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Original article

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

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A glenohumeral internal rotation deficit of the dominant shoulder relative to the non-dominant shoulder (GIRD) 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 rotation range of motion (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 (IR) ROM and total rotation ROM, and increased external rotation (ER) 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 IR ROM in both shoulders compared with the no-pain group, no significant differences between groups were found for ER ROM, side-to-side ROM asymmetries, years of tennis practice or years of professional play. In professional tennis players, limited IR ROM rather than a GIRD, 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.

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 (Stanley et al., 2004; Niederbracht et al., 2008; Saccol et al., 2010), scapular dyskinesis (Kibler, 1998; Struyf et al., 2011), and asymmetries between the dominant and non-dominant shoulders in rotational passive range of motion (ROM), i.e., higher glenohumeral external rotation (ER) (Ellenbecker et al., 1996; Kibler et al., 1996), lower glenohumeral internal rotation (IR) (Chandler et al., 1990; Ellenbecker et al., 1996; Kibler et al., 1996; Burkhart et al., 2003; Vad et al., 2003; Schmidt-Wiethoff et al., 2004; Stanley et al., 2004; Torres and Gomes, 2009; Hjelm et al., 2012) 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 (43.8° ± 11°) and higher ER (89.1° ± 13.7°) in the dominant shoulder than a control group (IR: 61.6° ± 8.1°; ER: 85.4° ± 7.6°).

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; Ticker et al., 2000; Gerber et al., 2003), 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 and Cools, 2010) in tennis players. The current

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recommendation for defining a GIRD is a 20° difference in IR between the dominant and non-dominant glenohumeral joints (Kibler et al., 2012). However, GIRDs of as little as 11° and 18° 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 (Chandler et al., 1990; Kibler et al., 1996; Ellenbecker et al., 1996, 2002; 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 (Kibler, 1998; Schmidt-Wiethoff et al., 2004; Hjelm et al., 2012). 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.

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	0.063
Height (cm)	183.6 ± 5.0	184.1 ± 5.8	182.7 ± 3.6	0.886	0.352
Mass (kg)	77.5 ± 6.5	77.60 ± 7.6	77.5 ± 4.8	0.006	0.938
Years of tennis practice	16.2 ± 5.6	15.3 ± 5.2	17.6 ± 6.0	1.883	0.177
Years of professional play	5.9 ± 3.9	5.1 ± 3.3	7.0 ± 4.5	2.914	0.095

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).

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 90° of abduction and the elbow flexed to 90° (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 (Fig. 1a) and IR (Fig. 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 (Fig. 1a and b). 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 analyses were performed. Intra-rater reliability analysis was carried out on 94 pictures (47 participants × 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 (Kibler, 1998; Schmidt-Wiethoff et al., 2004; Hjelm et al., 2012). In this study, ROM measurements were based on photos of maximum

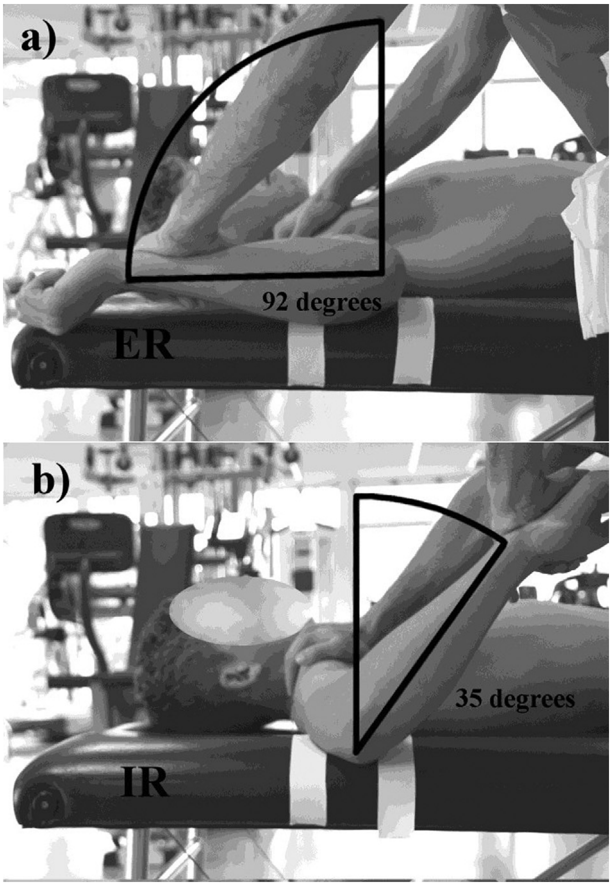

Fig. 1. Assessment of the glenohumeral external and internal rotation range of motion (ER and IR, respectively): a) maximum ER position; b) maximum IR position. Note that the researcher rests his right hand on the subject's anterior shoulder area, applying enough force to stabilize the scapula-thoracic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

passive ER and IR (Fig. 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.

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 ($ICC_{2,1}$) 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 (<1.75°) 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 1.04° to 3.90°. ICC values for between-shoulder differences in the glenohumeral rotation ROMs ranged between 0.74 and 0.79, while SEM values ranged from 3.00° to 6.09°, consistently higher than those of the TAM, ER and IR ROMs.

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: $p = 0.307$, $\eta^2 = 0.023$; IR: $p = 0.615$, $\eta^2 = 0.006$), nor significant differences between the NPH and PH groups in ER ($p = 0.916$, $\eta^2 = 0.001$). However, significant between-group differences were found in TAM and IR (TAM: $p = 0.028$, $\eta^2 = 0.101$; IR: $p = 0.003$, $\eta^2 = 0.179$), and between the dominant and non-dominant sides for TAM, ER and IR (TAM: $p = 0.01$, $\eta^2 = 0.246$; ER: $p = 0.001$, $\eta^2 = 0.577$; IR: $p = 0.001$, $\eta^2 = 0.640$).

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.

Variables	Test-retest reliability ($N = 10$)		Intra-rater reliability ($N = 47$)	
	$ICC_{2,1}$	SEM	$ICC_{2,1}$	SEM
Total arc of motion				
Dominant (°)	0.86	3.90	0.99	1.07
Non-dominant (°)	0.93	2.36	0.99	0.91
Diff (°)	0.74	4.41	0.98	1.37
Relative diff (%)	0.75	3.51	0.98	1.00
External rotation				
Dominant (°)	0.95	1.83	0.98	1.18
Non-dominant (°)	0.95	1.75	0.98	0.90
Diff (°)	0.78	3.00	0.94	1.33
Relative diff (%)	0.79	3.96	0.94	1.75
Internal rotation				
Dominant (°)	0.86	3.47	0.99	0.75
Non-dominant (°)	0.98	1.04	0.99	0.52
Diff (°)	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
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 (°)	136.2 ± 15.4[a]	139.4 ± 14.5[a]	131.5 ± 15.8[a]
Non-dominant (°)	142.3 ± 15.0	146.5 ± 13.0	136.1 ± 15.8[b]
Diff (°)	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 (°)	90.5 ± 9.0[a]	90.3 ± 9.0[a]	90.8 ± 9.4[a]
Non-dominant (°)	84.2 ± 7.7	84.7 ± 6.7	83.6 ± 9.2
Diff (°)	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 (°)	45.8 ± 12.1[a]	49.3 ± 11.3[a]	40.6 ± 11.6[a,b]
Non-dominant (°)	58.6 ± 11.8	62.6 ± 11.0	52.5 ± 10.6[b]
Diff (°)	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 ($p < 0.05$).

Specifically, ER was 6.3° (7.6%) higher and IR was 12.8° (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: $p = 0.423$, $\eta^2 = 0.014$; ER: $p = 0.307$, $\eta^2 = 0.023$; IR: $p = 0.936$, $\eta^2 = 0.001$) and relative (TAM: $p = 0.429$, $\eta^2 = 0.014$; ER: $p = 0.246$, $\eta^2 = 0.030$; IR: $p = 0.477$, $\eta^2 = 0.011$) differences in the rotational ROMs.

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.

4. Discussion

Previous literature suggests that a GIRD is associated with shoulder injury in overhead athletes (Chandler et al., 1990; Kibler et al., 1996; Ellenbecker et al., 1996, 2002; 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 (Vad et al., 2003; Schmidt-Wiethoff et al., 2004; Torres and Gomes, 2009; Hjelm et al., 2012); 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% (12.8°) less passive IR and 7.6% (6.3°) more passive ER than the non-dominant shoulder, thus supporting the findings of previous studies on overhead athletes (Kibler et al., 1996; Ellenbecker et al., 1996, 2002; 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* (Tyler et al., 2000; Myers et al., 2006, 2007) and *in vitro* (Harryman et al., 1990; Grossman et al., 2005) 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 (Warner et al., 1990; Vad et al., 2003; Myers et al., 2006; 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

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		0.921[b]	0.904[b]	−0.325[a]	−0.341[a]	−0.472[b]	−0.426[b]	−0.211	−0.037
	TP			0.922[b]	−0.313[a]	−0.239	−0.426[b]	−0.424[b]	−0.166	−0.202
	Age				−0.449[b]	−0.221	−0.475[b]	−0.430[b]	−0.084	−0.238
Dom	IR					0.058	0.691[b]	0.160	−0.352[a]	0.129
	ER						0.138	0.795[b]	0.130	−0.528[b]
NDom	IR							0.159	0.401[b]	−0.005
	ER								0.004	0.095
Diff	IR									−0.208
	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.
[a] Pearson correlation is significant at the 0.05 level.
[b] Pearson correlation is significant at the 0.01 level.

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 40.6° of IR in the dominant shoulder, compared with 49.3° obtained by the NPH players (Table 3). However, IR ROM in the non-dominant shoulder was similarly greater in the NPH group (PH: 52.5° vs. NPH: 62.6°). 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 (Warner et al., 1990; Vad et al., 2003; Myers et al., 2006; 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 (Kibler, 1998; Schmidt-Wiethoff et al., 2004; Hjelm et al., 2012), 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 (Stanley et al., 2004; Hjelm et al., 2012) 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 (Stanley et al., 2004; Niederbracht et al., 2008; Saccol et al., 2010), 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).

5. Conclusions

In this group of professional tennis players, the shoulder on the dominant side averaged less IR and TAM, but increased ER, when compared to the non-dominant side. These 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 TAM; ER less consistently) correlated negatively with the years of tennis practice, years of professional play and players' age.

Although side-to-side asymmetry in glenohumeral IR, ER and TAM, years of tennis practice and years of professional play did not demonstrate significant differences between the two groups of tennis players, the group with a history of shoulder pain showed decreased glenohumeral IR bilaterally and decreased TAM in the non-dominant shoulder when compared with the NPH group.

It is therefore suggested that decreased glenohumeral IR may be used as criteria for the implementation of prevention and rehabilitation programs in professional tennis players as a means to reduce injury incidence. Future studies with higher sample size are necessary to identify more precise values of shoulder IR that may be associated with increased risk of shoulder injury in this population.

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