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original research

Age-Related, Sport-Specific Adaptions of the Shoulder Girdle in Elite Adolescent Tennis Players

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Context: Tennis requires repetitive overhead movements that can lead to upper extremity injury. The scapula and the shoulder play a vital role in injury-free playing. Scapular dysfunction and glenohumeral changes in strength and range of motion (ROM) have been associated with shoulder injury in the overhead athlete.

Objective: To compare scapular position and strength and shoulder ROM and strength between Swedish elite tennis players of 3 age categories (<14, 14–16, and >16 years).

Design: Cross-sectional study.

Setting: Tennis training sports facilities.

Patients or Other Participants: Fifty-nine adolescent Swedish elite tennis players (ages 10–20 years) selected based on their national ranking.

Main Outcome Measure(s): We used a clinical screening protocol with a digital inclinometer and a handheld dynamometer to measure scapular upward rotation at several angles of arm elevation, isometric scapular muscle strength, glenohumeral ROM, and isometric rotator cuff strength.

Results: Players older than 16 years showed less scapular upward rotation on the dominant side at 90° and 180° ($P < .05$). Although all absolute scapular muscle strength values increased with age, there was no change in the body-weight–normalized strength of the middle ($P = .9$) and lower ($P = .81$) trapezius or serratus anterior ($P = .17$). Glenohumeral internal-rotation ROM and total ROM tended to decrease, but this finding was not statistically significant ($P = .052$ and $P = .06$, respectively). Whereas normalized internal-rotator strength increased from 14 to 16 years to older than 16 years ($P = .009$), normalized external-rotator and supraspinatus strength remained unchanged.

Conclusions: Age-related changes in shoulder and scapular strength and ROM were apparent in elite adolescent tennis players. Future authors should examine the association of these adaptations with performance data and injury incidence.

Key Words: upper extremity, scapular position, scapular muscle strength, range of motion, rotator cuff strength

Key Points

- Elite adolescent tennis players showed some sport-specific adaptations in glenohumeral internal-rotation range of motion, rotator cuff strength, and scapular upward rotation.
- Sport-specific adaptations seemed to change within the 10- to 20-years-old age range.

The tennis serve uses rapid upper extremity movements to create high racket and ball speeds. Optimal upper extremity strength, flexibility, and neuromuscular coordination are necessary for attaining a high-velocity outcome.[1,2]

Due to the high loads and forces put on the shoulder complex during serving and hitting, tennis players are at increased risk for shoulder pain. Injury risk seems to increase with age[3,4] and, despite some lack of evidence, has been suggested to be related to the level and volume of play.[3–5] Shoulder injuries in overhead athletes are commonly due to repetitive use,[6] muscle fatigue,[7] and may be related to scapular dyskinesis,[8,9] rotator cuff injury and weakness,[10] or glenohumeral internal-rotation deficit,[11,12] resulting in int ernal impingement or labral injury (or both).[13,14]

In high-performance sports, athletes start full-time practice in early childhood, which overlaps with the period of skeletal and muscular development.[15,16] As a result of the high demands on joint mobility, muscle strength, and complex biomechanics in the shoulder girdle during overhead sport movements, sport-specific adaptations at the glenohumeral and scapulothoracic level may occur even during adolescence.[4,8,17]

Numerous authors have reported glenohumeral[18,19] and scapulothoracic[20,21] alterations in adult overhead sport populations. In addition, changes in glenohumeral range of motion[3] and rotator cuff strength[17] have been described in elite junior tennis players. Only recently have some studies[4,8] been published describing the scapular position, strength, and flexibility variables in this young population. However, in these investigations, only general data were established for the whole period of adolescence. The specific age-related changes within adolescents (11–18 years) and the progression over time in this age category were not apparent. Moreover, even though the literature highlights the importance of the coupled movements at the shoulder and scapulothoracic joint for optimal kinematics during the tennis serve,[1] to date no authors have combined glenohumeral and scapulothoracic measurements in adolescent tennis players. Therefore, the purpose of our study was to describe the age-related, sport-specific adaptations in the shoulder girdle in adolescent elite tennis players: in

Table 1. Participants' Demographic Data

Age Category, y (Mean ± SD)	n	Tennis Exposure, h/wk	Height, cm (Mean ± SD)	Weight, kg (Mean ± SD)
<14 (12.7 ± 0.8)	24	12.3	154.1 ± 8.8	44.8 ± 6.9
14–16 (14.6 ± 0.4)	22	15.3	168.8 ± 8.4	57.1 ± 9.1
>16 (17.4 ± 1.5)	13	15.6	172.4 ± 7.8	72.5 ± 9.0

particular, glenohumeral rotational range of motion and strength and scapular upward rotation and muscle strength.

METHODS

Participants

We tested 59 adolescent Swedish elite tennis players (31 boys, 28 girls), selected by the Swedish Tennis Federation on the basis of their national ranking. All but 3 players were right handed, and all players used a 2-handed backhand stroke. Participants were free from any upper extremity injury at the time of testing and in the 6 months before data collection. This study was performed between April 2009 and April 2011, was approved by the Ethical Committee of the Swedish University, and was coordinated with the Swedish Tennis Federation. We obtained informed consent from all players and their parent or legal guardian. The players were tested during a high-performance physical training camp.

Players were divided into 3 subgroups, based on age: younger than 14 years (n = 24), 14 to 16 years (n = 22), and older than 16 years (n = 13). Demographic data of the players are summarized in Table 1.

Measurement Procedures

The study design consisted of 2 scapular measurements (scapular upward rotation and isometric scapular muscle strength) and 2 glenohumeral measurements (rotational range of motion [ROM] and isometric rotator cuff muscle strength). All measurements were randomized to control for familiarization, fatigue, and a learning curve and were performed by the same examiner, who was knowledgeable about the procedures.

Scapular Upward Rotation. Scapular upward rotation was measured using the Pro 3600 digital inclinometer (SPI Tronic, Penn Tool Co, Maplewood, NJ).[4,20,22] Two Y-shaped adjustable plastic locator rods, designed to rest comfortably over the bony contours of the spine of the scapula, were attached to the inclinometer. A bubble level was attached to ensure minimal anterior-posterior tilting of the inclinometer around an axis parallel to the scapular spine.

Scapular upward rotation was measured in 3 positions: 0°, 90°, and 180° of elevation in the scapular plane (30° angle from the frontal plane as determined by goniometric measurement; Figure 1). All procedures were repeated twice. This method showed good to excellent intra-examiner reliability and good to excellent criterion validity.[22]

Scapular Muscle Strength. Isometric muscle strength of the scapular muscles was measured using a hand-held dynamometer (HHD; CompuFET, Hoggan Health Industries Inc, Groningen, The Netherlands). The reliability and validity of the HDD in the assessment of upper extremity muscle strength have been documented and found acceptable for clinical and research use.[23] A pilot study regarding the intertester and intratester reliability of this protocol revealed intraclass correlation coefficients between 0.83 and 0.95. This protocol was already used by the same examiners in a previous study.[4] Therefore, for the specific procedure, we refer readers to the previously published paper.[4]

Figure 1. Measurement of scapular upward rotation using a PRO 3600 digital inclinometer (SPI Tronic, Penn Tool Co, Maplewood, NJ).

The 4 major scapular muscles were tested: upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA). All participants performed the manual muscle testing in the same order: UT, MT, LT, SA. The nondominant arm was tested first. Strength tests were not randomized because we did not expect either fatigue or learning effects during the protocol. Each muscle test was repeated twice, using a 5-second "make test."[23] Data were collected and directly stored by the software program (version 1.0A; CompuFET Biometrics, Kabelstraat, The Netherlands). The absolute and weight-normalized strength data were generated by the software program.

Glenohumeral Internal- and External-Rotation ROM. Shoulder internal-rotation (IR) and external-rotation (ER) passive ROMs were measured for the dominant and nondominant shoulders using an Acumar digital inclinometer (model ACU360; Lafayette Instrument Co, Lafayette, IN). The manufacturer's specifications indicate that this instrument is capable of measuring a range up to 180° with an accuracy of 1°. Participants were placed supine and their shoulders positioned in 90° of abduction in the coronal plane. Measurements for IR and ER were performed in the plane of abduction, and a small towel roll was used to maintain the position of the humerus. The inclinometer was mounted on a bar that was aligned from the olecranon to the ulnar styloid process.[24] The examiner palpated the coracoid process with her thumb and the spine of the scapula with her fingers to control for scapular movement.[11,12,24] The inclinometer was stabilized on the player's forearm, and the shoulder was passively moved to the end of ROM into IR (Figure 2) and ER (Figure 3); scapular movement was controlled by palpation of the coracoid process and visual inspection, without using passive overpressure.[11] The mean of 2 trials was used for data analysis. In a previous study,[24] this measurement protocol had good reliability (IR:

Figure 2. Measurement of glenohumeral internal-rotation range of motion using an Acumar inclinometer (Lafayette Instrument Co, Lafayette, IN).

Figure 4. Measurement of isometric muscle strength of the external rotators using a hand-held dynamometer (CompuFET, Hoggan Health Industries Inc, Groningen, The Netherlands).

interclass correlation coefficient (ICC)[2,k] = 0.93, SEM = 1.6°; ER: ICC[2,k] = 0.8, SEM = 4°). After data collection, ROMs for IR and ER were noted, and total ROM was calculated by summing IR and ER ROM.

Glenohumeral Muscle Strength. Isometric strength of the glenohumeral muscles was measured using a hand-held dynamometer (HHD; CompuFET). Strength measurements were taken from the internal rotators, external rotators, and supraspinatus. Strength of the internal and external rotators was assessed with the participant supine, the shoulder in neutral position, and the elbow flexed to 90°. We chose this position because of the applicability of this procedure on a wide variety of participants, including injured athletes and those in rehabilitation after shoulder surgery. In addition, performing external rotation in neutral position has been suggested to elicit high activity in the infraspinatus.[25] Infraspinatus weakness is a possible factor associated with shoulder injury in overhead athletes.[26]

We chose the supine position because of scapular stabilization from the participant's trunk on the bench. The examiner manually stabilized the upper arm at the participant's side in 0° of rotation. The HHD was then placed on the dorsal (ER) or ventral (IR) aspect of the forearm, 5 cm proximal to the wrist crease.[10] The participant was asked to perform ER and IR against the examiners' resistance for a "make test" (Figures 4 and 5). For supraspinatus strength, we selected the empty-can position.[27] The participant stood with the shoulder elevated to 90° in the scapular plane in full IR. Resistance was provided against further elevation, placing the HHD 5 cm proximal of the styloid process of the ulna (Figure 6). All participants performed the manual muscle testing in the same order: ER, IR, supraspinatus. The nondominant arm was tested first. Two repetitions of 5 seconds each were performed and averaged for further analysis. Data regarding the absolute and weight-normalized strength were collected and directly stored by the software program. In addition, the ER/IR isometric strength ratio was calculated based on the results of ER and IR isometric strength.

Figure 3. Measurement of glenohumeral external-rotation range of motion using an Acumar inclinometer (Lafayette Instrument Co, Lafayette, IN).

Figure 5. Measurement of isometric muscle strength of the internal rotators using a hand-held dynamometer (CompuFET, Hoggan Health Industries Inc, Groningen, The Netherlands).

Figure 6. Measurement of isometric muscle strength of the supraspinatus using a hand-held dynamometer (CompuFET, Hoggan Health Industries Inc, Groningen, The Netherlands).

The intrarater and interrater reliability and validity of isometric handheld dynamometry have been established.[23] In general, reliability and construct validity are considered acceptable when the participant's and examiner's positions are standardized and repeatable, stabilization is thorough, and the examiner can exceed the participant's force.

Statistical Analysis

We calculated descriptive statistics for all variables and controlled for normal distribution and homogeneity of variance of all dependent variables using the 1-sample Kolmogorov-Smirnov test and the Levene test. All data were normally distributed, so we performed parametric statistical analysis.

The dependent variables of interest were (1) scapular upward rotation at 0°, 90°, and 180° of elevation in the scapular plane; (2) absolute (N) and weight-normalized (N/kg) isometric muscle strength of the UT, MT, LT, SA; (3) shoulder ROM in ER and IR and total ROM (IR + ER) (in degrees); and (4) absolute (N) and weight-normalized (N/kg) strength of the supraspinatus and external and internal rotators and the ER/IR ratio (%).

We analyzed differences in scapular upward rotation using a general linear model 3-way analysis of variance (ANOVA) for repeated measures, in which the within-subject factors were side (2 levels) and position (3 levels), and the between-subjects factor was age category (3 levels).

Differences in shoulder range of motion and scapular and glenohumeral muscle strength were analyzed with a general linear model 2-way ANOVA for repeated measures, in which the within-subject factor was side (2 levels) and the between-subjects factor was age category (3 levels).

We were also interested in 3-way interactions (side × position × age category). In the absence of significant 3-way interactions or when only 2 factors were defined in the ANOVA, we explored 2-way interactions among the variables of interest (side × age category and position × age category). In the absence of any interaction effects, main effects (for side, position, and age category) were analyzed. Alpha was set on .05 for the ANOVA. Post hoc analyses were performed using a Bonferroni procedure when the ANOVA revealed a significant difference.

All statistical analyses were performed using SPSS (version 19.0; SPSS Inc, Chicago, IL).

RESULTS

Scapular Upward Rotation

The scapular upward-rotation measurements are presented in Table 2. In all tables, only significant group differences are marked; however, we discuss all (side and/or position) significant differences in this section. Analysis of variance for repeated measures did not show any 3-way interaction effects, but we did find significant position × age category ($P = .002$) and position × side ($P = .024$) interaction effects. Upward rotation on the dominant side in the older players was less than in the other age groups, in 90° and 180° of scapular elevation ($P < .05$). In the resting position, no differences were observed among the groups, and no group differences were apparent between the 2 younger age categories. The younger players showed more upward rotation on the dominant side at 90° and 180° ($P < .05$) compared with the nondominant side. In the oldest age group, no side differences were apparent. Because differences among the 3 positions tested reflect normal scapular upward rotation during arm elevation, we did not pursue post hoc analysis on this factor.

Scapular Muscle Strength

The descriptive analysis of the isometric muscle tests of the scapular muscles is presented in Table 3. For the absolute muscle-strength data, no interaction effects for side × age category were significant. Main effects for side were significant for UT ($P = .002$) and LT ($P = .01$) but not for MT ($P = .638$) and SA ($P = .519$). As expected in view of the growth and muscular development in this population, we found increased absolute muscle strength for all the muscles examined ($P < .001$). Post hoc analysis showed increases in muscle strength for UT ($P < .001$) and SA (*P*

Table 2. Scapular Upward Rotation

	Arm Elevation in the Scapular Plane, Mean ± SD					
	0°		90°		180°	
Age Group, y	ND	D	ND	D	ND	D
<14	4.3 ± 3.6	5.6 ± 4.0	22.8 ± 6.7	27.5 ± 7.5	48.8 ± 6.9	54.7 ± 6.9
14–16	3.9 ± 2.8	5.7 ± 4.0	22.2 ± 7.0	27.5 ± 7.2	51.4 ± 8.5	56.4 ± 8.6
>16	4.6 ± 4.0	5.1 ± 4.1	19.8 ± 5.6	19.6 ± 7.5[a]	45.2 ± 6.9	46.6 ± 9.7[a]

Abbreviations: D, dominant side; ND, nondominant side.

[a] Group difference ($P < .05$).

Table 3. Absolute Muscle Strength and Normalized Muscle Strength

Muscle	Age Group, y	Absolute Muscle Strength, N (Mean ± SD)		Normalized Muscle Strength, N/kg (Mean ± SD)	
		Nondominant Side	Dominant Side	Nondominant Side	Dominant Side
Upper trapezius	<14	114.5 ± 33.0	128.4 ± 35.2	2.57 ± 0.64	2.86 ± 0.64
	14–16	162.83 ± 34.8[a]	178.3 ± 43.1[a]	2.87 ± 0.59	3.18 ± 0.77
	>16	243.0 ± 44.1[a]	247.1 ± 41.8[a]	3.44 ± 0.30[b]	3.68 ± 0.71[b]
Middle trapezius	<14	30.9 ± 9.1	31.1 ± 7.9	0.66 ± 0.26	0.67 ± 0.21
	14–16	39.15 ± 8.9[b]	38.9 ± 11.3[b]	0.70 ± 0.16	0.69 ± 0.14
	>16	46.2 ± 14.6	47.8 ± 13.1	0.69 ± 0.29	0.63 ± 0.22
Lower trapezius	<14	26.3 ± 9.5	27.7 ± 8.9	0.57 ± 0.25	0.59 ± 0.23
	14–16	30.3 ± 7.2	32.8 ± 9.9	0.55 ± 0.17	0.59 ± 0.18
	>16	41.5 ± 14.7	45.3 ± 16.8[b]	0.63 ± 0.27	0.64 ± 0.28
Serratus anterior	<14	118.7 ± 49.7	127.9 ± 57.1	2.64 ± 0.95	2.83 ± 1.09
	14–16	178.5 ± 61.1[b]	188.82 ± 59.5[b]	3.1 ± 1.02	3.30 ± 1.00
	>16	254.4 ± 44.1[b]	243.8 ± 43.1[b]	3.48 ± 0.33	3.30 ± 0.53

[a] Different from the younger age group ($P < .001$).

[b] Different from the younger age group ($P < .05$).

$< .05$) over all 3 age categories on both sides. For MT, increases were seen between age groups 1 and 2 for both sides ($P < .05$) but not from the middle to the oldest age group (nondominant: $P = .24$; dominant: $P = .12$). The LT strength only increased between the middle and oldest age group on the dominant side ($P = .027$).

Taking into account the general increase in muscle mass and performance in this adolescent population, we normalized the results of the strength measurements to body weight. No interaction effects were significant in the statistical analysis. Only the normalized UT strength was greater on the dominant side (main effect $P = .001$); the other muscles showed equal strength on both sides. Moreover, only the normalized UT strength increased with age ($P = .018$); the other muscles (MT [$P = .90$], LT [$P = .81$], SA [$P = .17$]) did not increase in strength.

Glenohumeral IR and ER ROM

The descriptive data are summarized in Table 4. For IR, ER, and total ROM, we found no significant interaction. However, for all measurements, side differences were observed ($P < .001$), with a trend toward significance with age for IR ($P = .052$) and total ROM ($P = .060$). In view of the results from the ANOVA for repeated measures, we did not perform post hoc analyses on these variables.

Glenohumeral Muscle Strength

The glenohumeral muscle-strength data are presented in Table 5. For absolute glenohumeral muscle strength data, there were no side × age category interaction effects. However, for all 3 tests performed, significant main effects for side ($P < .01$) and age category ($P < .001$) were present. Thus, players were stronger on the dominant side than the nondominant side and strength increased with age. Post hoc tests revealed increased strength for the internal and external rotators and the supraspinatus over all 3 age categories ($P < .05$), except for the supraspinatus between the middle and oldest age groups for both the nondominant ($P = .09$) and the dominant ($P = .15$) sides.

For the normalized strength data, we found a strength increase for IR on the dominant side ($P = .009$) between the middle and oldest age groups and more IR strength on the dominant side in all age categories ($P < .01$).

No side × age category ($P = .225$) or main group ($P = .543$) or side ($P = .052$) effects were evident for the variable ER/IR ratio.

DISCUSSION

The purpose of our investigation was to generate a descriptive profile of age-related, sport-specific adaptations during adolescence in elite junior tennis players. To our knowledge, we are the first to perform combined scapulothoracic and glenohumeral measurements in this population for shoulder-girdle strength, mobility, and scapular position and to look at specific age categories within adolescence. In particular, we were interested in possible adaptations that would put the player at a higher risk for injury or decreased performance.

Scapular Upward Rotation. At higher elevation angles (90° and 180°), the older players (>16 years) had less upward rotation than those in the other 2 age categories. It seems that the advantage of more upward rotation on the dominant side, as seen in the younger players and confirming the results from a previous study,[4] was no longer present in late adolescence. The presence of sufficient upward rotation during overhead movements has been suggested as vital to injury-free performance by clearing the acromion from the underlying subacromial structures.[8] Our results are in favor

Table 4. Glenohumeral Range of Motion

Age Group, y	Range of Motion, °					
	Internal Rotation		External Rotation		Total	
	ND	D	ND	D	ND	D
<14	59.4 ± 6.5	49.4 ± 8.2	100.0 ± 5.3	104.4 ± 6.5	159.5 ± 8.2	153.8 ± 9.1
14–16	58.1 ± 7.9	43.4 ± 11.3	98.4 ± 7.9	105.1 ± 6.5	156.5 ± 10.9	148.6 ± 12.4
>16	55.5 ± 8.9	40.6 ± 7.4	99.5 ± 11.0	101.7 ± 11.9	155.1 ± 13.2	142.3 ± 11.0

Abbreviations: D, dominant side; ND, nondominant side.

Table 5. Glenohumeral Muscle Strength

Variable	Age Group, y	Absolute Muscle Strength (N)		Normalized Muscle Strength (N/kg)	
		Nondominant Side	Dominant Side	Nondominant Side	Dominant Side
Internal-rotation strength	<14	78.4 ± 23.9	86.0 ± 28.7	1.75 ± 0.36	1.93 ± 0.48
	14–16	100.7 ± 14.8[a]	114.6 ± 22.9[a]	1.80 ± 0.32	2.01 ± 0.33
	>16	136.2 ± 40.8[a]	165.5 ± 36.7[a]	1.94 ± 0.31	2.6 ± 0.48[b]
External-rotation strength	<14 y	57.2 ± 13.8	61.4 ± 13.7	1.29 ± 0.26	1.39 ± 0.29
	14–16 y	72.4 ± 13.3[a]	77.9 ± 15.3[a]	1.28 ± 0.25	1.39 ± 0.28
	>16 y	105.3 ± 26.2[a]	109.4 ± 31.3[a]	1.54 ± 0.44	1.7 ± 0.56
Supraspinatus strength	<14 y	47.9 ± 7.8	50.5 ± 8.3	1.09 ± 0.22	1.14 ± 0.19
	14–16 y	56.7 ± 11.5[a]	62.5 ± 13.6[a]	1.00 ± 0.17	1.11 ± 0.18
	>16 y	71.7 ± 20.9	79.0 ± 26.3	1.21 ± 0.23	1.33 ± 0.38
External-rotation/internal-rotation ratio	<14 y	74.4 ± 13.3	74.1 ± 13.8		
	14–16 y	71.8 ± 9.6	69.0 ± 12.7		
	>16 y	78.3 ± 12.3	66.2 ± 11.6		

[a] Different from the younger age group ($P < .05$).
[b] Different from the younger age group ($P < .01$).

of optimal scapulohumeral kinematics in the younger age groups (<14 and 14–16 years), which may protect them from subacromial impingement. However, in the older players (>16 years), less upward rotation possibly puts them at more risk for developing shoulder pain: altered scapular kinematics have been identified as a risk factor for developing chronic shoulder pain in overhead athletes.[9] The alterations we found in scapular position based on dominance and age of the athlete confirm previous reports of asymmetric resting scapular posture in healthy overhead athletes, although some past reports have shown conflicting results.

Scapular Muscle Strength. Although absolute muscle strength increased over time during adolescence, this strength gain, when normalized for body weight, was only present for the UT. No other scapular muscles investigated showed an increase in body-weight–normalized strength during adolescence. Taking into account the specific function of the scapular force couple, in which all muscles must be activated in an optimal balance, the relative overload of 1 muscle (in this case, the UT) might lead to a disturbance in the force couple.[28] Our results confirm alterations in scapular muscle balance in overhead athletes, which were previously established in gymnasts,[29] tennis players,[4] and swimmers,[30] but these results were inconsistent. On the basis of our results, we might suggest coaches and clinicians emphasize strength training of the scapular stabilizers, in particular the MT, LT, and SA, to maintain the balance in the scapular force couple. Recently, specific exercises to strengthen the MT, LT, and SA were shown to be effective in restoring muscle balance.[31]

Glenohumeral IR and ER ROM. In agreement with other studies,[3,18,19] we found side differences in the tennis players for IR, ER, and total ROM, with less IR, larger ER, and smaller total ROM on the dominant side. Explanations for the ROM adaptations in unilaterally dominant upper extremity athletes include capsular, musculotendinous, and osseous factors. Contrary to our expectations, the group differences did not reach statistical significance. This lack of significance is probably due to the small sample size in each age category, leading to less statistical power (post hoc power analysis revealed a power of 0.45 for the IR ROM results). Nevertheless, in view of the side differences for IR (reaching 15° in the oldest age category) and with the knowledge that loss of IR ROM in the overhead athlete is considered a risk factor for shoulder pain,[11,12] we recommend stretching of the posterior shoulder structures as a preventive measure[13,14,24,32] in adolescent tennis players.

Glenohumeral Muscle Strength. Our results show a general increase in glenohumeral strength based on age. However, when the data were normalized to body weight, only the internal rotators on the dominant side of the oldest players showed increased strength compared with the 2 other age categories. The strength of the external rotators and the supraspinatus, which are known to play an important role in glenohumeral stability during overhead sport performance (in particular, in eccentrically decelerating the arm during the follow-through phase),[14] remains unchanged when normalized to body weight. This strength imbalance might jeopardize the rotator cuff force couple during the tennis serve and stroke and might put the athlete at more risk for overuse injury.[10] Indeed, in the oldest age category, the ER/IR ratio was 66.2%, whereas in the younger player, the ratio was 74.1%, reflecting a relative weakness of the external rotators in the oldest players. In view of our results, eccentric strength training of the external rotators and supraspinatus might be suggested for the adolescent tennis player.[14]

Limitations of the Study and Future Directions

For all the measurement techniques and protocols in this study, we used field measurement tools. They are easy to transport and to use in a sport-specific setting, such as a tennis court or training area. They are affordable for clinicians, who very often lack access to the high-technology equipment for strength and kinematic behavior measurements available in research centers and specialized training settings. This is 1 of the strengths of the study but also leads to a limitation. Clinical measurements often do not achieve the same reliability, validity, and accuracy as those in laboratory investigations. Therefore, we encourage clinicians to maximize standardization and reliability in reproducing the tests in this study by limiting the testing to 1 examiner, blinding the results from the tester during testing, performing pilot studies to become familiar with the procedures if needed, and ensuring standardization in palpation, participant position, and task instruction.

A second limitation is the absence of statistical correlation analysis between the variables measured. Although we report on scapular as well as glenohumeral results in elite adolescent tennis players, we were not able to perform a correlation analysis between these variables due to the limited number of players available to participate in each subgroup of the study. In particular, the sample in the age category >16 years was small. Given the purpose of the investigation, we selected only elite players to participate. A priori power analysis revealed that, in order to identify clinically relevant correlations (>0.60), a minimum of 26 participants were necessary in each subgroup. Future authors should try to expand the study group to that number of players by performing longer-term studies or collaborating internationally.

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