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Facultad de Ciencias de la Actividad Física y el Deporte

SHOULDER AND HIP RANGES OF MOTION AND THEIR RELATIONSHIP WITH INJURY HISTORY IN ELITE TENNIS PLAYERS

Doctoral Thesis

A dissertation presented by

Víctor Moreno Pérez

Degree in Physiotherapy

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El Dr. D. Juan Carlos Marzo Campos, director del Departamento de Psicología de la Salud de la Universidad Miguel Hernández de Elche.

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Que el trabajo de investigación titulado: "SHOULDER AND HIP RANGES OF MOTION AND THEIR RELATIONSHIP WITH INJURY HISTORY IN ELITE TENNIS PLAYERS" realizado por D. Víctor Moreno Pérez bajo la dirección de Dr. D. Francisco José Vera García sea depositado en el departamento y posteriormente defendido como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

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Tesis Doctoral presentada por:

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ABSTRACT

Joint flexibility deficit has been considered to be one of the intrinsic risk factors with a higher prevalence in sports; nevertheless, there is controversy regarding the relationship between flexibility levels and the occurrence of sport injuries. Furthermore, in tennis and especially at the elite level there are only a few studies that have examined the relationship between risk factors and injury history. The main purposes of this doctoral thesis were: a) to describe the glenohumeral rotational ranges of motion (ROMs) and the hip ROMs of the dominant and non-dominant sides in elite tennis players; b) to assess the relationship between deficits and side-to-side asymmetries in the glenohumeral and hip ROMs and elite tennis players' history of shoulder and low back pain (LBP), respectively. Three studies were performed to achieve these objectives, one related to shoulder flexibility and the other two related to hip flexibility. Based on the results, while the shoulder on the dominant side averaged less internal rotation and total arc of rotation when compared with the non-dominant side, bilateral measurement of hip flexion, extension, abduction and rotation ROMs did not identify clinically significant differences between limbs. In addition, although no significant differences between tennis players with and without a history of shoulder pain were found for the side-to-side glenohumeral ROM asymmetries, limited internal rotation and total arc of rotation seem to be associated with shoulder pain history in professional tennis players. Regarding hip ROMs, restricted values of hip flexion, extension and abduction ROM were found in both limbs for males and females, and male tennis players reported restricted hip internal rotation ROM. However, no meaningful differences were found in hip extension and rotation ROMs between elite tennis players with and without a history of LBP. Overall, this doctoral thesis provides useful information to assist clinicians and

tennis professionals in the identification of athletes with possible hip and/or shoulder abnormalities, who therefore may be at risk of injury.

Key Words: Shoulder, Hip, ROM, Flexibility, Tennis, Injury

RESUMEN

El déficit de flexibilidad articular ha sido considerado como uno de los factores de riesgo intrínseco de mayor prevalencia en el deporte en general, sin embargo, existe cierta controversia acerca de la relación entre los niveles de flexibilidad y la aparición de lesiones en los deportistas. Además, en el tenis y especialmente en el tenis de élite, son escasos los trabajos que han estudiado la asociación entre factores de riesgo y la historia de lesión. Los objetivos principales de esta tesis doctoral fueron: a) describir los rangos de movimiento (ROMs) de rotación glenohumeral y los ROMs de la cadera de los lados dominante y no dominante en jugadores de tenis de élite; b) evaluar la relación de los déficits y las asimetrías entre lados de los ROMs del hombro y la cadera con la historia de dolor de hombro y con la historia de dolor lumbar (LBP) en tenistas de élite, respectivamente. Para lograr estos objetivos se realizaron tres estudios, uno de ellos relacionado con la flexibilidad del hombro y los otros dos con la flexibilidad de la cadera. Basándonos en los resultados de estos estudios, mientras el hombro del lado dominante promedio menor rotación interna y menor arco total de rotación en comparación con el lado no dominante, las medidas bilaterales de los ROMs de flexión, extensión, abducción y rotación de cadera no mostraron diferencias clínicamente significativas entre lados. Además, aunque no se encontraron diferencias significativas en las asimetrías entre los lados de los ROM de rotación glenohumeral entre los jugadores de tenis con y sin historia de dolor en el hombro, los déficits de rotación interna y del arco total de rotación se asociaron a la historia de dolor en el hombro en los jugadores de tenis profesional. Respecto a los ROMs de la cadera, se registraron valores reducidos de flexión, extensión y abducción de cadera en ambas extremidades, tanto en hombres como en mujeres, así como valores reducidos de rotación interna en los tenistas varones. Sin embargo, no se encontraron diferencias significativas en los

ROMs de extensión y rotación de cadera entre los tenistas de élite con y sin historia de dolor lumbar. En general, esta tesis doctoral proporciona información útil para ayudar a los médicos, rehabilitadores, preparadores físicos y otros profesionales del tenis en la identificación de los deportistas con posibles anomalías en las caderas y/o en los hombros, y por tanto, en riesgo de lesión.

Palabras clave: Hombro, Cadera, ROM, Flexibilidad, Tenis, Lesión

ABBREVIATIONS

ROMs: Ranges of motion.

LBP: Low Back Pain.

ROM: Range of motion.

ER: External rotation.

IR: Internal rotation.

TAM: Total arc of motion.

GIRD: Glenohumeral internal rotation deficit.

ATP: Association of Tennis Professionals.

NPH: No pain history.

PH: Pain history.

ICC: Intra-class correlation coefficient.

SEM: Standard error of measurement.

WTA: Women's Tennis Association.

ITF: International Tennis Federation**.**

SD: Standard deviation.

VAS: Visual analogue scale for pain.

CHAPTER 1

GENERAL INTRODUCTION

CHAPTER 1

GENERAL INTRODUCTION

Tennis is a sport played in more than 200 countries (Pluim et al., 2007a) and it is a game which allows for personal development in different fields (Crespo and Reid, 2009): social, affective, intellectual, physical and ludic, amongst others. Approximately 83 million people play tennis worldwide (Casper and Andrew, 2008), with the vast majority of participants being recreational players (Pluim et al., 2015). Furthermore, in recent years there has been an increase in participation (Turner and Pluim, 2007).

Tennis is considered a complex and unpredictable sport due to the existence of a wide variability of characteristics such as point and match duration (Fernandez et al., 2006; Ferrauti et al., 2003; Kovacs, 2006). Furthermore, it is characterized by short intense efforts (acyclical movements with a high demand of strength and velocity), which are carried out over a relatively long period of time (Girard et al., 2006; Kovacs, 2006). Fast accelerations and decelerations, rapid cutting movements and powerful strokes are performed repetitively during the game (Chandler, 1995; Fernandez-Fernandez et al., 2009a). The tennis strokes are normally unilateral actions and therefore establish the asymmetrical nature of this sport (Ellenbecker et al., 2006).

The positive effects of regular tennis practice on health are many, such as the improvement of aerobic capacity, bone density and muscle strength, and also the reduction of various risk factors related to cardiovascular diseases (Fernandez-Fernandez et al., 2009b; Pluim et al., 2007b). Nevertheless, the increase of tennis practice in the last years and the physical demands of this practice have also caused an increase in the number of sport injuries (DiFiori et al., 2014; Ekegren et al., 2015).

Furthermore, if we focus on elite or professional athletes, in which the main objective is to obtain peak sport performance (García et al., 2009), the athlete is under constant physical, physiological and psychological stress (García et al., 2009), a fact which increases the risk of injury in the musculoskeletal system (García et al., 2009; Pluim et al., 2006).

The appearance of injuries implies a threat and a limitation in any athlete's career as it can negatively affect playing the sport, at an economical and/or psychological level (Bahr and Krosshaug, 2005; Small et al., 2009). The intense and repetitive stress imposed on the musculoskeletal system during practice for elite or professional tennis favours overloading and the appearance of injuries in many anatomical structures (Ellenbecker and Cools, 2010; Roetert et al., 2009a). The highest occurrence of injuries due to overuse can be found in the upper extremities and in the trunk (Hjelm et al., 2010; Kibler and Safran, 2005; Maquirriain et al., 2015; Reece et al., 1986; Winge et al., 1989), with the shoulder and lumbar region comprising the majority of injuries (Hjelm et al., 2010; Kibler and Safran, 2005; Maquirriain et al., 2015; Reece et al., 1986; Winge et al., 1989).

1.1. Risk factors in sport injuries

A risk factor can be defined as any attribute, characteristic or behaviour by a person/athlete that contributes to the predisposition or susceptibility to suffer an injury (Bahr and Krosshaug, 2005; van Mechelen et al., 1992). In a traditional sense, risk factors have been divided into two categories (Petersen and Hölmich, 2005; van Mechelen et al., 1992): a) extrinsic or external risk factors, considered as environmental and external to the athlete; and b) intrinsic or internal risk factors, related to biological and psychological characteristics of the athlete.

Identifying risk factors linked to injuries is essential in order to establish injury risk profiles in athletes. Furthermore, this may facilitate the decision making by coaches and sport medical professionals with the aim of reducing the prevalence (Sell et al., 2014), severity and costs linked to injuries (Mickel et al., 2006; Mohammadi, 2007; Waldén et al., 2012).

There are several variables that have been considered extrinsic and intrinsic risk factors of injuries in sport (Bahr and Krosshaug, 2005). Sport factors (e.g., coaching and rules), sport equipment (e.g., shoes, balls and racket) and the environment (e.g., type of court surface and weather) can be highlighted as extrinsic risk factors (Bahr and Krosshaug, 2005; Hjelm et al., 2012). On the other hand, sex (Renstrom et al., 2008), age (Ekstrand et al., 2011; Orchard, 2001), history of previous injuries (Hjelm et al., 2012; Orchard, 2001), anatomical factors (Renstrom et al., 2008), muscle strength (Croisier, 2004; Croisier et al., 2002), joint instability (Witchalls et al., 2012) and joint flexibility (Ekstrand and Gillquist, 1983; Garret, 1996; Gleim and McHugh, 1997; Kibler and Chandler, 2003; Smith, 1994; Witvrouw et al., 2001; 2003) can be grouped as intrinsic risk factors. Despite these factors being used regularly as variables to be taken into consideration for sport injury prevention, few studies have proven the link between them and the injury appearance or injury history in tennis players (Pluim et al., 2006).

1.2. Flexibility as a risk factor in sport injuries

Flexibility can be defined as the ability to move a joint (or several of them in a series) throughout the complete range of motion (ROM) required for an activity or specific action (Magnusson and Renstrom, 2006). Flexibility is characterized as being a physical capacity that facilitates or that is complementary to other physical capacities such as strength or endurance (Bagur and Serra, 2004; Corbin and Noble, 1980). Furthermore it has been identified as an important factor in the fitness and performance of an athlete (Chandler et al., 1990; Smith, 1994), as a lack of flexibility may complicate the athlete's correct technical execution, modify the joint biomechanics (Chandler et al., 1990) and increase the probability of suffering an injury (Chandler et al., 1990; Kibler and Chandler, 2003; Smith, 1994).

The lack of joint flexibility has been considered to be one of the highest intrinsic risk factors in sport (Ekstrand and Gillquist, 1983; Garret, 1996; Gleim and McHugh, 1997; Kibler and Chandler, 2003; Smith, 1994; Witvrouw et al., 2001; 2003). In this sense, numerous studies have established a relationship between a lack of flexibility and the increase of suffering musculoskeletal injuries (Arnason et al., 2004; Bradley and Portas, 2007; Ekstrand and Gillquist, 1983; Henderson et al., 2010; Ibrahim et al., 2007; Witvrouw et al., 2001; 2003) or joint injuries (Almeida et al., 2012; Evans et al., 2005; Harris-Hayes et al., 2009; Murray et al., 2009; Roach et al., 2015; Vad et al., 2003; 2004; Van Dillen et al., 2000; 2008; Witvrouw et al., 2000) in several sports.

Furthermore, maintaining a good flexibility level may prevent the occurrence of different musculoskeletal and joint injuries in sport (Dadebo et al., 2004; Kibler and Chandler, 2003). However, most of the research examining flexibility has focused mainly on analyzing the stretching methodology (length, intensity, frequency, etc.), and on its preventive capacity or on its effectiveness to reduce the risk of suffering injuries (McHugh and Cosgrave, 2010). There is also controversy between the different prospective studies that have analyzed the relation between flexibility levels and the occurrence of injuries in athletes. While some studies have established that low flexibility levels could be related to the occurrence of sport injuries (Arnason et al., 2004; Ekstrand and Gillquist, 1983; Witvrouw et al., 2001; 2003), other studies do not support this possible relationship (Emery and Meeuwisse, 2001; Engebretsen et al., 2010; O'Connor, 2004; Orchard et al., 1997; Tyler et al., 2001), therefore questioning the belief that flexibility is a protective factor against injuries. The lack of agreement between the results of the different studies could be due to many factors, mainly the low number of injuries found in some studies, which makes the establishment of significant correlations difficult (Romero and Tous, 2009), and also due to differences between the studies in the characteristics of the samples analysed (Hrysomallis, 2009) as well as in the methodology used to measure flexibility (Hrysomallis, 2009; Romero and Tous, 2009).

1.3. Flexibility in tennis

Mechanically and medically, tennis is considered a ‘rotational’ and ‘throwing’ sport because of the stroke techniques performed during the game. The forehand stroke and serve represent 75% of the technical actions performed by the tennis players and they are performed unilaterally, a fact which determines the asymmetric character of this sport (Ellenbecker et al., 2009). Moreover, the stroke techniques favor the development of specific musculoskeletal adaptations (Chandler et al., 1990), which although for some occasions may be considered positive (e.g., muscle strength increase), in many cases are considered negative, such as the shortening of the muscles and a reduction in the joint flexibility (Chandler et al., 1990; Kovacs, 2006), factors which could be connected with the appearance of injuries in tennis players (Ellenbecker and Cools, 2010; Roetert et al., 2009a).

In this sense, most research examining injury prevention in tennis have focused on evaluating the flexibility level of the tennis player, especially in the glenohumeral joint (Ellenbecker et al., 1996; 2002; Chandler et al., 1990; Hjelm et al., 2012; Kibler et al., 1996; Schmidt-Wiethoff et al., 2004; Stanley et al., 2004; Torres and Gomes, 2009; Vad et al., 2003) and to a lesser level at the hip level (Ellenbecker et al., 2007; Chandler et al., 1990; Vad et al., 2003; Young et al., 2004). Nevertheless, these studies present certain limitations as follows:

- Most of the studies have been carried out with junior, senior and/or recreational tennis players (Chandler et al., 1990; Ellenbecker et al., 1996; 2002; Hjelm et al., 2012; Kibler et al., 1996; Stanley et al., 2004; Torres and Gomes, 2009), and possibly do not reflect the musculoskeletal adaptations typical of the elite and/or professional tennis player.
- Researchers have focused on evaluating the flexibility mainly in a horizontal plane (rotation movements), both in the glenohumeral joint (Chandler et al., 1990; Ellenbecker et al., 1996; 2002; Hjelm et al., 2012; Kibler et al., 1996; Schmidt-Wiethoff et al., 2004; Stanley et al., 2004; Torres and Gomes, 2009; Vad et al., 2003), and at the hip (Ellenbecker et al., 2007; Vad et al., 2003; Young et al., 2014), obviating other planes of joint movement considered important for tennis players (e.g., shoulder abduction, hip extension, hip abduction, etc.), which could show important variations and contribute to the occurrence of injuries.

On the other hand, many of the studies that have been used in tennis to establish injury risk factors for shoulder and hip ROM deficits, have been carried out with overhead athletes (Almeida et al., 2013; Myers et al., 2006; Warner et al., 1990; Wilk et al., 2011) or athletes who regularly participate in rotation-related sports (e.g., golf, judo, etc.) (Almeida et al., 2012; Evans et al., 2005; Harris-Hayes et al., 2009; Murray et al., 2009; Roach et al., 2015; Vad et al., 2004; Van Dillen et al., 2008), but not with elite or professional tennis players.

Therefore, studies that exhaustively (in all planes) describe the joint ROMs of tennis players who are exclusively dedicated to tennis practice (elite/professional players) and also that describe the possible relationship between flexibility and injuries in tennis are needed. These works will allow us to characterize a high performance tennis player in terms of flexibility and will provide useful information to establish injury risk in tennis players.

CHAPTER 2

RESEARCH OBJECTIVES AND HYPOTHESIS

CHAPTER 2

RESEARCH OBJECTIVES AND HYPOTHESIS

2.1. General objective

Based on the limitations of the literature, the general objectives of this doctoral thesis were as follows:

1. To describe the glenohumeral rotational ROMs and the hip ROMs of the dominant and non-dominant sides in elite tennis players.

2. To assess the relationship between deficits and side-to-side asymmetries in the aforementioned ROMs and the elite tennis players' history of shoulder and low back pain (LBP).

To carry out these objectives, three studies were performed, one on shoulder flexibility and two on hip flexibility:

– Study 1: Comparison of shoulder rotation ROM in professional tennis players with and without history of shoulder pain.
– Study 2: Descriptive profile of hip ROMs in elite tennis players.
– Study 3: Comparison of hip flexion and rotation ROMs in elite tennis players with and without a history of LBP.

2.2. Specific objectives

The specific objectives have been structured depending on the three studies of this doctoral thesis:

Study 1:

1. To describe the profile of glenohumeral rotation ROMs in professional tennis players.

2. To quantify the differences in passive ROM of glenohumeral rotation between the dominant and non-dominant sides, and to compare rotation ROM and sided differences between two samples of professional tennis players: one with a history of shoulder pain and a second with no such pain history.

3. To analyze the relationship between rotation ROMs, dominant vs. non-dominant shoulder ROM differences, years of tennis practice and years of professional tennis play.

Study 2:

4. To describe the hip ROM profile in elite tennis players: hip flexion, extension, abduction and rotation (external and internal) ROMs of the dominant and non-dominant limbs.

5. To analyze if there are sided and/or sex-related differences in the hip ROMs in elite tennis players.

Study 3:

6. To compare hip extension and rotation ROM measures in elite tennis players with and without a history of LBP.

2.3. Research hypothesis

The lack of studies on flexibility in tennis players hinders the development of several hypotheses for this doctoral thesis. Nevertheless, the following hypotheses were established:

Study 1:

1. Based on previous studies with junior and amateur tennis players (Ellenbecker et al., 1996; Kibler et al., 1996) and due to the asymmetric nature of tennis strokes, the players will show a deficit in both internal rotation ROM and total arc of rotation and an increase in external rotation ROM in the dominant shoulder compared to the non-dominant side.

2. Based on several studies with throwers (Myers et al., 2006; Wilk et al., 2011), the tennis players with a history of pain will show higher glenohumeral internal rotation and total arc of rotation deficits in the dominant shoulder than the players without a history of pain.

3. Considering the study by Kibler et al. (1996) and due to chronic exposure to tennis demands, the players' age, the years of tennis practice and the years of professional tennis play will be linked to glenohumeral rotational deficits in the dominant shoulder.

Study 2:

4. As a result of the musculoskeletal adaptations caused by repetitive multidirectional and cutting movements during training and competing in tennis, male and female elite tennis players will show lower passive and active hip ROMs than those of normative data from the general population (Gerhardt et al., 2002; Peterson-Kendall et al., 2005).

5. In light of the results obtained by Vad et al. (2003) and because of the large numbers of unilateral strokes performed by the elite tennis players, they will show bilateral differences in hip rotational ROM, especially internal rotation ROM reductions in the dominant side.

6. Females have higher estrogen production than males, which may result in lower tissue viscosity (Ibáñez, 1993). Based on this hormonal difference between sexes, elite female tennis players will show higher hip ROMs than elite male tennis players.

Study 3:

7. Considering that previous studies suggest that a deficit in hip extension and rotation ROM may be associated with LBP in athletes who regularly perform rotation-related sports (e.g., golf, judo, etc.) (Almeida et al., 2012; Murray et al., 2009; Vad et al., 2003), tennis players with a history of LBP will show lower hip extension and/or internal rotation ROM in both limbs than tennis players without a history of LBP.

CHAPTER 3

STUDY 1

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CHAPTER 3

STUDY 1

Comparison of shoulder rotation range of motion in professional tennis players with and without history of shoulder pain.

by

Moreno-Pérez V, Moreside J, Barbado D, Vera-Garcia FJ.

Abstract

A glenohumeral internal rotation deficit of the dominant shoulder relative to the non-dominant shoulder is considered a risk factor for shoulder injury in overhead athletes. The aim of this study was to investigate whether professional tennis players with a history of self-reported shoulder pain show differences in ROM of the dominant and non-dominant shoulder compared to asymptomatic controls. Forty-seven professional tennis players belonging to the Association of Tennis Professionals World Tour took part in the study: 19 with shoulder pain history and 28 without. Passive shoulder ROM was measured using a process of photography and software calculation of angles. The dominant shoulder had reduced internal rotation ROM and total rotation ROM, and increased external rotation ROM compared to the non-dominant side. These differences did not correlate significantly with years of tennis practice, years of professional play, nor the players' age. However, glenohumeral rotation ROMs correlated negatively with the duration of tennis practice and players' age. Although tennis players with shoulder pain history showed less internal rotation ROM in both

shoulders compared with the no-pain group, no significant differences between groups were found for external rotation ROM, side-to-side ROM asymmetries, years of tennis practice or years of professional play. In professional tennis players, limited internal rotation ROM rather than a glenohumeral internal rotation deficit of the dominant shoulder relative to the non-dominant shoulder, seems to be associated with shoulder pain history, duration of tennis practice and the players' age, when compared to a similar cohort with no history of shoulder pain.

Key words: *Elite athlete; Injury; Passive range of motion; Tennis.*

1. Introduction

Shoulder injuries are the most frequent type of upper extremity injury in professional tennis players with an incidence between 25 and 47.7% (Kibler and Safran, 2000, 2005; Pluim et al., 2006) and most being due to mechanical overload and/or repetitive mechanisms (Silva et al., 2003; Torres and Gomes, 2009). The literature describes several anatomical and mechanical adaptations which may be associated with increased risk of shoulder injury in overhead athletes, including strength imbalance between the agonist/antagonist muscles of the glenohumeral joint (Niederbracht et al., 2008; Saccol et al., 2010; Stanley et al., 2004), scapular dyskinesis (Kibler, 1998; Struyf et al., 2011), and asymmetries between the dominant and non-dominant shoulders in rotational passive ROM, i.e., higher glenohumeral external rotation (ER) (Ellenbecker et al., 1996; Kibler et al., 1996), lower glenohumeral internal rotation (IR) (Burkhart et al., 2003; Ellenbecker et al., 1996; Chandler et al., 1990; Hjelm et al., 2012; Kibler et al., 1996; Schmidt-Wiethoff et al., 2004; Stanley et al., 2004; Torres and Gomes, 2009;

Vad et al., 2003) and lower total arc of motion (TAM: the sum of internal and external rotation) of the dominant shoulder (Myers et al., 2006; Wilk et al., 2011). These differences between glenohumeral shoulder ROMs have been observed in comparison with control groups. In this way, Schmidt-Wiethoff et al. (2004) found that professional tennis players shown lower IR (43.8º ± 11º) and higher ER (89.1º ± 13.7º) in the dominant shoulder than a control group (IR: 61.6º ± 8.1º; ER: 85.4º ± 7.6º).

The difference in IR between the dominant and non-dominant sides, which is referred to as glenohumeral internal rotation deficit (GIRD) of the dominant shoulder, has been shown to affect shoulder stability (McCann and Bigliani, 1994; Tyler et al., 2000), potentially resulting in rotator cuff impingement and tears of the labrum (Burkhart et al., 2000; Gerber et al., 2003; Ticker et al., 2000), and has therefore been proposed as a criteria for the implementation of prevention (Gerber et al., 2003; Torres and Gomes, 2009) and rehabilitation programs (Cools et al., 2008; Ellenbecker et al., 2010) in tennis players. The current recommendation for defining a GIRD is a 20º difference in IR between the dominant and non-dominant glenohumeral joints (Kibler et al., 2012). However, GIRDs of as little as 11º and 18º have been associated with shoulder injury in baseball players (Myers et al., 2006; Wilk et al., 2011).

Although differences in glenohumeral rotation ROM between the dominant and non-dominant side have been observed in throwing (Thomas et al., 2010; Wilk et al., 2011) and racquet sports (Ellenbecker et al., 1996; 2002; Chandler et al., 1990; Kibler et al., 1996; Schmidt-Wiethoff et al., 2004; Torres and Gomes, 2009), few studies have analyzed the relationship between side-to-side asymmetries in rotation ROM and the history of shoulder pain in tennis players (Hjelm et al., 2012; Kibler 1998; Schmidt-Wiethoff et al., 2004). In that previous studies have focused on young tennis players (Hjelm et al., 2012) or recreational athletes (Stanley et al., 2004), their shoulders may not yet have reached full muscular development nor been subjected to the high demands of elite competition. Therefore, further research analyzing the relation between the GIRD and the risk of injury in elite tennis players is needed.

In this study, bilateral passive ROM of glenohumeral rotation (IR, ER and TAM) was analyzed in two samples of professional tennis players: one with a history of shoulder pain and the other with no such pain history. The objectives were to quantify the differences in ROM between the dominant and non-dominant sides, and compare rotation ROM and sided differences between the two participant groups. In addition, in that previous studies suggested that the dominant shoulder's GIRD and TAM deficit may be linked to a player's age and years of tennis practice (Kibler et al., 1996), the relationship was investigated between rotation ROMs, dominant vs. non-dominant shoulder ROM differences, years of tennis practice and years of professional tennis play.

2. Methods

2.1. Participants

Forty-seven professional tennis players, belonging to the ATP (Association of Tennis Professionals) World Tour, volunteered for this study (Table 1). Forty-three players were right-hand dominant and four were left-hand dominant. All were adult males, who at the time of the study were currently competing in the ATP tour. According to the ATP, during the recording phase of this study (2011-2013), 42.5% of the participants were ranked among the top 100, while 57.5% of the remaining players ranked among the top 1000 world tennis players.

The participants' inclusion criteria were: belonging to the ATP World Tour, to be actively competing at the time of the study, to not have shoulder pain nor have taken any type of medication for the treatment of pain or musculoskeletal injuries at the time of the study, and to not have undergone shoulder surgery.

Written informed consent was obtained from each participant prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethic Committee of the University.

The tennis players were divided into two groups according to the following criteria: a) Group with no pain history (NPH group) included 28 individuals who had not experienced shoulder pain; b) Group with pain history (PH group) included 19 tennis players who had experienced shoulder pain that had prevented them from training and/or competing during the 14 months prior to the study. ANOVA did not show significant differences between the NPH and PH groups for age, height, mass, years of tennis practice or years professional play (Table 1).

Table 1
Descriptive characteristics (mean ± standard deviation) of the professional tennis players organized by group.

	All tennis players (N = 47)	**No pain history (N = 28)**	**Pain history (N = 19)**	**F**	***p***
Age (years)	23.2 ± 4.9	22.2 ± 4.3	25.6 ± 3.0	3.624	.063
Height (cm)	183.6 ± 5.0	184.1 ± 5.8	182.7 ± 3.6	.886	.352
Mass (kg)	77.5 ± 6.5	77.60 ± 7.6	77.5 ± 4.8	.006	.938
Years of tennis practice	16.2 ± 5.6	15.3 ± 5.2	17.6 ± 6.0	1.883	.177
Years of professional play	5.9 ± 3.9	5.1 ± 3.3	7.0 ± 4.5	2.914	.095

2.2. Data collection

All data collections were performed during the pre-season months of November and December, 2011-2013. Upon the arrival of each participant, the measurement protocol was explained and demonstrated on each arm. Once the procedure was understood, measurements were performed in random order for both, dominant and non-dominant shoulder (Ellenbecker et al., 2002), and range of motion (ER and IR).

To measure passive glenohumeral rotation, each participant lay supine on a bench, with his shoulder in 90º of abduction and the elbow flexed to 90º (forearm perpendicular to the bench). From this starting position, a researcher held the participant's proximal shoulder region (i.e., clavicle and scapula) against the bench to stabilize the scapula while rotating the humerus in the glenohumeral joint to produce maximum passive ER (Figure 1a) and IR (Figure 1b). In both cases, glenohumeral rotation started at the perpendicular neutral position and finished upon reaching firm resistance to passive rotation. The forearm was placed and remained in a pronated position for the duration of the testing. Special attention was paid to constrain motion to pure glenohumeral rotation and minimize compensatory movements of the scapula-thoracic region during the maneuver. A photograph was taken once full ER or IR was achieved, thus capturing arm position for subsequent digitizing (Figures 1a, 1b). The camera (Canon® IXUS75 digital camera, Tokyo, Japan) was secured on a tripod at the participant's elbow height, at a distance of 70 cm from the elbow, with the optical axis perpendicular to the plane of movement. Based on Almeida et al. (2012) and Wilk et al.'s study (2011), digital pictures were taken when the examiner perceived the end of the passive ROM had been reached and before the occurrence of any compensatory scapular motion. Throughout the study, the arm was positioned, and photographs digitized, by the same physiotherapist who had 15 years of clinical experience. All photographs were taken by one researcher, with 5 years' experience in this area.

In order to evaluate the reliability of the measurements, two different analyzes were performed. Intra-rater reliability analysis was carried out on 94 pictures (47 participants x 2 sides), to test the examiner's ability to re-digitize the same photo twice (4 weeks apart). In addition, to assess the consistency of the entire protocol, we performed a test-retest reliability analysis of the measurements. Ten of the participants (age: 25.1 ± 4.9 years; height: 183.0 ± 4.8 cm; mass: 78.4 ± 4.8 kg) were measured a second time in a separate recording session, at least one week later.

2.3. Data analysis

In most previous studies, glenohumeral rotation has been measured using a goniometer with the participant lying supine (Hjelm et al., 2012; Kibler 1998; Schmidt-Wiethoff et al., 2004). In this study, ROM measurements were based on photos of maximum passive ER and IR (Figure 1). Corel Draw© v.12 software was used to digitize the ulnar styloid process and the olecranon (thus defining the forearm segment), and to calculate the range of ER and IR; i.e., the angles formed by the forearm segment and the vertical plane at the point of maximum rotation. To calculate glenohumeral TAM, the ER and IR values were added together. Absolute (degrees) and relative (%) ROM differences between the dominant and non-dominant shoulders were calculated relative to the non-dominant shoulder for ER, IR and TAM.

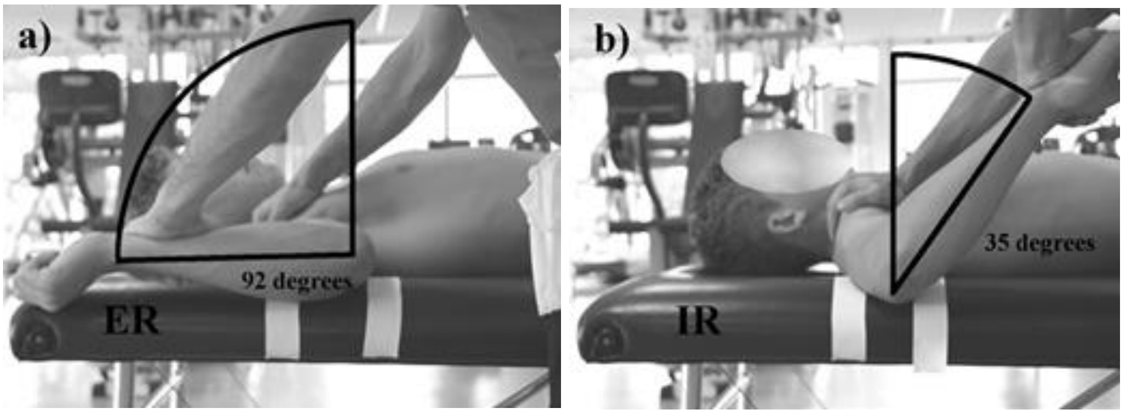

Figure 1. Assessment of the glenohumeral external and internal rotation range of motion (ER and IR, respectively): a) maximum ER position; b) maximum IR position. Note that the researcher rests his right hand on the subject's anterior shoulder area, applying enough force to stabilize the scapula-thoracic region and constrain shoulder motion to the sagittal plane. Corel Draw© v.12 software was used to digitalize and calculate the angles.

2.4. Statistical analysis

The average and standard deviation of the NPH and PH groups as well as the total sample were calculated for the following variables: TAM, ER, IR (both the dominant and non-dominant limbs for these 3 measurements), between-shoulder differences in ER, IR and TAM, as well as years of tennis practice and years of professional play.

Data normality was examined using the Kolmogorov-Smirnov statistic with a Lilliefors correction. The intra-class correlation coefficient (ICC2,1) and the standard error of measures (SEM) in degrees and percentage were calculated to assess both the intra-rater (N = 47) and test-retest (N = 10) relative and absolute reliability of the glenohumeral rotation ROMs and the between-shoulder differences in ROM. Two-way mixed-design ANOVAs were performed to explore the differences in the TAM, ER and IR between shoulders (within-subject factor: dominant and non-dominant) and between groups (between-subject factor: NPH and PH), and interactions. A one-way independent-measures ANOVA was carried out to compare between-shoulder differences in glenohumeral rotation ROMs among the NPH and PH groups, using a Bonferroni adjustment for pairwise comparisons.

Finally, Pearson's correlation coefficients were calculated to determine the relationship between the following variables: years of tennis practice, years of professional play, players' age, glenohumeral rotation ROMs of both shoulders, and between-shoulder differences in the glenohumeral rotation ROMs. All analyses were performed using the SPSS package (version 18, SPSS Inc., Chicago, IL, USA) with a significance level chosen at $p < 0.05$.

3. Results

Intra-rater reliability showed excellent values of ICC (> 0.94) and SEM (< 1.75º) for all ROM variables (Table 2). For test-retest reliability, ICC values of glenohumeral rotation ROMs were consistently higher than 0.90 excepting dominant shoulder TAM and IR (with ICCs of 0.86), and SEM values of glenohumeral rotation ROMs ranged from 1.04º-3.90º. ICC values for between-shoulder differences in the glenohumeral rotation ROMs ranged between 0.74 and 0.79, while SEM values ranged from 3.00º-6.09º, consistently higher than those of the TAM, ER and IR ROMs.

Table 2

Absolute and relative reliability assessed by standard error of measurement (SEM) and intraclass correlation coefficient ($ICC_{2,1}$) of the different glenohumeral rotation measurements collected.

	Test-retest reliability (N = 10)		Intra-rater reliability (N = 47)	
Variables	**$ICC_{2,1}$**	**SEM**	**$ICC_{2,1}$**	**SEM**
Total Arc of Motion				
Dominant (º)	0.86	3.90	0.99	1.07
Non-dominant (º)	0.93	2.36	0.99	0.91
Diff (º)	0.74	4.41	0.98	1.37
Relative Diff (%)	0.75	3.51	0.98	1.00
External Rotation				
Dominant (º)	0.95	1.83	0.98	1.18
Non-dominant (º)	0.95	1.75	0.98	0.90
Diff (º)	0.78	3.00	0.94	1.33
Relative Diff (%)	0.79	3.96	0.94	1.75
Internal Rotation				
Dominant (º)	0.86	3.47	0.99	0.75
Non-dominant (º)	0.98	1.04	0.99	0.52
Diff (º)	0.74	3.26	0.99	0.84
Relative Diff (%)	0.76	6.09	0.98	1.75

Abbreviations: Diff = absolute (degrees) differences between dominant and non-dominant shoulders; Relative Diff = relative (%) differences between dominant and non-dominant shoulders.

Table 3 shows glenohumeral rotation ROMs and between-shoulder differences in ROM for the two groups of participants: those with a history of shoulder pain and those without. Data is also presented for all the participants combined. Age, years of tennis practice and years of professional play were included as co-variables for ANOVAs, but showed no significant effects.

For the glenohumeral rotation ROMs, the two-way mixed-design ANOVA demonstrated no shoulder*group interactions (TAM: $p = 0.423$, $\eta 2 = 0.014$; ER: $p =$

0.307, η2 = 0.023; IR: p = 0.615, η2 = 0.006), nor significant differences between the NPH and PH groups in ER (p = 0.916, η2 = 0.001). However, significant between-group differences were found in TAM and IR (TAM: p = 0.028, η2 = 0.101; IR: p = 0.003, η2 = 0.179), and between the dominant and non-dominant sides for TAM, ER and IR (TAM: p = 0.01, η2 = 0.246; ER: p = 0.001, η2 = 0.577; IR: p = 0.001, η2 = 0.640). Specifically, ER was 6.3º (7.6%) higher and IR was 12.8º (21.6%) lower in the dominant shoulder (Table 3). Nevertheless, the one-way independent-measures ANOVA did not show significant differences between the NPH and PH groups for the between-shoulder absolute (TAM: p = 0.423, η2 = 0.014; ER: p = 0.307, η2 = 0.023; IR: p = 0.936, η2 = 0.001) and relative (TAM: p = 0.429, η2 = 0.014; ER: p = 0.246, η2 = 0.030; IR: p = 0.477, η2 = 0.011) differences in the rotational ROMs.

Table 3

Statistics (mean ± standard deviation) of the different glenohumeral rotation measurements collected.

	All tennis players (N = 47)	**No pain history (N = 28)**	**Pain history (N = 19)**
Total Arc of Motion			
Dominant (º)	136.2 ± 15.4[A]	139.4 ± 14.5[A]	131.5 ± 15.8[A]
Non-dominant (º)	142.3 ± 15.0	146.5 ± 13.0	136.1 ± 15.8[B]
Diff (º)	6.1 ± 10.3	7.1 ± 9.3	4.6 ± 11.6
Relative Diff (%)	4.1 ± 7.0	4.8 ± 6.3	3.1 ± 7.9
External Rotation			
Dominant (º)	90.5 ± 9.0[A]	90.3 ± 9.0[A]	90.8 ± 9.4[A]
Non-dominant (º)	84.2 ± 7.7	84.7 ± 6.7	83.6 ± 9.2
Diff (º)	6.3 ± 5.5	5.6 ± 5.6	7.2 ± 5.3
Relative Diff (%)	7.6 ± 6.9	6.6 ± 6.8	9.0 ± 7.0
Internal Rotation			
Dominant (º)	45.8 ± 12.1[A]	49.3 ± 11.3[A]	40.6 ± 11.6[AB]
Non-dominant (º)	58.6 ± 11.8	62.6 ± 11.0	52.5 ± 10.6[B]
Diff (º)	12.8 ± 9.4	13.3 ± 8.6	11.9 ± 10.5
Relative Diff (%)	21.6 ± 13.9	20.4 ± 12.5	23.4 ± 15.9

Abbreviations: Diff = absolute (degrees) differences between dominant and non-dominant shoulders; Relative Diff = relative (%) differences between dominant and non-dominant shoulders.

Pairwise comparisons with Bonferroni adjustment:

[A]Significantly different from non-dominant shoulder ($p < 0.05$).

[B]Significantly different from the no pain history group ($p < 0.05$).

Pearson's correlation coefficients (Table 4) showed no significant correlations between the absolute between-shoulder difference in glenohumeral rotational ROM and years of tennis practice, years of professional play, nor players' age. While decreased IR of the dominant shoulder correlated significantly with increased years of tennis practice, years of professional play and players' age, decreased ER of the dominant shoulder correlated only with increased years of professional play. Moreover, decreased ER and

IR of the non-dominant shoulder correlated significantly with increased years of tennis practice, years of professional play and players' age.

Table 4

Bivariate correlations of the different glenohumeral rotation measurements collected.

			Years		Dom		NDom		Diff	
		PP	**TP**	**Age**	**IR**	**ER**	**IR**	**ER**	**IR**	**ER**
Years	**PP**		.921†	.904†	-.325*	-.341*	-.472†	-.426†	-.211	-.037
	TP			.922†	-.313*	-.239	-.426†	-.424†	-.166	-.202
	Age				-.449†	-.221	-.475†	-.430†	-.084	-.238
Dom	**IR**					.058	.691†	.160	-.352*	.129
	ER						.138	.795†	.130	-.528†
NDom	**IR**							.159	.401†	-.005
	ER								.004	.095
Diff	**IR**									-.208
	ER									

PP = Years of professional play; TP = Years of tennis practice; Age = players' age; IR = Internal rotation; ER = External rotation; Dom = Dominant shoulder; NDom = Non-dominant shoulder; Diff = Differences between dominant and non-dominant shoulders.

*Pearson correlation is significant at the 0.05 level.

†Pearson correlation is significant at the 0.01 level.

4. Discussion

Previous literature suggests that a GIRD is associated with shoulder injury in overhead athletes (Ellenbecker et al., 1996; 2002; Chandler et al., 1990; Kibler et al., 1996; Schmidt-Wiethoff et al., 2004; Torres and Gomes, 2009). However, few studies have specifically analyzed the relationship between shoulder injuries/pain and GIRD in tennis players (Hjelm et al., 2012; Schmidt-Wiethoff et al., 2004; Torres and Gomes, 2009; Vad et al., 2003); and of these, only one (Vad et al., 2003) was carried out with professional athletes. The current study analyzed glenohumeral rotation characteristics and their possible relationship to shoulder pain history in elite tennis players with a long professional sport career (16.2 ± 5.6 years of tennis practice and 5.9 ± 3.9 years at professional level). According to the results, professional tennis players showed important adaptations in the dominant shoulder, specifically 21.6% (12.8º) less passive IR and 7.6% (6.3º) more passive ER than the non-dominant shoulder, thus supporting the findings of previous studies on overhead athletes (Ellenbecker et al., 1996; 2002; Kibler et al., 1996; Torres and Gomes, 2009). However, no significant differences were found among the NPH and PH groups for the side-to-side asymmetries in glenohumeral rotation ROMs. Conversely, there was significantly less IR in both shoulders and less TAM in the non-dominant shoulder for the PH group compared to the NPH group (Table 3).

Studies in vivo (Myers et al., 2006; 2007; Tyler et al., 2000) and in vitro (Grossman et al., 2005; Harryman et al., 1990) relate the IR deficit of the dominant shoulder to posterior glenohumeral joint capsule tightness and resulting anterior migration of the humeral head relative to the glenoid fossa. However, the biomechanical effect of posterior shoulder tightness on throwing pathologies remains unclear (Mihata et al., 2013). In most studies analyzing rotational ROM and shoulder pain in overhead athletes, the non-dominant shoulder is used as the reference to establish an IR deficit in the dominant shoulder (Myers et al., 2006; Vad et al., 2003; Warner et al., 1990; Wilk et al., 2011). However, based on the current results, an absolute low range of glenohumeral IR motion, rather than a unilateral IR reduction in the dominant shoulder (GIRD), seems to be associated with shoulder pain in professional tennis players. The non-dominant shoulder may also have limited glenohumeral IR due to circumstances such as innate poor flexibility, previous injuries and/or training adaptations in the shoulder. It would therefore seem appropriate to use IR of the dominant shoulder of players with no pain history and similar professional experience as the reference (normative data). In this sense, reliability analysis seems to support the use of glenohumeral rotation ROM as an index of shoulder injury rather than glenohumeral ROM differences between sides. Despite both groups of variables (absolute ROM values and side-to-side ROM differences) having shown good reliability (Atkinson and Nevill, 1998; Schabor 1998), in our study only glenohumeral rotation ROMs achieved ICC values > 0.90, which is a recommended threshold for clinical validity (Portney and Watkins, 1993).

In this study, professional tennis players in the PH group showed a mean of 40.6º of IR in the dominant shoulder, compared with 49.3º obtained by the NPH players (Table 3). However, IR ROM in the non-dominant shoulder was similarly greater in the NPH group (PH: 52.5º vs. NPH: 62.6º). Thus, the GIRD metric, which compares IR ROM in the dominant shoulder with that of the non-dominant side, was unable to differentiate between players with and without pain history.

These results differ from works by previous authors (Myers et al., 2006; Vad et al., 2003; Warner et al., 1990; Wilk et al., 2011) who reported a significant relationship between a GIRD and injury history in the dominant shoulder of overhead athletes, although only one study (Vad et al., 2003) was carried out on tennis players. This lack of agreement between the current data and those of previous authors may be due to differences in recording protocols and/or participant characteristics. For example, the study by Vad et al. (2003) does not provide a detailed description of the GIRD measuring protocol, nor information regarding players' ranking or number of years each had played at the professional or amateur level; all of which may affect outcomes. In addition, while most previous studies on glenohumeral rotation used goniometry to measure ROM (Hjelm et al., 2012; Kibler 1998; Schmidt-Wiethoff et al., 2004), an image-based analysis technique was used to perform measurements. Goniometry may be more readily available, but video and photo analyses allow researchers to both verify the correct test execution and measure the variables repeatedly post-collection, if necessary. In addition, using photography allows repeated training sessions for the examiner, facilitating good inter and intra rater reliability without the influence of the natural variability of the participants.

Previous works with junior and amateur tennis players (Hjelm et al., 2012; Stanley et al., 2004) concur with the present results, finding no relation between GIRD and pain in the dominant shoulder. However, the demands of training and competition (intensity, duration, frequency, etc.) are very different for the professional athlete, thus it is difficult to compare with these studies. Further research with professional and amateur tennis players together needs to be carried out to elucidate the effects that long-term repetition of tennis strokes have on the glenohumeral joint.

Previous literature indicates that loss of IR in the dominant shoulder is linked to duration of tennis practice and player's age (Kibler et al., 1996). The current study partially supports these results (Table 4), in that glenohumeral rotation ROM of both shoulders correlated negatively with years of tennis practice, years of professional play and players' age, despite the fact that no relationship was found between years of tennis or professional play and between-shoulder differences in glenohumeral rotation. Therefore, the range of IR, which has been linked to shoulder pain history in this study, seems to decline with both age and years of intense tennis practice (i.e., more matches and shots). Early detection of decreased glenohumeral ROM (specifically IR), as well as injury prevention training programs, may be useful to reduce the effects of age and years of tennis practice. However, future studies are required to further understand the relationship between age, internal rotation deficit and risk of shoulder injury.

Several limitations exist as to the interpretation of data in this study. While it would have been interesting to group the tennis players according to shoulder pathologies rather than pain, it was not possible to find a large enough sample of professional players with specific shoulder injuries to subdivide the groups in this way. Another limitation was that the post-injury rehabilitation programs undergone by the PH players were neither controlled or investigated, and may have modified their ROM at the time of this study. While other shoulder pain etiologies such as agonist/antagonist strength imbalances (Niederbracht et al., 2008; Saccol et al., 2010; Stanley et al., 2004), or scapular dyskinesis (Kibler, 1998; Struyf et al., 2011) would have been interesting to analyze, this was not possible due to difficulty coordinating the already lengthy data collection with the rigorous schedule of the professional tennis players. A final limitation is that skin markers were not used to identify anatomical landmarks, which could potentially reduce the accuracy of measurement. However, the small distance (70 cm) from the camera to the participants' arms allowed easy identification of the ulnar styloid process and olecranon process, thus achieving good intra-rater reliability (Table 2).

CHAPTER 4

STUDY 2

In press in Physical Therapy in Sport:

Descriptive profile of hip range of motions in elite tennis players.

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CHAPTER 4

STUDY 2

Descriptive profile of hip range of motions in elite tennis players.

by

Moreno-Pérez V, Ayala F, Fernandez-Fernandez J, Vera-Garcia FJ.

Abstract

Objective: To describe the ROM profile (flexion, extension, abduction, IR and ER) of the hip in elite tennis players; and (b) to analyze if there are sex-related differences in the hip ROM.

Design: Cohort study.

Setting: Controlled laboratory environment.

Participants: 81 male and 28 female tennis players completed this study.

Main outcome measures: Descriptive measures of passive hip flexion, extension and abduction, and internal and external active and passive hip rotation ROMs were taken. Magnitude-based inferences on differences between sex (males vs. females) and hip (dominant vs. non-dominant) were made by standardizing differences.

Results: No clinically meaningful bilateral and sex-related differences in any of the hip ROM measures. In addition, it was found that both males and females had restricted mobility measures on hip flexion (< 80º), extension (< 0º) and abduction (< 40º). Furthermore, the 30% of males also presented restricted active and passive hip IR ROM

values (< 25º). Finally, both males and females have reported normal mobility measures on hip ER ROM (active [> 25º] and passive [35º]).

Conclusions: Asymmetric hip joint ROM measures found during clinical examination and screening may indicate abnormalities and the need of rehabilitation (e.g., flexibility training). In addition, clinicians should include specific exercises (e.g., stretching) in their conditioning, prevention and rehabilitation programs aiming to avoid the restricted mobility on hip flexion (males = 74º; females = 78º), extension (males = -1.5; females = -0.4), abduction (males = 35º; females = 34º) and IR (males = 30º; females = 35) that might be generated as a consequence of playing tennis.

Keywords: *hip clinical examination; injury prevention; sport therapy; muscle strain*.

1. Introduction

Tennis has experienced a significant increase in popularity in recent years, becoming one of the most popular sports in the world, with more than 75 million people participating both, at recreational or at professional levels (Pluim et al., 2007). At professional level, the demanding competitive calendar of players can result in athletes focusing on competition and thus compromising training, leading to suboptimal recovery and preparation (Ellenbecker et al., 2009; Sell et al., 2014). Furthermore, in a tennis match, players usually perform a high number of multidirectional and cutting movements, together with asymmetric rotational actions produced by the serve and groundstrokes (Roetert et al., 2009b). These above-mentioned aspects could lead to an overload in the joints, impairing their normal motion and thus increasing the relative risk of injury (Chandler et al., 1990).

Previous studies analyzed the impact of these high repetition loads on the upper extremity joints at elite levels in order to effectively plan and establish successful prevention and rehabilitation programs, and reported a deficit in glenohumeral IR ROM of the dominant arm (Ellenbecker et al., 2002; Kibler et al., 1996; Moreno-Pérez et al., 2015; Roetert et al., 1996). This deficit has been suggested as a predisposing factor for increasing the likelihood of several shoulder and elbow pathologies (Moreno-Perez et al., 2015; Myers et al., 2011). Thus, tennis health care professionals began to include stretching exercises of the glenohumeral external rotator muscles in the dominant arm, during both, the pre- and in-season training schedules (Kovacs, 2006).

As previously mentioned, during tennis play the lower extremities are also subjected to repetitive loading forces (e.g., cutting movements). However, joint ROMs in the lower extremity have not been studied with the same vigor as that of the upper extremity. To the best of our knowledge, only two studies have examined the tennis-related alterations on the lower extremity joints (i.e., hip IR and ER ROM profile) in elite or professional players (Ellenbecker et al., 2007; Young et al., 2014), showing no specific hip alterations in rotational ROM.

Thus, it remains to be clarified whether the repetitive loading forces generated during tennis play induce alterations in the complete hip joint ROM profile in elite tennis players, such as bilateral differences or deficit in one or more ROMs. If these alterations do occur it may predispose tennis players to be more prone to several pathologies, such as: osteochondral and groin injuries (deficit in hip abduction ROM) (Verrall et al., 2007), low back pain (deficit in hip flexion and IR ROM) (Vad et al., 2003), abdominal strain (deficit in hip extension ROM) (Young et al., 2014), patello-femoral pain and hamstring strains (deficit in hip extension ROM) (Witvrouw et al., 2003, 2011).

Therefore, the aims of the present study were twofold: (a) to describe the hip ROM profile in elite tennis players; and (b) to analyze if there are sex-related differences in the ROM.

2. Methods

2.1 Participants

A total of 109 elite tennis players (81 males and 28 females) volunteered to participate in the study. Participants were recruited from 10 different high performance Spanish tennis academies. To qualify as an elite tennis player for the purpose of this study, participants held national rankings in their respective sex-related categories (48 males and 18 females) or played on the professional tennis tours (ATP or WTA) (34 males and 9 females). The exclusion criteria were: (a) history of orthopaedic problems in the previous three months that prevented practice or competition; and (b) presence of delayed onset muscle soreness at the testing session. The study was conducted during the pre-competitive phase of the year 2013. Demographic information was recorded from the participants before data collection (Table 5).

Prior to any participation, the experimental procedures and potential risks were fully explained to the participants and all provided written informed consent. The study was approved by the University Office for Research Ethics, and conformed to the Declaration of Helsinki.

Table 5

Demographic variables for the elite tennis players*

	Males	**Females**
Age (years)	19.7 ± 4.8	17.7 ± 2.2
Height (cm)	180.1 ± 6.5	171.3 ± 6.2
Body mass (kg)	72.1 ± 8.4	62.5 ± 5.7
Years playing tennis (years)	12.4 ± 5.3	10.7 ± 3.4
Weekly practice frequency ± SD	5 ± 1.2	4 ± 0.8
Hours of tennis practice per week ± SD	12.2 ± 2.1	10.8 ± 1.3
Hours of tennis practice per day ± SD	2.6 ± 0.5	2.1 ± 0.5

* All values are mean ± standard deviation

2.2. Procedure

The passive hip flexion (passive straight leg raise test [figure 2a]), extension (modified Thomas test [figure 2b]) and abduction (hip abduction with knee extended test [figure 2c]) ROMs of the dominant and non-dominant limbs were assessed following the methodology previously described (Cejudo et al., 2014). Furthermore, the active and passive hip rotation (IR [figure 2d and figure 2f for passive and active modalities respectively] and ER [figure 2e and figure 2g for passive and active modalities respectively]) ROMs were also measured using a previously described methodology (Almeida et al., 2012).

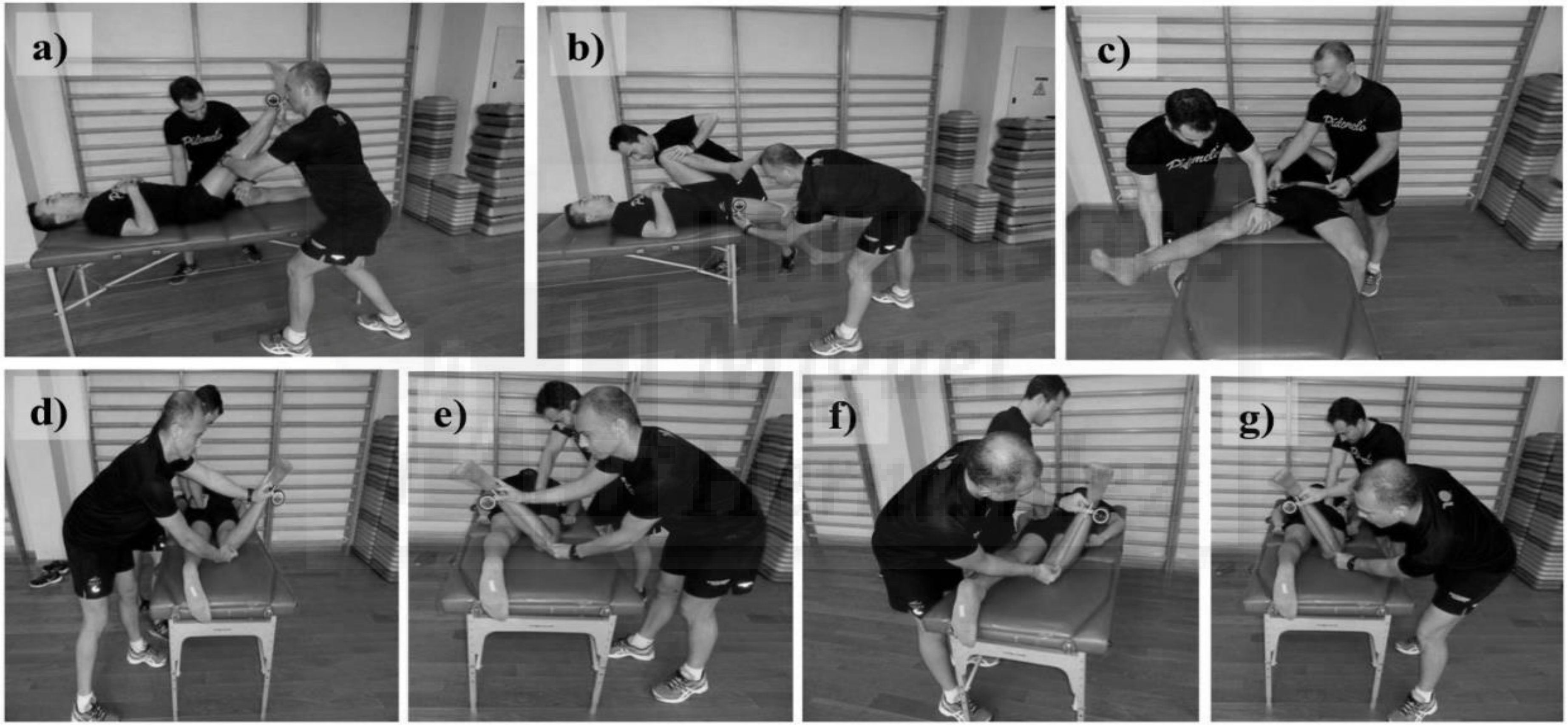


Figure 2. Hip range of motion assessment tests used in this study (a: passive straight leg raise test; b: modified Thomas test; c: hip abduction with knee extended test; d: passive hip internal rotation test; e: passive hip external rotation test; f: active hip internal rotation test; g: active hip external rotation test).

All tests were carried out by the same two physical therapists with more than 10 years' experience (one conducted the tests and the other ensured proper testing position of the participants throughout the assessment maneuvers) and under stable environmental conditions.

The dominant limb was determined according to the definition of Ellenbecker et al. (2007) for assigning lower extremity dominance in tennis players, defining the dominant leg as the lower extremity of the ipsilateral side of the forehand ground stroke and the same side as the upper extremity with which the player served.

Prior to the testing sessions, all participants performed a warm-up consisting in 5-min jogging and 8-min standardized static stretching exercises, emphasizing the lower-limb muscles (Cejudo et al., 2014). Participants performed 2 repetitions of 5 different unassisted static stretching exercises, holding the stretched position for 30 s.

After the warm-up, participants were instructed to perform, in a randomized order (using the software at http://www.randomizer.org), 2 maximal trials of each ROM test for each limb, and the mean score for each test was used in the subsequent analyses. When a variation > 5% was found in the ROM values between the two trials of any test, an extra trial was performed, and the two most closely related trials were used for the subsequent statistical analyses. Participants were examined wearing sports clothes and without shoes. A 30 s rest was given between trials, limbs and tests.

2.3. Measurements

An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for all hip ROMs except for the hip abduction ROM, where a flexible adjustable long arm goniometer was employed. A low-back protection support

(Lumbosant, Murcia, Spain) was used to standardize the lordotic curve (15º) during the assessments. The inclinometer was placed approximately over the external malleolus (for the hip flexion ROM [figure 2a]), the mid-point of the distal end of the fibula (for the hip IR and ER ROM [figure 2d-g]), and the greater trochanter of the femur (for the hip extension ROM [figure 2b]), and the distal arm was aligned parallel to an imaginary bisector line of the limb throughout each trial (Cejudo et al., 2014). For the assessment of the hip abduction ROM, one arm-goniometer was placed joining both anterior-superior iliac spines and the other arm was placed over the anterior face of the tested limb following its bisector line (Cejudo et al., 2014).

Variations in pelvic position and stability may affect the final score of several hip ROM measurements (Bohannon et al., 1985). Thus, to accurately evaluate hip ROMs, the assistant physical therapist ensured the suitable stabilization of the pelvis during all the tests in this study.

One or both of the following criteria determined the endpoint for each test: (a) palpable onset of pelvic rotation, and/or (b) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain. An extra endpoint criterion was established for the passive tests, i.e., the examiner's perception of firm resistance.

2.4. Statistical analysis

Prior to the statistical analysis, the distributions of raw data sets were checked using the Kolomogorov-Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for hip flexion, extension, abduction and rotation (ER and IR) ROM measures separately by sex and limb. Based on Ellenbecker et al. (2007), the number of athletes with side-to-side differences > 10º in each ROM measures were also calculated.

Furthermore, in each participant, the hip ROM scores were categorized as normal or restricted according to the reference values previously reported to consider an athlete as being more prone to suffer an injury (Holla et al., 2012; Peterson-Kendall et al., 2005; Roach et al., 2013; Young et al., 2014). In case no cut-off scores for detecting athletes at high risk of injury had been previously reported (i.e., passive hip abduction ROM, passive and active hip ER ROMs), comparing them with those which the general population have shown. Thus, ROM values were reported as restricted according to the following cut-off scores: < 80º for the passive hip flexion ROM (Peterson-Kendall et al., 2005), < 0º for the passive hip extension ROM (Young et al., 2014), < 40º for the passive hip abduction ROM (Gerhardt et al., 2002), < 25º for the passive hip IR ROM (Roach et al., 2013), < 35º for the passive hip ER (Roach et al., 2013), < 25º for the active hip IR ROM and < 30º for the active hip ER ROM (Holla et al., 2012; Roach and Miles, 1991).

Data were log-transformed prior to analysis to reduce the non-uniformity of error and back-transformed to obtain differences in means and variation as percentages. Magnitude-based inferences on differences between sex (male vs. female) and limb (dominant versus non-dominant) were made by standardizing differences following the procedure reported by Batterham and Hopkins (2006). Magnitudes of standardized differences in means were assessed with the following scale: 0 to 0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, 2.0 to 4.0 very large, and ≥ 4.0 extremely large. To reduce the likelihood of errors about inferred magnitudes, 99% was chosen as the level for the confidence intervals. A difference was reported as unclear when the confidence interval of the standardized difference crossed the threshold for both substantially positive (0.2) and negative (-0.2) values. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, v. 20.0 for

Windows; SPSS Inc, Chicago) and a spreadsheet design by Hopkins (2007). The level of significance was set at $p < 0.05$.

3. Results

Tables 6 and 7 show the descriptive ROM values (mean ± SD) for passive hip flexion (males = 75.1 ± 8.2º; females = 81.0 ± 9.2º), extension (males = -1.1 ± 5.6º; females = -0.7 ± 7.6º), abduction (males = 34.5 ± 5.6º; females = 33.5 ± 5.7º) and passive (IR [males = 31.1 ± 9.4º; females = 36.0 ± 7.5º] and IR [males = 51.2 ± 8.0º; females = 49.4 ± 5.7º]) and active rotation (IR [males = 28.5 ± 8.6º; females = 34.2 ± 9.5º] and ER [males = 51.9 ± 7.6º; females = 49.1 ± 8.7º]) from both, males and females, respectively. A large percentage of all participants showed restricted passive hip flexion (males ≈ 76%; females ≈ 45%), extension (males ≈ 55%; females ≈ 50%) and/or abduction (males ≈ 86%; females ≈ 75%) ROM values. In addition, approximately 40% of males reported restricted active and/or passive hip IR ROM values. Contrarily, most players reported normal active and passive hip ER ROM scores, with percentage values ranging from 70% (passive hip ER ROM) to 99% (active hip ER ROM) and from 95% (passive hip ER ROM) to 100% (active hip ER ROM) for males and females, respectively.

As presented in table 6, in males, there were no meaningful differences between dominant and non-dominant passive hip extension, passive hip ER and active hip IR and ER (standardized differences in means < 0.20). However, small but statistically significant differences (standardized differences in means from 0.20 to 0.60) were found in passive hip flexion, passive hip abduction and passive hip ER between dominant and non-dominant limb. In females, there were no significant differences between dominant and non-dominant passive hip extension, passive hip ER and IR and active hip IR and

ER (standardized differences in means < 0.20). However, small differences were found in passive hip flexion and abduction ROM measures between dominant and non-dominant limb.

Table 6

Males descriptive values and inference about side-to-side difference for hip flexion, extension, abduction and internal and external rotation ranges of motion (n = 81).

Range of motion (º)	Dominant limb		Non-dominant limb		Players with side-to-side differences >10º	Standardized difference[T]	Qualitative Outcome
	Mean ± SD	Qualitative Outcome*	Mean ± SD	Qualitative Outcome*			
Passive hip flexion	75.1 ± 8.2	Restricted (61)	73.6 ± 8.2	Restricted (63)	0	0.20 ± 0.15	Small +
Passive hip extension	-1.1 ± 5.6	Restricted (40)	-1.75 ± 5.5	Restricted (49)	0	-0.12 ± 0.10	Trivial
Passive hip abduction	34.5 ± 5.6	Restricted (72)	35.6 ± 5.1	Restricted (68)	2	-0.20 ± 0.15	Small -
Passive hip internal rotation	31.1 ± 9.4	Normal (25)	28.9 ± 9.7	Normal (28)	10	0.28 ± 0.15	Small +
Passive hip external rotation	51.2 ± 8.0	Normal (4)	49.9 ± 7.9	Normal (2)	16	0.13 ± 0.17	Trivial
Active hip internal rotation	28.5 ± 8.6	Normal (33)	30.6 ± 8.4	Normal (26)	0	-0.11 ± 0.05	Trivial
Active hip external rotation	51.9 ± 7.6	Normal (1)	52.7 ± 7.6	Normal (0)	1	-0.06 ± 0.02	Trivial

º: degrees; *: qualitative score of the mean range of motion, in parentheses the number of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section); T: mean ± 90% confidence limits; + or − indicates an increase or decrease from dominant limb to non-dominant limb.

Table 7

Women´s descriptive values and inference about side-to-side difference for hip flexion, extension, abduction and internal and external rotation ranges of motion (n = 28).

Range of motion (º)	Dominant limb		Non-dominant limb		Players with side-to-side differences >10º	Standardized difference^{T}	Qualitative Outcome
	Mean ± SD	Qualitative Outcome*	Mean ± SD	Qualitative Outcome*			
Passive hip flexion	81.0 ± 9.2	Normal (11)	77.2 ± 10.1	Restricted (15)	0	0.41 ± 0.31	Small +
Passive hip extension	-0.7 ± 7.6	Restricted (15)	0.2 ± 7.0	Normal (14)	0	0.11 ± 0.20	Trivial
Passive hip abduction	33.7 ± 5.7	Restricted (22)	35.7 ± 5.3	Restricted (20)	0	-0.33 ± 0.21	Small -
Passive hip internal rotation	36.0 ± 7.5	Normal (2)	35.2 ± 8.8	Normal (3)	2	0.18 ± 0.26	Trivial
Passive hip external rotation	49.4 ± 5.7	Normal (0)	49.2 ± 7.9	Normal (1)	2	0.10 ± 0.40	Trivial
Active hip internal rotation	34.2 ± 9.5	Normal (4)	36.9 ± 9.9	Normal (2)	0	-0.04 ± 0.02	Trivial
Active hip external rotation	49.1 ± 8.7	Normal (1)	48.1 ± 7.3	Normal (0)	0	0.05 ± 0.09	Trivial

º: degrees; *: qualitative score of the mean range of motion, in parentheses the number of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section); T: mean ± 90% confidence limits; + or − indicates an increase or decrease from dominant limb to non-dominant limb.

Statistical analysis also reported trivial differences between sexes for passive hip abduction, passive hip flexion, passive hip extension and active hip ER ROM measures (standardised difference < 0.20). However, moderate differences (standardized differences in means > 0.60) between sexes were found for passive and active IR ROM measures, with females showing higher scores than males.

4. Discussion

The results obtained in the present study reported statistically significant bilateral differences between the dominant and non-dominant hip flexion and abduction ROM in both sexes, and in hip IR ROM for males. However, from a clinical standpoint application, the magnitude of these differences (< 6º) could be considered as non-relevant because none of them exceed the threshold of 10º proposed in previous studies for male and female elite tennis players (Ellenbecker et al., 2007; Young et al., 2014). Furthermore, by calculating the number of players with bilateral differences greater than 10º in any hip ROM measure, fewer than 14% of the players were identified (passive hip flexion = 0%, extension = 0%, abduction = 1.8%, IR = 10.9% and ER = 13.8%; and active hip IR = 0.9% and ER = 0%).

Unlike glenohumeral IR in elite tennis players, for which tennis-specific bilateral differences have been consistently measured and identified (Kibler et al., 1996; Moreno-Pérez et al., 2015), the results of the current study support previous findings and stated that there doesn’t seem to be similar bilateral differences in hip ROMs patterning (Ellenbecker et al., 2007; Young et al., 2014). A possible explanation for this above-mentioned discrepancy between hip and shoulder ROMs might be due to the fact that tennis requires a different movement patterns between the upper and lower body. The demands of the game (e.g., velocity of the ball) require the players to use “open stance" positions for both, forehand and backhand strokes (Roetert et al., 2009b), and repetitive loading forces may be more balanced across the hip than in the shoulder, in which the kinetic chain mainly involves one upper limb. In addition, it may also be that bony rather than soft tissue constraints to ROM are more relevant in the hip joint, which in turn would be less prone to adaptations such as capsular tightness than in the shoulder (Young et al., 2014). Thus, based on the results of this study, the identification of hip ROM bilateral differences between extremities cannot be thought to represent a tennis-specific adaptation. However, Sanchis-Moysi et al. (2011), using magnetic resonance imaging, found that iliopsoas and gluteal muscles were asymmetrically hypertrophied in professional tennis players (i.e., the non-dominant iliopsoas was 13% greater than the dominant) compared to a healthy control group. Based on these results and taking into account the dynamic nature of tennis, it seems that a more functional testing (e.g., unilateral countermovement jump, Y-balance test, etc.) could be recommended in order to analyze these bilateral asymmetries.

To consider an athlete as being more prone to suffer an injury, ROM values should be compared to reference values, normally obtained from general and healthy populations. Analyzing the present results, a large number of male and female players showed restricted ROM values for passive hip flexion (cut-off score < 80º; mean ± SD: males = 75.1 ± 8.2º; females = 81.0 ± 9.2º), extension (cut-off score < 0º; mean ± SD: males = -1.1 ± 5.6º; females = -0.7 ± 7.6º) and abduction (cut-off score < 40º; mean ± SD: males = 34.5 ± 5.6º; females = 33.5 ± 5.7º). These restricted ROM values might be explained by the on-court body positions adopted by players, as they need to show a "low ready position" which helps to generate power during tennis strokes (Kovacs, 2006; Roetert et al., 2009b). Together with the short and repetitive on-court movements, players are required to maintain the hip flexor, extensor and adductor muscles in a shortened contracted position for long periods. Comparisons are not possible as there is no previous study analyzing the restricted mobility of hip flexion, extension and abduction in elite tennis players. Based on the present results, preventive stretching exercises of the hip, enhancing flexion, extension and abduction ROM would be recommended, and they should be an integral part of a tennis player's conditioning and injury prevention programs.

Another interesting finding of the present study was that the mean ROM values obtained for the hip IR and RE might be considered as normal, based on the reference values reported in previous research (> 25º for active [mean ± SD: males = 28.5 ± 8.6º; females = 34.2 ± 9.5º] and passive [mean ± SD: males = 31.1 ± 9.4º; females = 36.0 ± 7.5º] IR; > 35º for active [mean ± SD: males = 51.2 ± 8.0º; females = 49.4 ± 5.7º] and passive [mean ± SD: [males = 51.9 ± 7.6º; females = 49.1 ± 8.7º] ER). In addition, the greater passive and active hip ER found, compared with IR, is consistent with values reported in different athletes, including elite tennis players (Ellenbecker et al., 2007; Young et al., 2014), as well as in general population (Kouyoumdjian et al., 2012; Roach et al., 2013).

When analyzing the number of tennis players with restricted hip IR and/or ER ROMs more in detail, a large number of male players reported a restriction in both passive and active hip IR ROMs (34% and 40%, respectively) in contrast with their counterpart females. A possible explanation for these sex-related differences could be related to the higher training volume (i.e., hours per week and day) reported in males (table 5), combined with a bigger sample size also in males (81 vs. 28), although when the number of players with restricted mobility in hip IR were transformed to percentages, the differences were still high (40% and 14% for males and females, respectively). Since we are not aware of similar studies addressing this issue in elite tennis players, comparisons are not possible. We could speculate that the higher training volumes reported for male players could lead to a higher number of repetitive and powerful rotational movements (i.e., serves and groundstrokes) during both, training sessions and matches (Brown and O'Donoghue, 2008; Fernandez-Fernandez et al., 2009a). It is plausible that these high torsional forces could lead to micro-trauma and capsular contracture, causing a hip IR ROM deficit in many of the male players (Vad et al., 2003). Therefore, preventive stretching exercises of the hip ER muscles would be also recommended for males.

While the results of this study have provided information regarding the profile of hip ROM in elite tennis players, limitations to the study must be acknowledged. The age distribution of participants was relatively narrow and the female sample size was small. Moreover, the use of different testing methodologies (i.e., active hip IR) (Ellenbecker et al., 2007) makes comparisons difficult.

CHAPTER 5

STUDY 3

Under review in Manual Therapy:

Comparison of hip flexion and rotation ranges of motion in elite tennis players with and without history of low back pain.

Moreno-Pérez V, Lopez-Valenciano A, Ayala F, Fernandez-Fernandez J, Vera-Garcia FJ.

CHAPTER 5

STUDY 3

Comparison of hip flexion and rotation ranges of motion in elite tennis players with and without history of low back pain.

by

Moreno-Pérez V, Lopez-Valenciano A, Ayala F, Fernandez-Fernandez J, Vera-Garcia FJ.

Abstract

Although LBP is known to be multi-factorial, it has suggested that a deficit in hip extension and rotation ROM may be associated with LBP in athletes who regularly participate in rotation-related sports. The aim of this study was to compare hip extension and rotation ROMs in elite tennis players with and without a history of LBP. A total of 42 male and 22 female elite tennis players completed this study. Participants were divided into two groups: (1) history of LBP (LBP group; 22 males and 10 females) and (2) no history of LBP (control group; 20 males and 12 females). Descriptive measures of passive hip extension and rotation (IR and ER) ROMs of the dominant and non-dominant limbs were taken. Furthermore, the active hip rotation (IR and ER) ROMs were also assessed. Magnitude-based inferences on differences between groups (LBP group vs. control group) and leg (dominant vs. non-dominant) were made by standardizing differences. The inter-group statistical analysis reported no significant differences ($p > 0.05$; trivial effect with a probability higher than 95%; $d \leq 0.4$) in any

ROM measure analyzed. Further, neither LBP group nor control group reported significant bilateral or side-to-side differences ($p > 0.05$; trivial effect with a probability higher than 99%; $d < 0.3$) between legs regarding hip extension and rotation ROM measures. The findings of this study did not report any association between hip extension and rotation ROMs and LBP incidence in elite tennis players.

Keywords: *Low back pain; Injury prevention; Injury risk; Flexibility training; Elite athlete, tennis.*

1. Introduction

Tennis is a global sport, with participation in more than 200 countries affiliated with the International Tennis Federation (ITF) (USTA, 2015). The repetitive loads produced by on-court movements and strokes place all types of players (from recreational to professional level) at risk of injury (Pluim et al., 2006). Non-specific LBP is one of the most prevalent musculoskeletal disorders in tennis players, with values ranging from 10% to 32% of all the registered injuries (Hjelm et al., 2010; Kibler and Safran, 2005; Lundin et al., 2001, Pluim et al., 2006). Each LBP episode may have negative consequences not only in the health status of the tennis players but also in the successful development of their sport career. For instance, in a sample of 148 professional tennis players, it was found that 38% of them reported LBP as the reason for missing at least one tournament (Hainline, 1995). Further, LBP resulted in an average of 34 days of missed training in Australian junior players (Campbell et al., 2013), representing nearly half of all days lost as a result of injury for these athletes.

However, despite the high prevalence, the etiology of LBP in tennis is poorly understood (Campbell et al., 2013; Harris-Hayes et al., 2009).

LBP is known to be a multi-factorial condition with potential risk factors grouped broadly into psychological, social and biological domains (McGill, 1997). However, the repetitive ballistic trunk movement required in tennis, that has been linked with the high frequency of pars interarticularis stress reactions in other populations (Foster et al., 1989), underpins the likelihood of a mechanical etiology in tennis (Alyas et al., 2007; Kibler and Safran, 2005). It has been suggested that the repeated rapid rotation of the lumbar spine during tennis groundstrokes, together with the "hyperextension" during the serve motion may be associated with the high rate of radiological abnormalities in tennis players (Alyas et al., 2007). In this sense, it has been theorized that the mechanical stress imposed to the lumbar spine during the serve and groundstrokes may be higher when a deficit in hip rotation ROM is present (Harris-Hayes et al., 2009; Vad et al., 2004; Van Dillen et al., 2008). The rationale of this statement is based on the fact that a deficit in the hip rotation motion may be compensated by hypermobility of the lumbopelvic region during tennis strokes, increasing loads on the lumbar spine and thus increasing the likelihood of suffering a LBP incident (Harris-Hayes et al., 2009,Vad et al., 2003; Van Dillen et al., 2008). Furthermore, it has been also suggested that a lack of hip extension motion might be compensated with an increase in anterior pelvic tilt during gait (Thambyah et al., 2003), which may produce not only an abnormal mechanical load distribution in the hip but also an increased activation of the low back musculature (Neumann, 2010). Excessive activation of lumbar spine extensor muscles may lead to early onset fatigue and decreased protection from the shearing and torsional loads to lumbar spine (Johanson et al., 2011), generated mainly during tennis serves and smashes, and this might increase the risk of suffering a LBP incident. The role that hip abduction, adduction and flexion ROMs play in the development of LBP appears to be limited based on current understandings of the condition (Roach et al., 2015).

Few studies have addressed scientifically the analysis of the relationship between LBP prevalence and reduced hip extension and rotation ROMs in athletes (Almeida et al., 2012; Evans et al., 2005; Murray et al., 2009; Roach et al., 2015; Vad et al., 2003; Vad et al., 2004; Van Dillen et al., 2008: Young et al., 2014). Among the above-mentioned studies, only two of them (to the authors´ knowledge) have analyzed the possible link between hip extension and rotation ROM measures and the incidence of LBP in tennis players, reporting conflicting results (Vad et al., 2003; Young et al., 2014). Therefore, it remains to be clarified whether tennis players who show restriction in hip extension and rotation ROMs might be more prone to suffer a LBP episode. This knowledge might enhance current screening methods and help to identify deficiencies in ROM measures that predispose a tennis player to LBP. Furthermore, in case of reporting a relationship between LBP and restricted hip flexion and rotation ROMs, it would be also very useful for coaches and physical trainer to develop both evidence-based sports-specific preventive and therapeutic strategies (e.g., specific stretching programs) to reduce the likelihood of suffering a LBP episode.

Therefore, the aim of the present study was to compare hip extension and rotation ROM measures in elite tennis players with and without a history of LBP in order to make evidence-based recommendations for preventive and therapeutic strategies.

2. Methods

2.1. Participants

A total of 75 elite tennis players (47 males and 28 females) took part in this study. Participants were recruited from 10 different high performance Spanish tennis academies. To qualify as an elite tennis player for the purpose of this study, participants held national rankings in their respective sex-related categories (13 males and 21 females) or played in the professional tennis tours (ATP and WTA) (34 males and 9 females). The study was conducted during the pre-competitive phase of the year 2013. Other inclusion criteria were: a) a history of LBP in the past 12 months; or b) never having had a history of LBP. It was determined that LBP must have lasted for at least two weeks in order to exclude simpler cases that lasted only a few days (Almeida et al., 2012; Murray et al., 2009; Vad et al., 2003). The exclusion criteria were: a) a history of hip/knee orthopedic problems within the previous three months that prevented practice or competition; and b) a presence of delayed onset muscle soreness at the testing session. Furthermore, participants with a history of LBP due to a traumatic mechanism or a history of spinal surgery were also excluded.

Prior to any participation, the experimental procedures and potential risks were fully explained to the participants and all provided written informed consent. The study was approved by the Ethic Committee of the University, and conformed to the Declaration of Helsinki.

Forty-two males and 22 females, classified as elite tennis players, completed this study. Five males and 6 females were excluded from the study because they reported degenerative disk disease (3 males and 2 females), herniated disk (1 male and 2 females) or presence of delayed onset muscle soreness at the testing session (1 male and 2 females).

2.2. Clinical Measures

Demographic information was recorded from the participants before data collection for different variables, including years of competitive sport performance, frequency of weekly practice and hours of practice per day and week. In addition, information related to LBP episodes in the previous 12 months, characteristics of LBP and a visual analogue scale for pain (i.e., VAS) was also collected. The Roland-Morris questionnaire was employed to assess subjective functional capacity of the lumbar region (Kovacs et al., 2002). Based on the results of the questionnaire, the participants were divided into two groups: (1) group with a history of LBP (LBP group; 22 males and 10 females) and (2) group with no a history of LBP (control group; 20 males and 12 females).

2.3. ROM measures

The passive hip extension (modified Thomas test [figure 3]) and the active and passive hip rotation (IR [figure 4] and ER [figure 5]) ROMs of the dominant and non-dominant limbs were assessed following the methodology previously described (Almeida et al., 2012; Cejudo et al., 2014). Tests were carried out under stable environmental conditions by the same two physical therapists with more than 10 years' experience (one conducted the tests and the other ensured proper testing position of the participants throughout the assessment maneuver). The dominant limb was determined according to the definition of Ellenbecker et al. (2007) for assigning lower extremity dominance in tennis players, defining the dominant leg as the lower extremity of the ipsilateral side of the forehand ground stroke and the same side as the upper extremity with which the player served.

Figure 3. Assessment of the passive hip extension ROM (modified Thomas test).

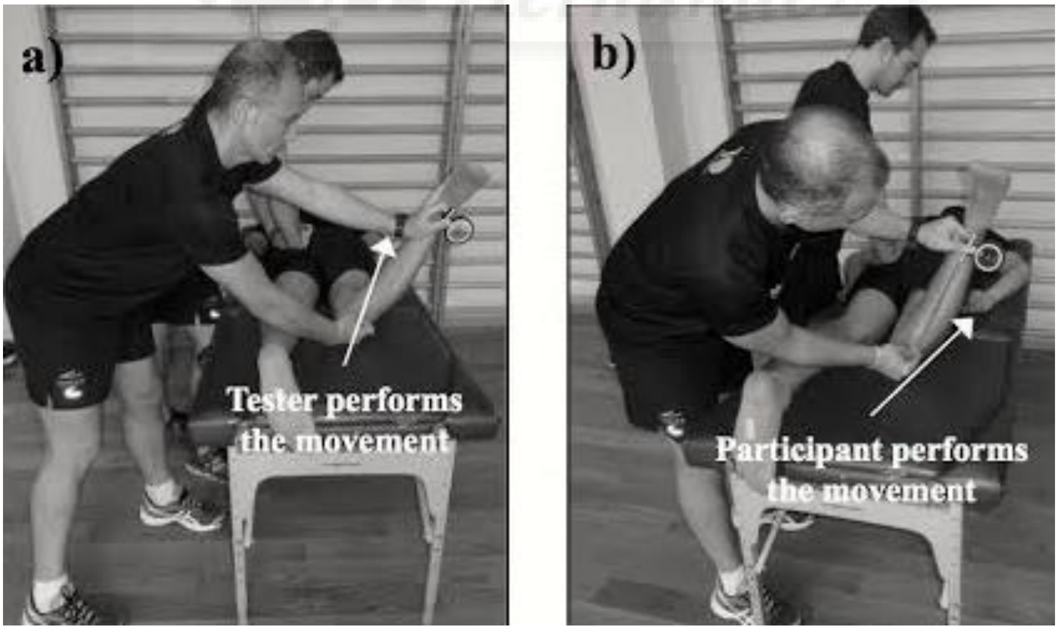


Figure 4. Assessment of the hip IR ROM test (a: passive hip IR test; b: active hip IR test).

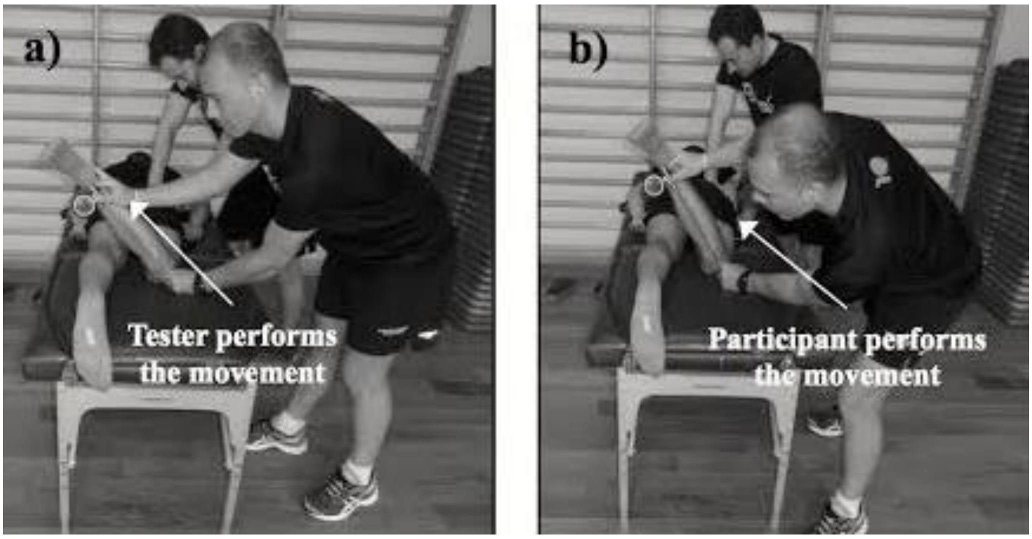


Figure 5. Assessment of the hip ER ROM test (a: passive hip ER test; b: active hip ER test).

Prior to the testing sessions, all participants performed a warm-up consisting in 5-min jogging and 8-min standardized static stretching exercises, emphasizing the lower-limb muscles (Cejudo et al., 2014). After the warm-up, participants were instructed to perform, in a randomized order, 2 maximal trials of each ROM test for each limb, and the mean score for each test was used in the subsequent analyses. Participants were examined wearing sports clothes and without shoes. A 30 s rest was given between trials, limbs and tests.

An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for all hip ROMs. The inclinometer was consistently placed level before each measurement to ensure that no change occurred in the sensitivity. A low-back protection support (Lumbosant, Murcia, Spain) was used to standardize the lordotic curve (15º) during the hip extension ROM assessment. The inclinometer was placed approximately over the greater trochanter of the femur (for the hip extension ROM [figure 3]) and over the mid-point of the distal end of the fibula (for the hip IR and ER ROM [figure 4 and figure 5, respectively]), and the distal arm was aligned parallel to an imaginary bisector line of the limb throughout each trial.

Variations in pelvic position and stability may affect the final score of several hip ROM measurements (Bohannon et al., 1985). Thus, to accurately evaluate hip ROMs, the assistant physical therapist ensured the suitable stabilization of the pelvis during all the tests in this study.

One or both of the following criteria determined the endpoint for each test: (a) palpable onset of pelvic rotation, and/or (b) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain. An extra endpoint criterion was established for the passive tests, i.e., the examiner's perception of firm resistance.

2.4. Statistical analysis

Before data collection, the intra-tester reliability of the passive hip extension and active and passive hip rotation (IR and ER) ROM measures using the procedures just described was determined by the test administrators using a test-retest design. Twenty healthy tennis players (10 males and 10 females) with no previous history of LBP who were not involved in this study agreed to participate in a pilot study to assess the measurement reliability. The hip extension and rotation ROMs were measured twice within a one-week interval. An ICC2k and a coefficient of variation (SEM expressed as a percentage [CV]) were calculated from the results of subsequent measurements. Results of the two testing sessions showed high reliability scores for all the ROM measures ($ICC > 0.95$ and $CV < 6\%$), which was consistent with previous studies (Almeida et al., 2012, Cejudo et al. , 2014).

The distributions of raw data sets were checked using the Kolomogorov-Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for each measure for LBP group and control group separately. The Student's t-test was used to identify differences in demographic and sport-related variables between the two groups.

A spreadsheet designed to compare means of the two groups was used to determine differences in hip extension and rotation ROM measures between groups (inter-groups comparisons) as well as to determine differences in hip extension and rotation ROM measures between the dominant and non-dominant limbs within each group (intra-group comparisons) (Hopkins et al., 2009). Alpha was $p < 0.05$. In addition, the analysis determines the chances that the true effects are substantial or trivial when a value for the smallest worthwhile change is entered.

For intra-group and inter-group comparisons, the standardized difference of 10º in hip rotation (IR and ER) ROMs has been previously suggested as the smallest worthwhile change to identify impairments in professional tennis players (Ellenbecker et al., 2007, Young et al., 2014). However, based on the authors´ extensive clinical experience, this difference of 10º was considered too restrictive. Consequently, a difference of 7º in both hip extension and rotation ROM scores was used to determine the smallest clinically relevant change to make inference about the true/real differences.

The qualitative descriptors previously proposed (Batterham and Hopkins, 2006) were used to interpret the probabilities (clinical inferences based on threshold chances of harm and benefit of 0.5% and 25%) that the true affects are harmful, trivial or beneficial: < 1%, almost certainly not; 1-4%, very unlikely; 5-24%, unlikely or probably not; 25-74%, possibly or may be; 75-94%, likely or probably; 95-99%, very likely; > 99%, almost certainly.

Effect sizes were also calculated to determine the magnitude of differences between the groups or limbs for each variable using the method previously described (Cohen, 2013), assigning descriptors to the effect sizes (d) such that an effect size of 0.4

or less represented a small magnitude of change, while 0.41–0.7 and greater than 0.7 represented moderate and large magnitudes of change, respectively.

3. Results

Table 8 shows the mean and standard deviation for the demographic (age, mass, height, body mass index) and sport-related (training experience, weekly training frequency and hours of training per day and per week) variables of the analyzed groups (LBP group and control group). There were not statistically significant differences ($p > 0.05$) between the LBP group and control group for demographic and sport-related variables.

Table 8
Characteristics of tennis players with history of low back pain (LBP) and those without LBP (control group [CG]).

	LBP group (N = 32)	**CG group (N = 32)**
Age ± SD (years)	19.6 ± 3.2	19.6 ± 2.9
Weight ± SD (kg)	71.1 ± 9.3	70.1 ± 10.1
Height ± SD (cm)	179.7 ± 6.9	176.9 ± 8.5
BMI (Kg/m^2)	21.9 ± 1.6	22.2 ± 1.9
Years of tennis practice ± SD	11.8 ± 5.7	12.4 ± 4.1
Weekly practice frequency ± SD	5 ± 1.2	5 ± 0.8
Hours of practice tennis per week ± SD	12.2 ± 2.1	11.8 ± 1.9
Hours of practice tennis per day ± SD	2.6 ± 0.5	2.5 ± 0.5

SD: standard deviation; cm: centimeters; kg: kilograms; m: meters

The inter-group statistical analysis reported no significant differences ($p > 0.05$; trivial effect with a probability higher than 95%; $d \leq 0.4$) in passive hip extension and rotation (IR and ER) ROM measures in the dominant and non-dominant limbs (Table 9). Further, for both legs the inter-groups differences for active hip IR and ER ROM measures were "very likely trivial" ($p > 0.05$; $d < 0.4$).

Table 9

Inter-group differences (LBP versus CG) for passive hip extension and rotation (internal and external) ROMs values as well as for active hip rotation (internal and external) ROM values. Chances that the true effects were substantial and practical assessments of the effects are also shown.

Range of motion (º)	Change[T]	Effect Size (d)	Chances that the true effects[a] were positive/ trivial / negative			Qualitative inference[b]
Dominant leg						
- Passive hip extension	-3.8 (-6.2 to -1.4)	-0.4	0	99	1	Very likely trivial
- Passive hip internal rotation	0.1 (-3.9 to 4.2)	0.1	0	100	0	Most likely trivial
- Passive hip external rotation	-4.0 (-7.1 to -0.9)	-0.5	0	95	5	Likely trivial
- Active hip internal rotation	1.0 (-3.4 to 5.3)	0.1	1	99	0	Very likely trivial
- Active hip external rotation	-1.8 (-5.5 to 1.8)	-0.1	0	99	1	Very likely trivial
Non-dominant leg						
- Passive hip extension	-3.0 (-5.3 to -0.7)	-0.4	0	100	0	Most likely trivial
- Passive hip internal rotation	-1.7 (-5.8 to 2.5)	0.2	0	98	2	Very likely trivial
- Passive hip external rotation	-2.6 (-6.1 to 0.9)	-0.3	0	98	2	Very likely trivial
- Active hip internal rotation	-0.7 (-5.1 to 3.8)	-0.1	0	99	1	Very likely trivial
- Active hip external rotation	-0.2 (-4.2 to 3.8)	-0.1	0	100	0	Most likely trivial

º: degrees; T: mean ± 90% confidence limits; LBP: group of tennis players with a history of low back pain; CG: group of tennis players without a history of low back pain (control group).

[a] Substantial is an absolute change in performance of > 10º for all ROM measures for passing accuracy (see Methods).

[b] If chance of benefit and harm both > 5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as follows: < 1%, almost certainly not; 1-5%, very unlikely; > 5-25%, unlikely; > 25-75%, possible; > 75-95%, likely; > 95-99%, very likely; > 99%, almost certain

Neither LBP group (Table 10) nor control group (Table 11) reported significant differences ($p > 0.05$; trivial effect with a probability higher than 99%; $d < 0.3$) between limbs regarding passive hip extension and rotation (IR and ER) ROM measures as well as in active hip IR and ER ROM measures.

Table 10.

Descriptive values and inference about bilateral differences (non-dominant limb versus dominant leg) for passive hip extension and passive and active rotation (internal and external) range of motions in the group of players without a history of low back pain (n = 32).

Range of motion (º)	Limb*		Change[T]	Effect Size (d)	Chances that the true effects[a] were positive / trivial / negative			Qualitative inference[b]
	Non-Dominant	Dominant						
Passive hip extension	0.0 ± 5.5	0.7 ± 5.7	-0.7 (-1.4 to 0.1)	-0.1	0	100	0	Most likely trivial
Passive hip internal rotation	32.0 ± 9.9	32.6 ± 8.7	-0.6 (-2.7 to 1.5)	-0.1	0	100	0	Most likely trivial
Passive hip external rotation	49.3 ± 8.2	50.7 ± 6.4	-1.4 (-3.4 to 0.7)	-0.1	0	100	0	Most likely trivial
Active hip internal rotation	29.0 ± 9.2	31.9 ± 10.2	-2.2 (-4.0 to -0.3)	-0.2	0	100	0	Most likely trivial
Active hip external rotation	49.3 ± 9.1	52.4 ± 6.7	-3.1 (-5.6 to -0.7)	-0.2	0	99	1	Very likely trivial

º: degrees; *: mean ± standard deviation; T: mean ± 90% confidence limits.

[a] Substantial is an absolute change in performance of > 10º for all ROM measures for passing accuracy (see Methods).

[b] If chance of benefit and harm both > 5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as follows: < 1%, almost certainly not; 1-5%, very unlikely; > 5-25%, unlikely; > 25-75%, possible; > 75-95%, likely; > 95-99%, very likely; > 99%, almost certain.

Table 11

Descriptive values and inference about bilateral differences (dominant versus non-dominant limb) for passive hip extension and passive and active rotation (internal and external) range of motions in the group of players with a history of low back pain (n = 32).

Range of motion (º)	Limb*		Change[T]	Effect Size (d)	Chances that the true effects[a] were positive/ trivial / negative			Qualitative inference[b]
	Dominant	Non-dominant						
Passive hip extension	-3.1 ± 5.6	-3.0 ± 5.5	0.2 (-0.6 to 0.9)	0.1	0	100	0	Most likely trivial
Passive hip internal rotation	32.7 ± 10.4	30.3 ± 9.9	-2.4 (-4.3 to -0.6)	-0.1	0	100	0	Most likely trivial
Passive hip external rotation	46.7 ± 8.3	46.7 ± 8.6	0.0 (-2.2 to 2.1)	0.0	0	100	0	Most likely trivial
Active hip internal rotation	32.1 ± 10.5	28.3 ± 11.9	-3.8 (-7.1 to -0.5)	-0.4	0	94	6	Likely trivial
Active hip external rotation	50.6 ± 10.3	49.1 ± 9.9	-1.5 (-3.9 to 0.9)	-0.1	0	100	0	Most likely trivial

º: degrees; *: mean ± standard deviation; T: mean ± 90% confidence limits.

[a] Substantial is an absolute change in performance of > 10º for all ROM measures for passing accuracy (see Methods).

[b] If chance of benefit and harm both > 5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as follows: < 1%, almost certainly not; 1-5%, very unlikely; > 5-25%, unlikely; > 25-75%, possible; > 75-95%, likely; > 95-99%, very likely; > 99%, almost certain.

4. Discussion

Although LBP is known to be complex and multi-factorial, previous studies suggest that a deficit in hip extension and rotation ROM may be associated with LBP in athletes who regularly perform rotation-related sports (Almeida et al., 2012; Evans et al., 2005; Harris-Hayes et al., 2009; Murray et al., 2009; Roach et al., 2015; Vad et al., 2003; 2004; Van Dillen et al., 2008). However, very few studies have specifically evaluated the relationship between hip extension and rotation ROMs and LBP in elite tennis players (Vad et al., 2003; Young et al., 2014). In the current study hip extension and rotation ROM measures and their possible relationship to LBP history in elite tennis players were analyzed. The findings of this study showed no significant differences in hip extension and rotation ROM measures between elite tennis players with and without a history of LBP. In addition, neither the LBP group nor the control group reported significant side-to-side differences between legs regarding hip extension and rotation ROM measures.

The present results were similar to those of a previous study (Young et al., 2014) conducted with 125 female professional tennis players (17-37 years) which followed comparable hip ROM measures (i.e., hip rotation in prone and Thomas test). The referred study found no important bilateral differences between the dominant and non-dominant side in hip extension (i.e., 1º less of extension in non-dominant limb compared to the dominant limb) and hip rotation ROM (i.e., 3º and 1º less of IR and ER in dominant compared to the non-dominant limb), and was unable to demonstrate any association of hip ROM measures with lower back injuries in female professional tennis players.

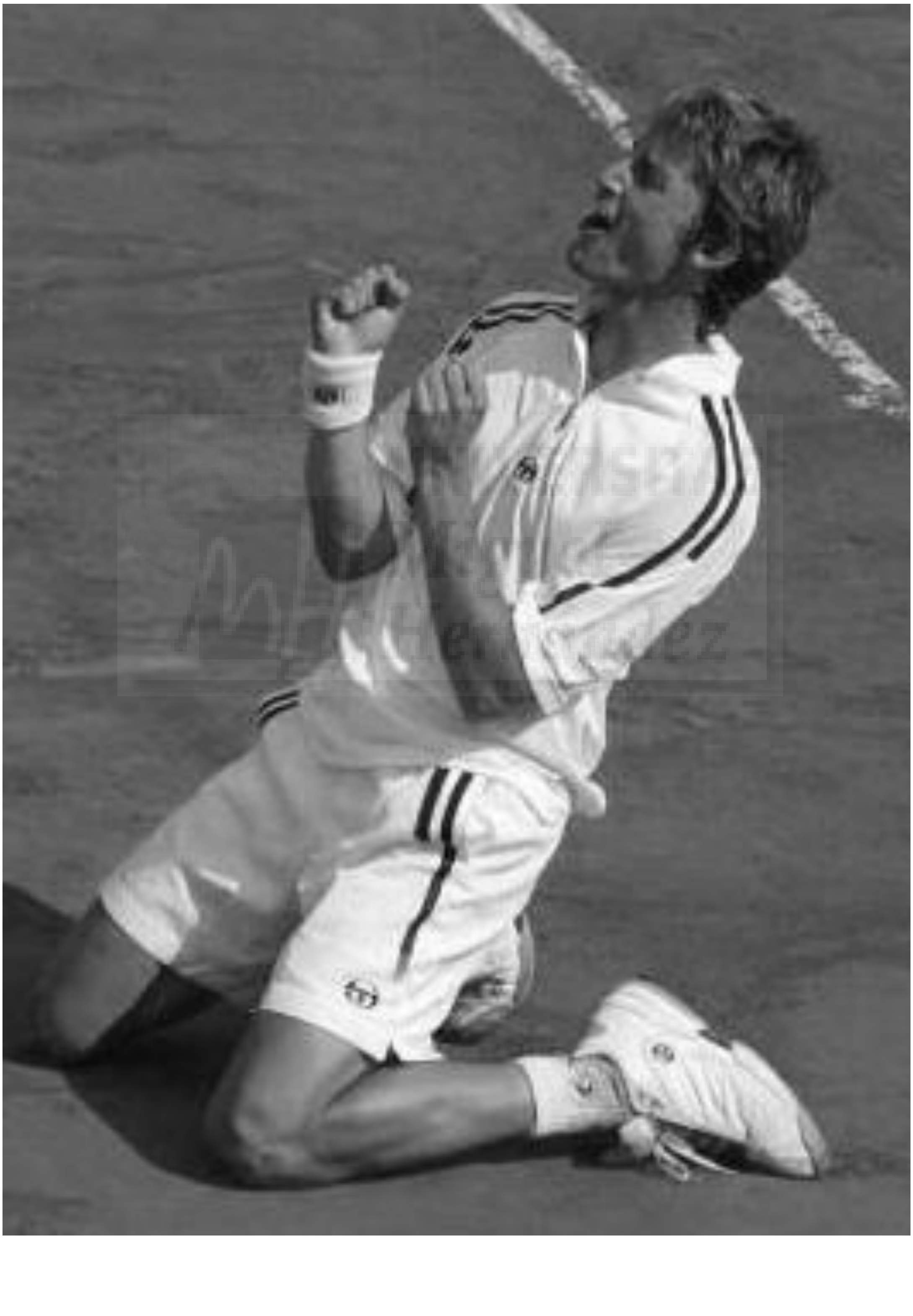
However, these and our results differ from those reported by Vad et al. (2003) who found a significant relationship between hip rotation ROMs and LBP in tennis players (Vad et al., 2003). Vad et al. (2003) found that players with a LBP history had a 7.6° deficit in hip IR ROM in the dominant limb when compared to the non-dominant limb, whereas there was only a 3.2° difference for the asymptomatic players; on the other hand, in our study we obtained 2.4º and 0.6º less of hip IR ROM in the dominant limb when compared to the non-dominant limb for the LBP and control group, respectively. This lack of agreement between the current data and those of Vad et al. (2003) may be due to differences in the testing maneuvers used. Vad et al. (2003) used the Fabere test to measure passive hip ER ROM. The Fabere test is a measure of the combined amount of available passive hip abduction, ER and extension motion rather than a specific measure of hip ER. The extent to which differences in hip ER rather than differences in hip abduction or extension contributed to the bilateral differences obtained with the Fabere test is unknown (Van Dillen et al., 2008). In contrast, the current study used more specific testing maneuvers to measure hip extension and rotation ROMs (they only involved an isolated hip movement), and minimized the possible compensatory hip movements using a lower back protection support and the aid of an assistant physical therapist.

The findings of the current study also disagree with the results reported by previous studies conducted with athletes practicing other sports which entail repeated hip and trunk rotations, such as golf and judo (Almeida et al., 2012; Evans et al., 2005; Murray et al., 2009). These sports use repetitive pivoting movements that could lead to micro-trauma and capsular contracture, causing a hip movement deficit and differences between dominant and non-dominant limbs (Almeida et al., 2012; Murray et al., 2009). However, tennis practice is different, as it involves multidirectional movements (i.e., accelerations, decelerations, changes of direction) requiring both legs, which can lead to more balanced rotational stresses (Young et al., 2014) and rotational ROMs in the hips (as has been shown in tables 10 and 11). Another possible explanation for the discrepancies between the current and the above-mentioned studies might be based on the differences in the ages of the participants. For instance, while the study of Murray et al. (2009) obtained amplitudes between 20º and 30º of passive hip IR in 64 amateur golf players with an average age over 50 years old, our study found amplitudes of 30º of passive hip IR in 64 tennis players with an average age of 19.6 years. Different studies in other sports have studied the range of hip rotation in individuals of different ages and demonstrated a progressive decrease as age increases, which may indicate an increase in hip passive stiffness (Manning and Hudson, 2009; Svenningsen et al., 1989).

While the results of this study have provided information regarding the absence of any relationship between hip extension and rotation ROM and LBP incidence in elite tennis players, limitations to the study must be acknowledged. The study used a self-reported participant injury history without any formal injury diagnosis. Self-reporting relies on subjective recall and memory. It is, therefore, possible that participants may not have been allocated to the appropriate group due to either over or underestimating the severity of their injuries. In addition, it would have been interesting to group the sample by specific pathology of LBP and to understand the causal relationship between other factors that may be related to the appearance of LBP in tennis players. In this sense, although the LBP in tennis is attributed to the repeated rapid rotation of the lumbar spine during tennis groundstrokes and the "hyperextension" during serving (Alyas et al., 2007), it can be produced by different structural damages and caused by or related to many other factors (Lawrence et al., 2006): decreased range of motion in the back, poor conditioning, repetitive loading, improper playing technique, and/or abrupt increases in training frequency/volume. Finally, we could neither control nor investigate the rehabilitation programs undergone by the players with LBP history after injury, which could modify the current players' hip extension and rotation ROMs.

CHAPTER 6

EPILOGUE



CHAPTER 6

EPILOGUE

6.1. Conclusions

Three studies on shoulder and hip flexibility in elite tennis players have been performed in this doctoral thesis. In the first study, glenohumeral rotational ROMs were analyzed in professional tennis players; especially, it was investigated whether tennis players with a history of self-reported shoulder pain showed differences in ROM of the dominant and non-dominant shoulder compared to asymptomatic controls. In the second and third study, hip ROMs were assessed in elite tennis players; specifically, the second study provided the ROM profile of the hip in male and female tennis players, and the third study explored whether there was an association between hip extension and rotation ROMs and LBP history in these athletes.

The following summarizes the major contributions of this thesis:

Study 1:

1. The elite tennis players' shoulder on the dominant side averaged less IR and total arc or rotation, but increased ER, when compared to the non-dominant side.

2. The group with shoulder pain history showed decreased glenohumeral IR bilaterally and decreased total arc of rotation in the non-dominant shoulder when compared with the group without shoulder pain history. However, no significant differences between the groups were found for ER ROM, side-to-side ROM asymmetries, years of tennis practice or years of professional play.

3. The sided differences in glenohumeral ROM did not correlate significantly with the tennis players' age, years of tennis practice, nor the number of years playing at a professional level. However, the glenohumeral rotation ROMs (IR and total arc of rotation; ER less consistently) correlated negatively with the years of tennis practice, years of professional play and players' age.

Study 2:

4. The results of this study provided a profile of passive hip flexion, extension and abduction, as well as passive and active IR and ER ROM in elite tennis players.

5. Bilateral measurement of hip flexion, extension, abduction, IR and ER ROMs did not identify clinically significant differences between limbs.

6. Restricted values of hip flexion, extension and abduction ROM were found in both limbs for males and females. Furthermore, male tennis players also reported restricted passive and active hip IR ROM values. However, both males and females have shown having normal mobility measures for active and passive hip ER.

Study 3:

7. The results of this study showed no meaningful differences in hip extension and rotation ROM measures between elite tennis players with and without a history of LBP.

8. Neither LBP group nor control group reported significant differences between the dominant and non-dominant limbs in hip extension and rotation ROM measures.

6.2. Conclusiones

En esta tesis doctoral se han desarrollado tres estudios sobre la flexibilidad del hombro y la cadera en tenistas de élite. En el primer estudio, se analizaron los rangos de movimiento de rotación de la articulación glenohumeral en tenistas profesionales; especialmente se evaluó si los tenistas con historia de dolor de hombro mostraban diferencias en los rangos de movimiento de los hombros dominante y no dominante en comparación con controles asintomáticos. En el segundo y tercer estudio, se analizaron los rangos de movimiento de la cadera de tenistas de élite; específicamente, en el segundo estudio se evaluó el perfil de rangos de movimiento de la cadera en tenistas de ambos sexos y en el tercer estudio se valoró si existía una asociación entre los rangos de movimiento de extensión y rotación de cadera y la incidencia de dolor lumbar en estos deportistas.

A continuación se presentan las principales aportaciones de esta tesis doctoral:

Estudio 1:

1. El hombro del lado dominante de los tenistas de élite promedió menos rotación interna y arco total de rotación y mayor rotación externa que el hombro del lado no dominante.

2. El grupo con historia de dolor de hombro mostró menos rotación interna glenohumeral en ambos hombros y menor arco total de rotación en el hombro no dominante en comparación con el grupo sin historia de dolor de hombro. Sin

embargo, no se encontraron diferencias significativas entre grupos para el rango de movimiento de rotación externa glenohumeral, las asimetrías entre lados en los rangos de movimiento, los años de práctica de tenis y los años de práctica de tenis profesional.

3. Las diferencias entre lados de los rangos de movimiento glenohumerales no correlacionaron significativamente con la edad de los tenistas, ni tampoco con los años de práctica de tenis o con los años de práctica de tenis a nivel profesional. Sin embargo, los rangos de movimiento de rotación glenohumeral (rotación interna y arco total de rotación principalmente) correlacionaron negativamente con los años de práctica de tenis, los años de práctica de tenis profesional y la edad de los tenistas.

Estudio 2:

4. Los resultados de este estudio proporcionan un perfil de rangos de movimiento de flexión, extensión y abducción pasiva de cadera, así como de rotación interna y externa pasiva y activa de cadera, en tenistas de élite.

5. No se encontraron diferencias clínicamente significativas entre lados para los rangos de movimiento de flexión, extensión, abducción, rotación interna y rotación externa de cadera.

6. Se encontraron déficits en los rangos de movimiento de flexión, extensión y abducción de cadera en ambos lados, tanto en hombres como en mujeres. Además, los tenistas varones también mostraron valores reducidos en los rangos

de movimiento de rotación interna pasiva y activa de cadera. Por otro lado, hombres y mujeres mostraron valores normales de movilidad para la rotación externa activa y pasiva de cadera.

Estudio 3:

7. Los resultados de este estudio no mostraron diferencias significativas en los rangos de movimiento de extensión y rotación de cadera entre los tenistas de élite con y sin historia de dolor lumbar.

8. Ni el grupo con dolor lumbar, ni el grupo control mostraron diferencias significativas entre la pierna dominante y no dominante en los rangos de movimiento de extensión y rotación de cadera.

6.3. Study limitations and future research

As with any research study, this doctoral thesis has several limitations which have been taken into consideration for the analysis and discussion of the results, but at same time can be a starting point for future research. Although many of these limitations have been discussed in the studies presented in chapters 3, 4 and 5, what follows are the most important limitations:

1. In studies 1 and 3 the tennis players were grouped based on the shoulder pain and the LBP, respectively. Nevertheless, taking into account that the origin of the pain in these structures can be varied, it would have been interesting to group players according to specific pathologies. At present our research group is carrying out different studies related with specific injury risk factors

in sports such as football and tennis, examining for example ankle sprains, hamstring injuries, tears of the anterior cruciate ligament, etc.

2. The three studies have been performed in samples of young and elite tennis players; therefore, the findings may not be extended to other athletes or to the general population. In addition, although the sample size in the studies was relatively high (taking into account the complexity of performing studies with elite tennis players), we would have liked to have a higher number of participants, especially in study number 1, in which the number of participants was the lowest and only male tennis players were studied. At present our research team is carrying out different studies in tennis players of different ages, performance levels, sex and health status, which will allow us to analyze different injury risk factors in samples with different characteristics.

3. The studies in which the history of shoulder pain or LBP were analyzed were retrospective, and therefore it was not possible to control either the work aimed at recovering from the injuries in the individuals with pain history nor the preventive programs aimed at the improvement of the ROMs. These interventions could have modified the ROMs that existed at the moment the injury occurred. Future prospective and experimental studies should study the relation between ROMs deficit and injury risk in tennis players in depth.

4. This doctoral thesis has analyzed the relationship between different shoulder and hip ROMs with shoulder pain and LBP history; however, the origin of

these injuries is multi-factorial, and therefore it would have been interesting to analyze different risk factors, especially the interaction between them and how this interaction modifies injury risk. Amongst the factors that could be analyzed in the future (together with the ROMs analyzed in this doctoral thesis), we can point out: in the *shoulder*, strength imbalances of the agonist/antagonist musculature (Niederbracht et al., 2008; Saccol et al., 2010; Stanley et al., 2004) and scapular dyskinesis (Kibler, 1998; Struyf et al., 2011); and in the *lumbar region*, decreased spine ROMs, poor trunk muscle conditioning, repetitive loading, improper playing technique and abrupt increases in training load (Campbell et al., 2013; Lawrence et al., 2006). At present our research team is working on the analysis and interaction of various risk factors for sports injury using *Bayesian networks*, also known as *causal networks* or *belief networks*. These networks provide a way to analyze data allowing us to manage the degree of uncertainty using learning algorithms in an *artificial intelligence* environment, in which probabilistic graphical theories are combined to represent causal relations of conditional dependence and independence between variables (Larrañaga and Moral, 2011).

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