MUSCULO-SKELETAL EXAMINATION

OF ELITE JUNIOR TENNIS PLAYERS

– Written by Todd Ellenbecker, USA

INTRODUCTION

The use of musculoskeletal testing in sports medicine is a widespread practice with a dual goal intended for the application of findings, both for injury prevention and performance enhancement. Knowledge regarding the typical or characteristic descriptive results of musculoskeletal tests is important for the optimal interpretation of test findings in individual populations of athletes. Sport-specific descriptive data aids the interpretation of these tests and helps to define characteristic adaptations inherent in certain homogenous populations. The purpose of this article is to present the current methods and descriptive findings of a sport-specific musculoskeletal profile used for elite junior tennis players.

Prior research has identified sport-specific shoulder and hip range of motion (ROM) and muscular strength patterns in elite junior[1–6] and adult[7] tennis players. These studies can also be found for high level baseball players[8–12] and in other upper extremity athletes as well[13,14]. These studies have most often utilised one specific measure of testing (i.e. isokinetic strength, goniometric range of motion etc.) using a specific highly skilled population of athletes.

Injuries in elite junior tennis players can involve virtually all anatomical regions of the body, due to the repetitive demands and musculoskeletal stressors imparted through the sequential, segmental, rotational loading of the entire kinetic chain during elite level tennis performance[15–18]. Therefore, the application and use of a comprehensive musculoskeletal examination using a series of tests throughout the entire body (rather than just a single joint or a small series of joints), is needed to attempt to identify subtle muscular weakness, muscular imbalance and both flexibility and range of motion deficits in the elite tennis player, with a goal of both injury prevention and performance enhancement.

Research published by the United States Tennis Association (USTA) Sport Science Committee[15] has provided key epidemiological information regarding the injury and training characteristics of elite junior tennis players. For example, with specific reference to shoulder injury, prior studies by Reese et al[19] and others[16,20,21] have reported shoulder injury rates of 8 to 24% in elite junior tennis players. In the USTA investigation by Kovacs et al[15], 861 elite level players between the ages of 10 to 17 years old were studied. Overall, 41% of all players reported at least one overuse injury that limited tennis play and competition in the past year. Of all the injuries reported in the study, shoulder injuries were reported by 17% of players in the survey, with elbow injuries comprising 3%. Of elite juniors, 18% reported lower back injury, 13% had knee, 5% foot and 14% had ankle injuries. Additionally, of the 41% of players reporting a musculoskeletal injury, 33% of these players reported a second musculoskeletal injury during that time period.

The USTA Sport Science Committee drafted a protocol for the musculoskeletal evaluation of elite junior tennis players in 2003 called the High Performance Profile (HPP). This protocol consisted of a series of 10 evidence-based musculoskeletal tests for the upper and lower body as well as core strength, specific to the demands and adaptations reported in the literature for elite level tennis players. The committee felt these tests best assessed the entire kinetic chain of an elite junior tennis player. The HPP was recommended for use with competitive players, using tests that could be readily performed by physical therapists, athletic trainers and physicians. Table 1 lists the original tests recommended by the USTA Sport Science Committee. This battery of tests formed the initial platform for the musculoskeletal testing programme assembled for this article, with additional tests added by the author (Table 2) due to availability of equipment in the physical therapy clinical setting where all tests performed in this review took place.

TABLE 1

- *Scapular dyskinesis*
- *Shoulder IR and ER range of motion at 90° abduction*
- *Shoulder ER @ 90° abduction manual muscle test*
- *Grip strength*
- *One-leg stability test*
- *Thomas Test*
- *Hip external rotation (Patrick's Test / FABER)*
- *Prone knee flexion*
- *Straight leg raise*
- *Abdominal bracing core stability test*

TABLE 2

- *Beighton Hypermobility Index*
- *Elbow extension range of motion*
- *Wrist flexion range of motion*
- *Wrist extension range of motion*
- *Empty can (supraspinatus strength testing)*
- *Hip IR range of motion (prone)*
- *Hip ER range of motion (prone)*

Table 1: USTA high performance profile tests.

Table 2: Additional musculoskeletal tests for elite tennis players.

ER=external rotation, IR=internal rotation, FABER=flexion, abduction, external rotation.

METHODOLOGY

Musculoskeletal testing of elite junior tennis players

This article contains the results of a retrospective 10-year review of 299 elite tennis players that presented to Physiotherapy Associates Scottsdale Sports Clinic for evaluation. All players were currently training and/or competing, and were free from injuries that prohibited their full participation in their competition or training activities at that time. All tests were performed by the author in one clinic location and using one methodology. Key components of the testing programme are described below.

UPPER EXTREMITY TESTS

Range of motion

Passive shoulder rotation

Glenohumeral joint range of motion (ROM) was measured with the player in a supine position, with the shoulder abducted 90° in the coronal plane using a universal goniometer. The player's elbow was maintained in 90° of elbow flexion while external (ER) and internal (IR) rotation ROM were measured using scapular stabilisation, with the examiners hand preventing scapular movement[2,3,22] (Figure 1). End range of motion was determined by the weight of the limb and gravity, with no overpressure exerted by the examiner. Total rotation ROM was obtained by adding the IR and ER measures together. It is recommended that these tests be performed bilaterally to allow for comparison to the non-dominant extremity. Test-retest reliability of this range of motion technique for shoulder internal rotation in 90° of abduction with scapular stabilisation has been studied by Wilk et al[22] with intraclass correlation coefficients reported as 0.62 for intra-rater reliability and 0.43 for inter-rater reliability.

Figure 1: Shoulder internal rotation range of motion measurement using a goniometer with technique for scapular stabilisation used during testing.

Figure 2: Testing for shoulder external rotation with 90° of glenohumeral joint abduction using a hand-held dynamometer.

Figure 3: Biodex isokinetic dynamometer used to assess shoulder internal and external rotation strength at 90°of glenohumeral joint abduction.

Figure 4: Empty can test position used to test for supraspinatus strength.

Distal upper extremity ROM

With the player in a seated position, elbow extension ROM was measured using a universal goniometer bilaterally. The shoulder was placed in 90° of flexion, with the forearm supinated during measurement. The goniometer was aligned along the lateral aspect of the elbow, using consistent landmarks[23]. Players actively extended their elbow to end ROM, with no overpressure or guidance provided by the examiner. Active wrist flexion and extension ROM was measured in a seated position, with the elbow extended and forearm in a pronated position. The goniometer was placed along the lateral aspect of the wrist and forearm/hand, using consistent landmarks[23].

UPPER EXTREMITY

Strength and stability

Shoulder ER strength

Players were tested using a Lafayette (Lafayette Instrument Company, Lafayette, IN, USA) hand-held dynamometer (HHD) in a seated position, with the shoulder abducted 90° in the coronal plane (Figure 2). The best of two maximal contractions were recorded in kilograms. The HHD was placed on the dorsal aspect of the forearm immediately proximal to the ulnar styloid process. The elbow remained flexed 90° during testing. Testing can also be performed with the shoulder in 0° abduction to assess the strength of the infraspinatus[24].

Additionally, an isokinetic test is used to assess internal and external rotation strength in the 90° abducted position in the coronal plane[1,5,7] (Figure 3). Testing speeds of 90°, 210° and 300° per second have been used with five repetitions at each speed with normative data reported for elite level tennis players. Equal external rotation strength and significantly greater internal rotation strength on the dominant arm have been reported with external to internal rotation ratios between 65 to 70% (75 to 80% in the non-dominant arm). Test-retest reliability of isokinetic shoulder strength measurement has been performed and is reported to range between intraclass correlation coefficient of 0.70 to 0.96 in multiple studies and dynamometer systems[28]. Additional reference to isokinetic testing and interpretation can be found in Ellenbecker and Davies[28], and Ellenbecker and Roetert[5].

> **Injuries in elite junior tennis players can involve virtually all anatomical regions of the body**

Supraspinatus strength

Testing utilised the empty can position (scapular plane abduction with internal rotation)[29] in the seated position. The shoulder was maintained in 90° of elevation during testing, with the HHD placed just proximal to the ulnar styloid process (Figure 4). The best of two maximal contractions were recorded in kilograms.

Grip strength

A Jamar hand grip dynamometer was used, with the player in a standing position. The elbow was maintained in an extended position, with no contact of the dynamometer with the player's body during testing. The best of two maximal effort trials was recorded in Kilograms.

Scapular evaluation

Using a 2 pound weight, players were visually observed during four to five repetitions of bilateral flexion, scapular plane abduction and coronal plane abduction repetitions by the examiner (Figure 5). Using the classification proposed by Kibler[30,31], each scapula was independently evaluated. Scapular dyskinesis was determined by the presence of abnormal motion or positioning of the scapular relative to the thorax[30]. Prominence of the scapula from the thoracic wall, as well as abnormal movement mechanics, were recorded according to Kibler et al[30]. A yes/no classification system was used based on the presence of scapular dyskinesis, with the dominant and non-dominant sides evaluated independently. Test-retest reliability of the Kibler system of scapular dysfunction has been studied with coefficient of agreements reported as 79% (Kappa 0.40) for the yes/no classification[30].

General Hypermobility Index

Players were evaluated using the Beighton Hypermobility Index[32]. The test utilises bilateral measures of 5th metacarpophalangeal joint hyperextension, flexion of the thumb to the volar surface of the forearm as well as hyperextension of the elbows and knees, and trunk flexion. To be considered as hypermobile, subjects were required to have 5/9 positive findings in the hypermobility index[33]. Psychometric properties of the Beighton scale include reliability estimates (intraclass correlation coefficients) ranging from 0.65 to 1.00 in multiple testing populations[33].

LOWER EXTREMITY TESTS

Range of motion

Hip rotation

Hip rotation ROM was measured with the player in the prone position, with the knees flexed 90°. Hip IR was measured by having the subject actively internally rotate both hips simultaneously, to minimise trunk and body rotation (Figure 6). A goniometer was used with the axis of rotation along the femur, with one arm placed along the tibia and the other remaining vertical[4]. Hip ER was measured one extremity at a time, with the examiner's hand placed on the ipsilateral pelvis to stabilise and minimise motion/rotation during measurement. Similar goniometer landmarks were again used for hip ER. Hip total rotation was obtained by summing the IR and ER measures together.

Thomas Test

The Thomas Test is used with the player in a supine position on a plinth. The description of this test is well referenced elsewhere[34]. A positive test was determined when the femur did not achieve a position parallel to the ground (hip flexor tightness) (Figure 7). Additionally, rectus femoris inflexibility was determined when the knee could not be flexed to 90° with the hip in the parallel position[7].

Prone knee flexion

Players were tested in a prone position and asked to actively flex their knee, moving their heel to their buttock. A goniometer was used to quantify knee flexion being placed along the lateral aspect of the femur and fibula as landmarks[23].

Hamstring flexibility

Multiple methods of assessing the length and flexibility of the hamstrings are reported in the literature and are used in the screening of elite tennis players. One method, the straight leg raise, is simply used by measuring passive hip flexion ROM with the knee extended and recording the angle using a goniometer relative to the trunk[34]. Another method involves the active extension of the knee from a 90/90 position and measuring the angle from vertical of the tibia[34]. Both tests involve a neutral extended position of the contralateral extremity.

5

6

Figure 5: Test for scapular stabilisation using a 2 pound weight with self-directed elevation in the scapular plane.

Figure 6: Prone hip internal rotation range of motion measurement method.

Figure 7: Thomas Test used to assess flexibility of the hip flexors.

Figure 8: One leg stability test used to test for hip and core stabilisation.

LOWER EXTREMITY STRENGTH AND CORE STABILITY TESTS

Two tests were used to assess lower extremity and core strength. The one leg stability test measured the players' ability to stand on one leg (Figure 8) and perform a 1/3rd squat while maintaining proper balance as well as trunk and lower extremity alignment[34,35]. Several repetitions were viewed by the examiner from an anterior position, with particular attention focused on the following three abnormal movement patterns:

1. Trendelenburg (contralateral hip drop).
2. Knee valgus angulation during descent .
3. Excessive forward lean.

The presence of any of these three abnormal movement patterns resulted in a failed test. The test was performed bilaterally, with the arms of the player at his or her side. Test-retest reliability of the single leg stability test has been reported for both inter- and intra-rater applications with coefficients of agreement reported as 73 to 87%, and kappa coefficients of 0.60 to 0.80.

The original core stability test recommended by the USTA sport science committee consisted of abdominal bracing during a series of independent leg extensions from the initial position of 90° of hip and knee flexion[36]. A blood pressure cuff was placed in the lumbar region of the player, with initial inflation of the cuff to 40 mmHG during contraction of the abdominal musculature to produce a posterior tilt of the pelvis into the cuff. The player was then instructed to alternatively lower one leg at a time to a position of hip and knee extension approximately six inches off the supporting surface (Figure 9). To pass the test, the player had to maintain the pressure in the cuff at or above 40 mmHg for 10 consecutive repetitions of lower extremity movements. Inability to perform 10 repetitions led to a 'failed' test[34,36].

In the updated USTA HPP, the abdominal bracing test was replaced by the plank test. The plank test involves a sustained hold of 30 seconds using an erect posture in a prone and side-lying position while maintaining optimal body alignment and postural control[34,35]. Both a prone (Figure 10) and unilateral side-lying (Figure 11) position are used and recommended.

Finally, an isokinetic test to assess knee extension and flexion strength has been utilised at testing speeds of 180°, 240° and 300° per second[37]. Five repetitions are used at 180° and 240° per second and an endurance test at 300° per second is used with 15 repetitions performed. Bilaterally symmetrical knee extension and flexion strength has been reported in elite tennis players[37].

RESULTS OF MUSCULOSKELETAL TESTING IN ELITE JUNIOR TENNIS PLAYERS

Player demographics

Table 3 displays the demographics of the 299 elite tennis players. To be considered elite, players were training year-round in tennis and competing in tournaments leading to the achievement of rankings in local, sectional, national and international standings. Male players had slightly more than 1 year more playing experience than the females and played the same number of competitive tournaments each year. Results showed males were taller and heavier than the female players tested (Table 3). A majority of players were right handed and, for the purposes of this article, all data was processed using the dominant and non-dominant classification rather than left or right. Two-handed backhands were used by 75% of male players and 97% of female players.

Upper extremity testing

Table 4 displays the results of shoulder rotation ROM and strength testing for the male and female players tested in this study. Male and female players had significantly less ($P < 0.01$) IR ROM on the dominant arm (-12.8° for males and -11.6° for females), also with significant ($P < 0.01$) dominant arm increases in ER ROM (+4.1° for males and +4.3° for females). The total rotation ROM was significantly ($P < 0.01$) smaller on the dominant arm by -8.6° for males and -7.2°

Figure 9: Abdominal bracing test with unilateral leg lowering using a blood pressure cuff in the lumbar region.

Figure 10: Prone plank position.

Figure 11: Side plank position.

for females. Additional results for distal upper extremity elbow and wrist ROM are also displayed in Table 4.

Shoulder ER and supraspinatus strength results are displayed in Table 4. Equal values for dominant and non-dominant ER and supraspinatus strength were measured bilaterally and are expressed in kilograms. Scapular dyskinesis was identified in 75% of males for the dominant arm and 56% for the non-dominant arm, with 65% and 48% for females respectively. Additionally, the Beighton Hypermobility Index was positive in 25% of male players and 62% of female players in this testing sample.

Lower extremity and core testing

The goniometric prone hip rotation ROM measurements found in this study show symmetrical IR, ER and total rotation values in both the male and female players with no significant differences (P >0.04) identified between extremities (Table 5). Prone knee flexion measures for the quadriceps were not different by more than 1° between the dominant and non-dominant lower extremity. Tightness of the hip flexors measured via a positive Thomas Test was recorded in 45% of male players and 50% of female players bilaterally. Failure of the one leg stability test occurred in 65% (dominant limb) and 68% (non-dominant limb) of male players and 56 and 65% (dominant and non-dominant limb respectively) of female players. The core stability test was failed (inability to perform 10 consecutive repetitions with abdominal bracing) by 61% of the male players and 56% of the female players in this sample.

Table 3

Variable	Males (mean±SD)	Females (mean±SD)
Age (yrs)	*17.2(3.2)*	*16.5(3.5)*
Height (in)	*69.9(4.0)*	*66.6(3.9)*
Weight (lbs)	*150.1(31.3)*	*128.9(25.7)*
Years tennis play	*8.3(3.4)*	*6.9(3.7)*
Number tournaments/year	*16.8(7.8)*	*16.7(8.3)*
Two-handed backhand	*75%*	*97%*
Right-handed players	*90%*	*94%*
Beighton Hypermobility Index (+)	*25%*	*62%*

Table 3: Player demographic variables.

Table 4

Variable	Males (mean±SD)			Females (mean±SD)		
	Dominant	Non-dominant	(Diff)	Dominant	Non-dominant	(Diff)
Shoulder IR	39.4(9.5)	52.2(9.7)	12.8	41.5(7.9)	53.1(7.0)	11.6
Shoulder ER	103.2(9.3)	99.1(9.8)	4.1	105.6(7.5)	101.3(7.9)	4.3
Total rotation	142.6(11.2)	151.2(10.5)	8.6	147.2(9.2)	154.4(8.9)	7.2
Elbow extension	-0.86(6.8)	+2.75(5.8)	3.61	+2.89(6.4)	+5.91(6.6)	2.9
Wrist flexion	68.2(9.3)	73.1(8.7)	4.9	73.0(9.0)	75.2(7.2)	2.2
Wrist extension	70.2(11.0)	75.4(9.8)	5.2	73.1(7.5)	77.4(7.8)	4.3
Empty can (kg)	8.3(2.6)	8.3(2.4)	0.0	6.9(2.5)	6.9(2.2)	0.0
ER 90 abduction (kg)	11.5(3.7)	11.5(3.7)	0.0	10.4(3.0)	9.9(2.3)	0.5
Grip strength (kg)	45.3(13.2)	39.6(12.0)	5.7	31.8(9.1)	27.1(8.3)	4.7
Scapular dyskinesis	65%	48%	17%	75%	56%	14%

Notes: All measures in degrees except for strength testing (empty can/supraspinatus), ER at 90˚ abduction and grip strength which are in kilograms.
*Scapular dyskinesis** expressed as number of positive findings for each extremity in percent.*

Table 4: Upper extremity variables in elite junior tennis players.

Table 5

Variable	Males (mean±SD)			Females (mean±SD)		
	Dominant	Non-dominant	(Diff)	Dominant	Non-dominant	(Diff)
Hip IR	35.9(9.3)	34.1(8.8)	1.8	45.3(9.9)	43.3(9.4)	2.0
Hip ER	36.8(9.7)	36.7(8.8)	0.1	34.7(6.8)	35.3(6.6)	0.6
Hip total rotation	72.9(13.6)	70.7(13.6)	2.2	80.2(12.3)	78.8(11.7)	1.4
Prone knee flexion	132.7(8.9)	131.5(9.6)	1.2	133.1(7.9)	132.3(7.9)	0.8
Thomas Test (+)	45%	45%	0.0	50%	50%	0.0
One-leg stability (+)	56%	65%	9%	65%	68%	3.0

Notes: All measures in degrees. Percent positive (failed) tests for Thomas and one-leg stability.

Table 5: Lower extremity variables in elite junior tennis players, IR=internal rotation, ER=external rotation.

Figure 12: Biodex isokinetic dynamometer used for testing quadricep and hamstring strength.

DISCUSSION

This study provides objective musculoskeletal descriptive results from a testing battery designed to assess critical areas throughout the body in elite level tennis players. Knowledge of the typical findings and results of the tests utilised in this study can assist individuals providing musculoskeletal screening for elite level tennis players. The tennis players in this study had an extensive competitive tennis and training history given their age and relied heavily on the use of a two-handed backhand (75 to 90% of players). Females had a much higher percentage of hypermobility measured using the Beighton Hypermobility Index. Cameron et al[33] has shown that athletes with positive Beighton Index were 2.5× more likely to have glenhumeral joint instability. This simple series of hypermobility screenings can provide valuable information on potential injury risk and provide guidelines for training and preventative conditioning emphasis based on the underlying mobility status of the player.

The glenohumeral joint ROM measures taken in this study are consistent with other studies identifying both decreased total rotation and decreased IR ROM in the dominant arm of elite level tennis players[1,3,5,7,38]. This is the largest sample size reported to date in elite junior tennis players and reports the normal, expected ROM in the dominant arm of healthy, uninjured players to have a mean decrease of 11 to 12° in IR and 7 to 8° in total rotation ROM. Knowledge of these normal ROM values in healthy players can serve to provide guidelines for the identification of players with abnormally increased ROM restriction and shoulder injury risk[9,10]. Further research is needed to correlate these potential ROM deficits with injuries to obtain direct correlations regarding injury risk.

Distal upper extremity ROM measures quantified in this study do not show limitations in elbow extension ROM reported in cohorts of baseball pitchers[39], however this sample of tennis players is younger than those measured in the study by Wright et al[39]. Additionally, the wrist flexion and extension measures do not differ by more than 2 to 5° bilaterally in these elite junior tennis players.

Shoulder strength testing has been shown to identify injury risk in professional baseball players[40] using a HHD. The tests used in this study evaluating ER strength at 90° of abduction and supraspinatus strength revealed symmetrical strength values between the dominant and non-dominant extremity in both male and female elite junior tennis players. Prior isokinetic testing has shown significantly greater dominant arm internal rotation strength and symmetrical external rotation strength in elite level tennis players and professional baseball pitchers[1,5,7,8,11]. Use of a HHD has also been applied to professional[41] and in collegiate baseball pitchers[42]. In college baseball pitchers, isometric testing showed 12% weaker supraspinatus strength measured in the empty can position on the dominant arm compared to the non-dominant extremity[42]. These values suggest that symmetrical ER and supraspinatus strength can be expected in healthy uninjured elite junior tennis players and the finding of weaker dominant arm strength would indicate the need for specific exercise for the posterior rotator cuff and scapular stabilisers[43]. Grip strength testing shows greater dominant arm grip strength consistent with prior reports in elite tennis players and serves as a gross distal upper extremity strength assessment[44].

Lower extremity tests for ROM showed a very high incidence of hip flexor tightness measured via the Thomas Test with symmetrical ROM for prone knee flexion and hip rotation. Reported descriptive values can guide musculoskeletal screening of the hip as only one prior report profiled hip rotation ROM in elite tennis players[4]. Symmetrical hip joint total rotation ROM arcs can be expected in uninjured players based on the results of this sample when measured in the prone position with 90° of knee flexion. Abnormal compensatory performance on the one leg squat test was identified in 55 to 68% of the players in this study. Prior research has reported correlations between hip abductor weakness and visually observed performance decrements during the one leg squat test[35]. Finally, core testing performed in this study using a technique of abdominal bracing with lower extremity movement[34] showed a failure rate of 56 to 61% of the players tested in this study. No prior published reports of core stability testing have been previously published in tennis players with the exception of isokinetic profiling studies by Roetert et al[45] for trunk extension/flexion showing preferential development of the trunk flexor muscles and altered trunk flexion/extension ratios in elite junior players when compared to normals and the study by Ellenbecker et al[46] for trunk rotation showing symmetrical bilateral rotation strength values. Given the incidence of low back pain and injury in epidemiological research in tennis[15,16,20,21], further research is clearly needed to identify injury risk and validate optimal methods for core strength testing in the clinical setting.

CONCLUSION

This study provides an overview of a musculoskeletal testing programme for elite level tennis players. Specific alterations in shoulder ROM were identified including decreased dominant arm internal and total rotation when compared to the non-dominant extremity. Symmetrical ROM patterns in the hip and symmetrical shoulder strength for ER and the supraspinatus were among the findings generated in the use of this musculoskeletal testing protocol. The information in this article is provided to guide the interpretation and application of objective musculoskeletal testing programmes in elite junior tennis players for both injury prevention and performance enhancement.

References available at www.aspetar.com/journal

Todd S. Ellenbecker D.P.T., M.S., S.C.S., O.C.S., C.S.C.S.

Clinic Director & National Director of Clinical Research

Physiotherapy Associates Scottsdale Sports Clinic

Vice President of Medical Services ATP World Tour

Scottsdale, USA

Contact: ellenbeckerpt@cox.net