes apprehensive and resists (muscle guards) against further motion. No translation should be expected in the normal shoulder because this test is performed in a position where the anterior ligaments are placed under tension.
   a. **Jobe Relocation test:** performed in conjunction with the crank test. A posterior directed force is applied to the test extremity resulting in the disappearance of the patient´s apprehension or muscle guarding.

Glenohumeral inferior instability

2. **Inferior sulcus sign:** tests for inferior instability of the glenohumeral joint by assessing the integrity of the coracohumeral and superior glenohumeral ligaments. The examiner stands beside the patient with the patient´s arm hanging at his side. The examiner then gives an inferiorly directed traction to the shoulder (pulls down on the elbow) a positive test results when there is an inferior slide of the humeral head or where there is a marked increase in the

space between the humeral head and the acromion. The scale is below used to grade the sulcus:

5 – 1 cm = +1 sulcus

1 – 2 cm= +2 sulcus

2 -3 cm= + 3 sulcus

a. **Yeargason test: a** test designed to identify tendonitis of the long head of the biceps. The seated patient´s arm is positioned at his or her side with the elbow flexed to 90º. Supination of the forearm against resistance produces pain in the biceps tendon in the area of the bicipital groove.

Glenoid labrum tear

Clunk test: a test used to determine if there is a tear of the glenoid labrum. The examiner is standing at the head of the patient who is lying supine. The examiner places one hand under the posterior portion or the shoulder while the other holds the arm just proximal to the elbow. The examiner takes the test extremity and fully abducts It over the patient´s head and simultaneously moves the humeral head anteriorly with the proximal hand and while externally rotating the humerus with the distal hand. The presence of a “clunk” or grinding sensation at the glenohumeral joint indicates a positive test for a labral tear. The test may also cause apprehension if anterior instability is present.

CHAPTER 10 - ATTACHMENTS