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Original Research

Range of Motion and Muscle Stiffness Differences in Junior Tennis Players with and without a History of Shoulder Pain

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Background

Due to its significant unilateral predominance, tennis can provoke functional and morphological asymmetries that develop over time and may result in undesired morphological alterations.

Hypothesis/Purpose

The goals of this study were a) to assess glenohumeral range of motion and muscular stiffness in young tennis players with and without a history of shoulder pain and b) to examine interlimb asymmetries in these variables in both groups. It was hypothesized that players with a history of shoulder pain would show a reduced glenohumeral internal rotation (IR) and total arc of motion (TAM) and increased stiffness in internal rotator muscles compared to those without shoulder pain.

Study Design

Cross-sectional observational study.

Methods

Twenty-five participants participated in the study (11 with a history of shoulder pain and 14 without pain). Participants performed stiffness measurements on muscles involved in the main tennis stroke motions alongside range of motion examinations on the dominant (D) and non-dominant (ND) extremities including IR, external shoulder rotation (ER), and TAM. A two-way mixed-design ANOVA analyzed group and limb effects, with effect sizes classified as small, medium, or large. Significant effects were further examined using Bonferroni post hoc tests.

Results

There were significant differences between the shoulder pain and no shoulder pain group in the D IR (-3.1º, 6.43%, $p = 0.048$; effect size [ES] = 0.58) and D TAM (-6.1º, 3.01%, $p = 0.024$; ES = 0.66). Moreover, significant differences were found between the D and ND extremities in IR in both groups (-9.2º, 14.94%, $p < 0.001$; ES = -1.72) and TAM in the shoulder pain group (-5.6º, 2,77%, $p = 0.038$; ES = 0.61). Stiffness measurements showed no significant differences between groups or extremities.

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Conclusions

Significantly lower values of D IR and TAM and higher IR asymmetries in the shoulder pain group suggest that a deficit in these parameters could be associated with shoulder pain history in junior competitors.

Level of Evidence

2

INTRODUCTION

Tennis has a significant unilateral predominance, as most game-play actions are performed with the dominant extremity.[1] Because of this, functional and morphological asymmetries develop due to continued training and match play.[2-4] Young competitors generally show specific values in shoulder strength, humeral retroversion (HRV), and range of motion (ROM) as a chronic alteration derived from competitive development.[1,5-7] Specifically, regarding ROM in uninjured athletes, the dominant arm typically shows a decreased shoulder internal rotation (IR), increased shoulder external rotation (ER), and a reduced total arc of motion (TAM) compared to the other extremity.[8] These adaptations are typically produced because of soft tissue pathophysiological alterations such as shoulder posterior capsule tightness[9] or protective adaptations like humeral retroversion that can start developing at young ages.[7] When analyzing professional athletes with a history of shoulder pain compared to uninjured participants, Marcondes et al.[10] and Moreno-Pérez et al.[11] found significant differences in ROM values that indicated greater and more evident alterations (i.e., decreased IR) in the shoulder pain group (SHP). These findings, alongside previous works in throwing/overhead athletes, suggest that a deficit in the IR of the dominant (D) shoulder compared to the non-dominant (ND) extremity (i.e., glenohumeral internal rotation deficit or GIRD) could be a relevant injury risk factor.[12] Specifically, differences higher than 20º could be associated with injury, and players may be at a higher risk of developing specific overuse problems that can impair progress, adequate training availability, and competition time.[11]

Muscle stiffness has been established as a contractile property that can aid in the stretch-shortening cycle (SSC) and be beneficial for high-speed sporting actions such as tennis strokes and on-court movements like sprinting and changing direction.[13,14] Nevertheless, high muscle stiffness values may also be counterproductive, as increased stiffness can raise peak shock forces and compromise technical and kinematic needs.[15] Specific stiffness values are yet to be studied and confirmed to establish detailed beneficial and detrimental standards for professional athletes.[16] However, similar to alterations in ROM, stiffness can influence performance and injury incidence and should be considered.[17] Specifically, Pruyn et al.[17] found that a high bilateral difference in leg muscle stiffness was related to a greater incidence of lower body soft tissue injury in Australian football players. Although comparing lower body and upper extremity results may have limitations, literature is scarce when studying muscle stiffness around the glenohumeral joint. Certain stiffness levels may influence the glenohumeral joint's overall performance and, to some extent, affect shoulder ROM or interlimb asymmetries.

Some investigations have analyzed young tennis competitors' injury risk factors[18] and shoulder ROM profiles of injured and uninjured professional players.[10,11] Nevertheless, no studies have focused on this issue in adolescent athletes or have included muscle stiffness testing. This perspective seems relevant since, as serious competitors, young players deal with high playing volumes that involve many actions that may place the player's body structures under stress.[19-21]

The goals of this study were a) to assess ROM and stiffness characteristics in young tennis players with and without a history of shoulder pain and b) to examine interlimb asymmetries in both groups. The authors' hypothesized that ROM values would be significantly altered in players with a history of shoulder pain, including reduced glenohumeral internal rotation and total arc of motion compared to players without shoulder pain. Regarding stiffness values, it was hypothesized that players with shoulder pain would present significantly greater stiffness of the internal rotator muscles (pectoralis major) compared to the non-pain history group.

MATERIALS AND METHODS

SUBJECTS

Twenty-five male junior (under 18 years old) tennis players from a high-performance tennis academy were recruited to participate in this study. Inclusion criteria required at least one year of participation in a structured strength and conditioning program and a minimum background of five years of tennis training and competition. Also, the inclusion criteria of the SHP group consisted of reporting shoulder pain or discomfort that prevented them from training or playing during the two months before the start of the study. The no-pain participants (NSHP) did not present any shoulder pain, and they had not undergone surgery or taken medication to relieve discomfort in the six months before the data collection. The diagnosis of shoulder pain and recommendations to drop out of training and competition were established by the accredited medical staff of the tennis academy. All participants were informed about the particularities of the study and signed informed consent. In the case of being underage, their legal guardians signed the arrangement. The study was conducted following the ethical principles for biomedical research with human beings, established in the Declaration of Helsinki of the World Medical Association (WMA) It was approved by a local Ethics Committee (19/2019/CEICEGC).

Table 1. Participant characteristics and group differences.

	No Shoulder pain (n = 14)	Shoulder pain (n = 11)	*p-value*
Age (years)	16.4 ± 1.1	17.0 ± 1.1	0.207
Height (cm)	178.6 ± 7	177.4 ± 7.1	0.656
Body mass (kg)	68.7 ± 6.6	71.9 ± 6.6	0.25
Competitive level (ITN)	2.8 ± 0.6	3.0 ± 0.6	0.387
Training background (years)	9.8 ± 1.4	10.0 ± 1.9	0.75

Values are Mean ± SD. ITN = International Tennis Number.

PROCEDURES

The testing was divided into two sessions, which were performed on the same day and separated by 10 minutes. Participants performed the ROM testing followed by the muscle stiffness assessment. Participants did not exercise for at least 18 hours before the protocol. They were asked to maintain their routine and to avoid moderate to intense exercise or consuming excitatory substances (i.e., caffeine) during the hours prior to the testing sessions. All measurements were performed in the morning, approximately from 8:00 am to 9:00 am. Data collection was conducted during the competition period.

RANGE OF MOTION (ROM)

Glenohumeral rotation was measured following previous research[11,22] using a manual inclinometer (Farway, Shenzhen Dobiy Electronic Co., Ltd, Shenzhen, China). Each participant lay supine on a bench, with both shoulders abducted to 90º and the dominant arm elbow flexed 90°. A coauthor stabilized the participant's proximal shoulder region to prevent undesired scapular movements and to record passive IR and ER. Values in degrees were recorded and used to calculate TAM (summation of IR and ER values). The following formula was used to calculate between limb differences: ER – IR/ER * 100.[23] Two measurements per extremity and participant were performed with no rest and in a randomized order. The best value was used for data analyses.

STIFFNESS MEASUREMENT

Stiffness, the resistance of the muscle to an external force that changes its initial shape,[24] was measured while in anatomical position in four muscle groups in both extremities using a handheld myometer (Myoton-Pro, Myoton AS, Tallinn, Estonia), following previous protocols.[13] Before the assessment, body marks were established for the measurement points using the SENIAM electrode placement guidelines.[25] The muscle groups chosen were the biceps brachii, infraspinatus, deltoids, and pectoralis major, which are all involved in the kinetic chain of tennis strokes.[26,27] The tip of the Myoton Pro was sampled at 15 ms with a force of 0.58 N. The accelerometers operated at 3200 Hz, offering an average value of five consecutive measurements. Interlimb absolute and relative stiffness differences were calculated using ROM measurements. The reliability of the measurements showed excellent test-retest values in previous investigations (ICC = 0.956 – 0.998; CV = 0.3 - 0.9; SEM = 3.2 – 6.5).[13]

STATISTICAL ANALYSES

Descriptive data were reported as mean ± standard deviation (SD). The distributions' normality and the variances' homogeneity were assessed with the Shapiro-Wilk test. Independent t-tests were used to check players' characteristics/demographic differences. Differences between groups (between-subject factor: NSHP and SHP) and limbs (within-subject factor: D and NDs) and interactions were tested with a two-way mixed-design ANOVA model, including the variables of interest (IR, ER, TAM, and muscle stiffness). The partial eta-square (η2) effect sizes were calculated to evaluate the main and interaction effects of the ANOVA. The η2 values of 0.01–0.05, 0.06–0.13, and >0.14 indicate small, medium, and large effect sizes, respectively.[28] When a significant difference was found for either main effect (limb or group), a Bonferroni post hoc analysis was performed, presenting the mean difference with 95% CI and Cohen's d effect size (ES). The magnitude of the effects was interpreted as follows: < 0.2 trivial; 0.2–0.5 small; 0.5–0.8 medium; >0.8 large.[28] All statistical analyses were performed with JASP (JASP 0.16.1, University of Amsterdam, The Netherlands).

RESULTS

Participants had a weekly training volume of 20 hours per week, including three hours of specific tennis sessions and one hour of physical fitness workouts daily from Monday to Friday. Two subjects were left-handed, while all other participants played using their right arms. Both groups were homogeneous and presented no significant differences in biometric measurements (Table 1).

Table 2 presents between group and limb differences, D shoulder ROM comparative descriptive data in the SHP and NSHP, and inter-limb asymmetry differences in both groups.

Regarding ROM, medium significant group-by-limb interactions were observed in the IR ($F = 6.554$, $p = 0.014$, $\eta^2 = 0.125$) whereas no interactions were found in ER ($F = 0.129$, $p = 0.721$, $\eta^2 = 0.003$) and TAM ($F = 3.283$, $p = 0.077$, $\eta^2 = 0.067$). Medium significant main effect of group was

Table 2. Glenohumeral range of motion and stiffness differences between no shoulder and shoulder pain groups.

	No shoulder pain (n = 14)		Shoulder pain (n = 11)	
	Mean	SD	Mean	SD
Internal rotation				
Dominant (°)	66.6[a]	4.3	59.6[a,b]	4.9
Non-dominant (°)	71.9	4.8	72.7	7.3
Mean difference (°)	5.3	3.7	13.1	4.4
Relative difference (%)	8.1	5.7	22.0	7.0
External rotation				
Dominant (°)	144.2	7.9	140.5	7.3
Non-dominant (°)	139.8	8.3	137.6	7.8
Mean difference (°)	4.4	9.7	2.8	3.6
Relative difference (%)	5.5	5.8	2.4	2.6
Total arc of motion				
Dominant (°)	210.9	9.0	200.1[a,b]	8.0
Non-dominant (°)	211.7	9.7	210.4	9.6
Mean difference (°)	0.9	10.9	10.3	6.2
Relative difference (%)	4.5	2.7	5.2	3.2
Biceps brachii stiffness				
Dominant ($N \cdot s^{-1}$)	212.9	21.8	210.8	24.1
Non-dominant ($N \cdot s^{-1}$)	213.6	35.3	218.8	45.0
Mean difference ($N \cdot s^{-1}$)	0.7	31.2	8.0	41.8
Relative difference (%)	0.5	14.4	4.3	19.8
Deltoids stiffness				
Dominant ($N \cdot s^{-1}$)	223.9	28.6	237.1	61.0
Non-dominant ($N \cdot s^{-1}$)	231.6	39.8	208.4	34.4
Mean difference ($N \cdot s^{-1}$)	7.7	37.3	28.7	51.1
Relative difference (%)	4.0	14.9	12.1	16.1
Infraspinatus stiffness				
Dominant ($N \cdot s^{-1}$)	242.5	95.2	228.6	51.9
Non-dominant ($N \cdot s^{-1}$)	249.3	49.7	247.6	53.6
Mean difference ($N \cdot s^{-1}$)	6.8	58.6	18.9	41.4
Relative difference (%)	9.1	23.1	9.8	19.8
Pectoralis major stiffness				
Dominant ($N \cdot s^{-1}$)	217.6	50.4	211.0	47.5
Non-dominant ($N \cdot s^{-1}$)	220.2	37.8	223.1	46.2
Mean difference ($N \cdot s^{-1}$)	2.6	39.8	12.1	21.9
Relative difference (%)	3.8	19.6	7.3	15.1

[a] Significantly different from non-dominant shoulder ($p < 0.05$)
[b] Significantly different from the no-pain group ($p < 0.05$)

found in IR ($F = 4.146$, $p = 0.048$, $\eta^2 = 0.083$) and TAM ($F = 5.437$, $p = 0.024$, $\eta^2 = 0.106$) and a large main effect of limbs was found in TAM ($F = 4.587$, $p = 0.038$, $\eta^2 = 0.091$) and IR ($F = 36.333$, $p = <0.001$, $\eta^2 = 0.441$). The post hoc tests showed significant differences between D and ND extremities in the IR ROM (-9.2°, 14.94%, $p < 0.001$; ES = -1.72) and TAM (-5.6°, 2,77%, $p = 0.038$; ES = 0.61), and between SHP and NSHP in the IR ROM (-3.1°, 6,43%, $p = 0.048$; ES = 0.58) and TAM (-6.1°, 3.01%, $p = 0.024$; ES = 0.66).

Regarding stiffness, no significant group-by-limb interactions or main effects of group and limb were found for any of the variables analyzed.

DISCUSSION

This study aimed to assess glenohumeral ROM and muscle stiffness differences in young tennis players with and without a history of shoulder pain, alongside examining the existence of interlimb asymmetries in both groups. The study hypothesis was partially confirmed, as results indicated significantly lower D IR and D TAM values in the SHP compared to the NSHP participants. Additionally, when comparing the D to the ND extremity, reduced values in the IR were found in both groups, while the SHP group also showed significant asymmetries regarding TAM. These results demonstrate that glenohumeral ROM alterations exist (i.e., reduced IR and TAM) irrespective of injury history. However, players with SHP have a greater IR deficit in the D arm and a higher level of asymmetry between limbs than NSHP participants.

Tennis practice and exposure to match-play is considered a highly asymmetrical activity, which will may induce glenohumeral strength and ROM alterations. Players generally show an increased ER and a reduced IR and TAM of the D extremity as an adaptation to upper limb load induced by training and competition.[1,6] Normative values of junior players' ROM show how these alterations are already present in U14 participants, and in the case of male athletes, these seem to increase progressively with age and level.[8] These increases appear as a consequence of an inevitable intensification in training and match-load, triggered by a higher number of overhead motions performed at higher competitive levels and older ages.[29] The observed differences in this study reaffirm that limb asymmetry is highly prevalent in sports performance but, although existent, previous research indicates it is not necessarily linked to injury risk.[30] For instance, in other prior studies, tested groups showed significant GIRD irrespective of their injury history.[11,18] In fact, and worth noting, the NSHP group here presented significant shoulder IR interlimb variances (5.29º; 8.05%) that may be expected in these participants but were below clinically meaningful thresholds (5 – 15%).[30]

Nevertheless, the SHP group showed differences of around 13.09º (21.96%), which are not close to typical injury risk thresholds regarding absolute values[11] but may account for percentual asymmetry levels that exceed normal morphological alterations and are of sufficient magnitude to be considered relevant.[12,30] In short, specific ROM differences can be expected in junior tennis players, and they may be regarded as 'normal' sport-specific alterations unrelated to a higher injury incidence.[18] However, values that exceed normative shoulder ROM profiles[8] may have to be carefully addressed because they play a role in subsequent injuries as external risk factors.

Following the idea of inherent side-to-side differences in sports performance, some authors suggest using dominant/non-dominant glenohumeral ROM comparison between groups rather than analyzing interlimb asymmetry as an indicator of injury risk.[11] The current results show similar values of ER between groups but a significantly higher deficit in the D IR and, consequently, in the D TAM of the SHP over the NSHP group. Factors such as humeral retrotorsion or capsular tightness can increase IR deficit, and while some are typical protective adaptations (i.e., humeral retrotorsion), some may evolve into undesired pathologies over time.[7,9] The mentioned deficits have been linked to years of practice, greater age, and level, which can increase the load (competitions and shots) and trigger specific morphological chronic adaptations[2-4] that may increase injury risk. Previous research relating glenohumeral shoulder ROM values and injury incidence has mainly concluded these ideas based on the analysis of professional players with extensive experience and accumulated training and competitive load (> 15 years of playing or < 5 years of professional experience).[11] These previous results add value to the current findings, in which competitive junior players with a history of SHP showed higher levels of IR deficit, a reduced TAM, and a greater IR interlimb asymmetry compared to players with NSHP. These results indicate that alterations in the glenohumeral ROM of the dominant limb appear early in athletes' careers, and U18 players with training loads of around 20h/week can present a significantly increased interlimb asymmetry in consequence. Early detection, prevention programs, and strategies to counteract the specificity of training are highly recommended to reduce the effects of age and years of tennis practice.

Regarding stiffness, none of the muscle groups tested showed significantly different values from one side to another. As hypothesized, limitations in shoulder glenohumeral ROM may also lead to an affected stiffness in the surrounding muscles. This effect was not seen since both groups' observed D IR asymmetries were not linked or accompanied by relevant differences in stiffness values when comparing extremities (Table 2). Although some previous investigations have found relatively high stiffness interlimb differences related to soft tissue injury incidence,[17] these were found in the lower limbs and when using active muscle versus passive testing. Results here align with previous investigations in junior tennis players in which passive stiffness measurements failed to find significant inter-limb differences, most likely due to the active nature of tennis training and match-play.[31] Also, comparisons between stiffness levels of the SHP and NSHP groups did not show relevant differences, suggesting passive measurements of this variable do not seem to discriminate between competitors with and without a history of shoulder pain. Active measurements are recommended for future investigations.

This study had some limitations. First, 'pain' can be a vague term that includes many possible discomforts and pathologies. Although the participants in this study were diagnosed by a health professional, different pathologies can affect shoulder ROM and stiffness adaptations. Second, not all participants were tested on the same day. Instead, measurements were gathered the following week to diagnose, which could have affected the results.

CONCLUSION

The results of this study indicate that ROM limb differences (i.e., decreased D IR and D TAM) are common in most junior tennis competitors, especially as age and level increase. However, players with a history of SHP show higher differences between limbs than their non-injured peers, suggesting the magnitude of these asymmetries should be carefully assessed if they exceed what can be considered normal thresholds.[8] Establishing specific injury prevention programs is highly recommended for junior players to reduce the effects of high loads of tennis exposure..

CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflicts of interest.

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