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Bilateral Asymmetries of Humeral Retroversion in Junior and Collegiate Tennis Players

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Context: Overhead-throwing athletes consistently display substantial bilateral differences in humeral retroversion (HRV). However, evidence is limited regarding HRV asymmetries in tennis players despite similarities between the overhead throw and tennis serve.

Objective: To determine whether (1) junior and collegiate tennis players demonstrated bilateral differences in HRV and (2) the magnitude of the HRV side-to-side difference (HRVΔ) was similar across age groups.

Design: Cross-sectional study.

Setting: Field-based setting.

Patients or Other Participants: Thirty-nine healthy tennis players were stratified into 3 age groups: younger juniors (n = 11, age = 14.5 ± 0.5 years), older juniors (n = 12, age = 17.1 ± 0.9 years), and collegiate (n = 16, age = 19.6 ± 1.2 years).

Main Outcome Measure(s): Three-trial HRV means were calculated for the dominant and nondominant limbs, and HRVΔ was obtained by subtracting the mean of the nondominant side from that of the dominant side. A paired-samples *t* test was used to determine bilateral differences in HRV, and a 1-way analysis of variance was used to compare HRVΔ among groups.

Results: For all 3 groups, HRV angle was greater in the dominant versus nondominant upper limb (younger juniors = 62.9° ± 9.1° versus 56.3° ± 6.8°, $P = .039$; older juniors = 75.5° ± 11.2° versus 68.6° ± 14.2°, $P = .043$; collegiate = 71.7° ± 8.5° versus 61.2° ± 6.9°, $P = .001$). However, no differences were detected in HRVΔ across age groups ($P = .511$).

Conclusions: Consistent with the findings of previous studies of overhead-throwing athletes, we demonstrated greater measures of HRV in the dominant limb of tennis players. Furthermore, HRV asymmetries appeared to have developed before the teenage years, as no changes were observed in HRVΔ among age groups.

Key Words: humeral torsion, humeral retrotorsion, sport-specific adaptation, upper extremity, overhead athlete

Key Points

- Junior and collegiate tennis players displayed greater measures of humeral retroversion in the dominant limb, and the magnitude of the asymmetry was similar across the age continuum of junior and collegiate players.
- Clinicians should be cautious when interpreting clinical measures of rotational range of motion of the dominant shoulder in tennis players, particularly when interventions may be prescribed to address motion deficits based on comparison with the contralateral limb.

A growing body of evidence suggests that asymmetric overhead activity can affect normal growth patterns of humeral retroversion (HRV). Over the past 2 decades, investigators have reported bilateral asymmetries in HRV in the upper limbs of baseball,[1–12] handball,[13] softball,[10] swimming,[10] and volleyball[14] athletes. Researchers studying HRV adaptations in overhead athletes have consistently described increased HRV angles in the dominant upper limb, with average bilateral differences ranging from 6.4° to 17.7°.[7,10] Despite a consistent pattern of increased HRV in the dominant limb, substantial within-subject variability exists that likely reflects contributing factors including age, genetic variation, measurement differences, participation history, and overhead mechanics.[15]

The bony adaptation is thought to result from repeated exposure to throwing during the years of skeletal growth, which impedes the normal derotational (anteversion) growth of the humerus.[16] Authors have attempted to gain some understanding of how and when HRV adaptations occur in youth overhead athletes. To date, such research has overwhelmingly focused on youth baseball players.[1,3,4,6,9–11,17] Bilateral differences in HRV appear to become evident around 11 years of age.[6,11,17] This coincides with the onset of rapid longitudinal growth of the humerus that occurs at the proximal humeral physis,[18] the predominant site of HRV growth and adaptation.[5] Kinetic analysis of youth baseball pitchers has demonstrated that the direction and magnitude of the torsional load on the epiphyseal cartilage during the late-cocking phase of the overhead throw are consistent with attenuating normal HRV development.[16] In support of this theory, others[6,17] have shown that HRV of the nondominant limb decreases with age, although HRV in the dominant limb seems to remain constant.

The implications of this apparent adaptation in overhead athletes are unclear. Increased HRV shifts the total arc of motion (TAM) of the shoulder to a more externally rotated position, which is thought to explain the commonly observed range-of-motion (ROM) asymmetries in overhead-throwing athletes.[2,8] Investigators[2,8,9,13] have speculated that increased HRV is a healthy adaptation because it allows for a more externally rotated position of the forearm without jeopardizing the stabilizing tissues of the glenohumeral joint. In contrast, evidence suggests that soft tissue adaptations contribute to these observed alterations in rotational motion.[19,20] Investigators[21–24] have demonstrated similar rotational ROM adaptations of the dominant shoulder in tennis players. However, HRV data pertaining to tennis players are scarce, further limiting our understanding of the implications of HRV adaptations on shoulder ROM.

The overhead-throwing and overhead-serving motions are similar, yet the literature to date is lacking regarding HRV adaptations in tennis players. Researchers[25] have noted that tennis players experience substantial bone-strength adaptations, specifically in response to torsional loads on the humerus in the serving extremity. In addition, Taylor et al,[26] using biomechanical modeling, presented data that suggested the torsional loads experienced during the overhead tennis serve were substantial enough to induce HRV changes. Despite these studies supporting the potential for HRV adaptations, data were needed to confirm and quantify the asymmetry in this specific population of overhead athletes. Therefore, the purpose of our study was to determine whether junior and collegiate tennis players demonstrated (1) bilateral differences in HRV and (2) similar HRV side-to-side differences (HRVΔ) across 3 age groups (younger juniors, older juniors, and collegiate). The first hypothesis was that junior and collegiate tennis players would display bilateral differences in HRV. The second hypothesis was that the HRVΔ would vary across different age groups of junior and collegiate tennis players.

METHODS

Participants

Forty tennis players were recruited to participate in this study. Competitive junior tennis players were identified and recruited via consultation with coaching tennis professionals at local tennis centers. Collegiate tennis players were recruited via in-person communications at local tennis centers and college campuses. The recruits were divided into 3 age groups: 2 groups of junior tennis players consisting of 14- to 15-year-old (younger juniors) and 16- to 18-year-old players (older juniors) and 1 group of tennis players currently participating on intercollegiate tennis teams (collegiate). Junior tennis players were required to be enrolled as a 9th- to 12th-grade high school student, be a current member of an area high school team or tennis club or association, and consider tennis their primary sport. Collegiate tennis players were current members of a university-sponsored tennis team competing in Division I or II of the National Collegiate Athletic Association.

An a priori power analysis was conducted using effect sizes from the literature for HRV measures in overhead athletes.[10] Using an α level of 0.05 and a desired power of 0.80, we estimated the necessary sample size at 10 participants per group and 36 participants total (version 3.1.9.2; G*Power[27]).

Participants were required to be free of shoulder injury in the 6 weeks before testing, and recruits were excluded from the study if they met any of the following criteria: (1) any elbow or shoulder surgery within the 6 months before testing or (2) any current shoulder or elbow pain that limited play. All participants provided written informed assent or consent. For participants <18 years of age, parental or guardian written consent was also obtained. The study was approved by the Duquesne University Institutional Review Board. One participant in the collegiate group was excluded from the study after a failed screening process. As a result, data collected on the remaining 39 participants (11 younger juniors, 12 older juniors, 16 collegiate) were included in the final analyses.

Procedures

We collected descriptive data including sex, age, height, mass, and upper limb dominance. The *dominant arm* was defined as the hand used to grasp the tennis racket during the serve. All data were collected before any stretching, warm-up, or playing activities. This study was field based; therefore, data were collected at various tennis centers and universities in the Augusta, Georgia, and Pittsburgh, Pennsylvania, regions.

Humeral retroversion were measured indirectly via diagnostic ultrasound involving a 1-person technique that had demonstrated reliability (intraclass correlation coefficient [3,1] = 0.992, SEM = 0.8°) and validity ($r^2 = 0.928$, $F_{1,28} = 361.753$, $P < .001$; Figure 1).[28] Reliability and validity of this technique as performed by the primary investigator (D.C.H.) were established in a previous study.[28] Each participant was positioned supine on a treatment table with the involved shoulder abducted to 70° and the elbow flexed to 90°. With 1 hand, the primary investigator positioned and maintained the participant's forearm in a vertical position, verified using a plumb line that was secured to the participant's wrist via a hook-and-loop strap. While maintaining the forearm in vertical alignment, the examiner tilted the ultrasound probe (13-6 MHz linear probe; Fujifilm Sonosite, Inc) about the long axis of the proximal humerus to achieve a short-axis view of the lesser and greater tubercles. A transparent film with printed horizontal gridlines spaced 0.5 cm apart was affixed to the display of the ultrasound unit (M-Turbo, Sonosite; Fujifilm, Inc) to aid in verifying parallel alignment of the probe's head with the tubercles. After achieving the desired position of the ultrasound probe, we measured the angular orientation using a digital inclinometer (model 12-1057; Baseline Digital Inclinometer; Fabrication Enterprises), which was firmly attached to the probe. Positive values were recorded when the probe was tilted laterally from vertical, and negative values were recorded when the probe was tilted medially from vertical. The HRV data were obtained by subtracting the recorded angle from 90° to create positive values for all measures of HRV. Therefore, larger angles represented greater values of HRV and smaller angles indicated lesser values of HRV. For each extremity, the mean of 3 trials was calculated for HRV and used for data analyses. The HRVΔ was determined by

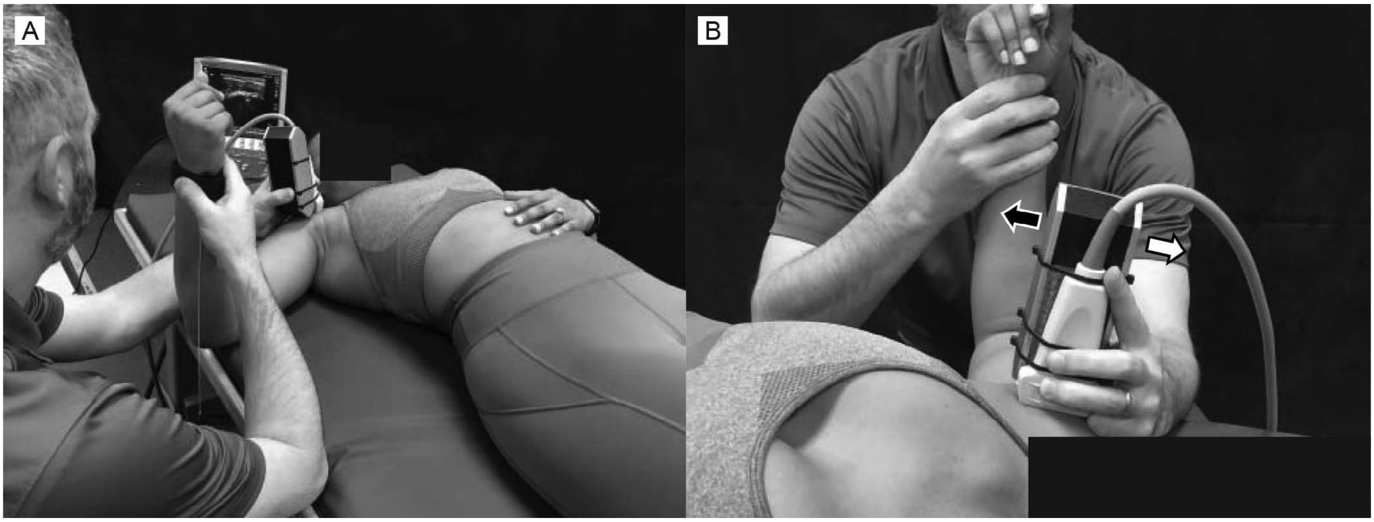

Figure 1. Setup for measuring humeral retroversion. A, The participant's forearm was held vertically, which served as a fixed reference point. Next, the ultrasound probe was tilted about the longitudinal axis of the humerus to align its contact surface parallel to the humeral tubercles. When aligned, the angular position of the probe was measured via the attached inclinometer. B, Aligning the probe in more medially tilted (black arrow) positions corresponded with larger measures of humeral retroversion, whereas more laterally tilted positions (white arrow) corresponded with smaller values.

subtracting the HRV of the nondominant side from that of the dominant side.

Data Analysis

We assessed data from the overall sample for normality using the Shapiro-Wilk test. In addition, data distributions for each age group were assessed for outliers via dot plots. A paired-samples *t* test was conducted to determine differences in HRV between the dominant and nondominant sides for each age group of tennis players. Effect sizes were calculated using Cohen d and interpreted as follows: <0.2, *trivial effect*; 0.2–0.5, *small effect*; 0.5–0.8, *moderate effect*; and >0.8, *large effect*. In addition, 1-way analysis of variance was performed to compare HRVΔ among age groups. Post hoc comparison procedures were applied when appropriate using Bonferroni adjustments. The α level was set at .05, and statistical analyses were conducted via SPSS (version 25.0; IBM Corp).

Table. Participant Characteristics

Characteristics	Younger Juniors	Older Juniors	Collegiate
		No.	
Sex			
Females	3	9	9
Males	8	3	7
Tennis participation only[a]			
Females	2	5	8
Males	3	3	6
		Mean ± SD	
Age, y	14.5 ± 0.5	17.1 ± 0.9	19.6 ± 1.2
Height, cm	171.9 ± 7.9	168.1 ± 8.3	169.9 ± 9.4
Mass, kg	59.1 ± 8.2	60.9 ± 9.6	69.3 ± 10.0
Age when began playing, y	6.3 ± 1.9	7.8 ± 3.4	6.7 ± 1.7
Playing experience, y	8.2 ± 2.1	9.3 ± 3.4	12.9 ± 1.9

[a] Participants who played no overhead-throwing sport other than tennis.

RESULTS

Descriptive data for the 3 age groups of tennis players are presented in the Table. For all groups, greater measures of HRV angle were observed in the dominant versus the nondominant limb (younger juniors = 62.9° ± 9.1° versus 56.3° ± 6.8°, $P = .039$, Cohen d = 0.715; older juniors = 75.5° ± 11.2° versus 68.6° ± 14.2°, $P = .043$, Cohen d = 0.659; collegiate = 71.7° ± 8.5° versus 61.2° ± 6.9°, $P = .001$, Cohen d = 1.011; Figure 2). However, no differences were detected in HRVΔ across all 3 groups (younger juniors: 6.5° ± 9.2°; older juniors: 6.9° ± 10.4°; collegiate: 10.5° ± 10.4°; $F_{2,36} = .683$, $P = .511$; Figure 3).

DISCUSSION

The purpose of our investigation was to determine if tennis players displayed bilateral differences in HRV and whether the magnitude of HRVΔ was similar across 3 age groups of junior and collegiate tennis players. We confirmed our first hypothesis, as bilateral HRV differences were present in all 3 groups. The average bilateral difference in HRV ranged from 6.5° to 10.5°. Contrary to our second hypothesis, we found that the magnitude of HRVΔ was similar across all 3 groups.

Measures of HRV were greater (approximately 8° overall) in the dominant than the nondominant limb in tennis players. The differences we observed were much larger than the nominal 1° to 4° of difference noted in the general population.[2,10,29] Our results were consistent with those of numerous investigators[2–4,7,10] who reported greater HRV measures in the dominant limbs of adolescent, collegiate, and professional overhead-throwing athletes. Despite similarities between the overhead throw and tennis serve, information in the literature regarding HRV adaptations in tennis players is scarce. To our knowledge, bilateral asymmetries in HRV in tennis players were described in

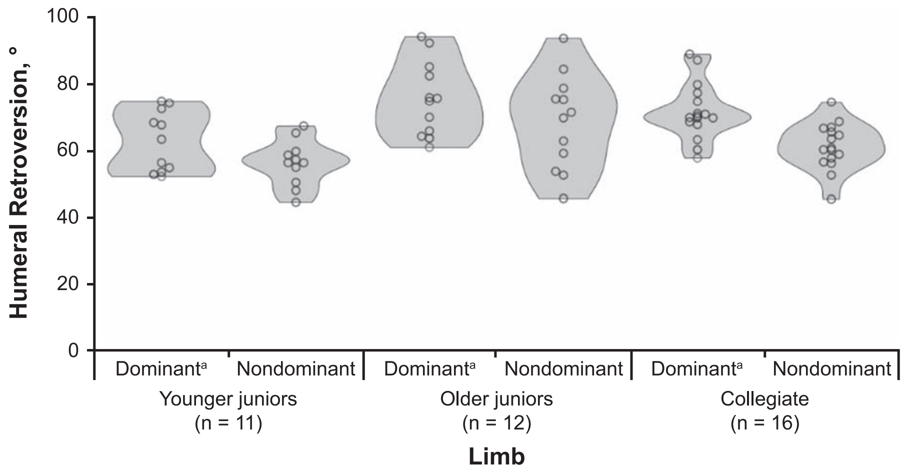

Figure 2. Violin plots with embedded data points depicting data distributions of the dominant and nondominant humeral retroversion measures in each age group of tennis players. [a] Greater humeral retroversion compared with that of the nondominant limb ($P < .05$).

only 1 other study.[30] Unfortunately, the authors did not provide specific statistics on the tennis players, as these data were aggregated with those from baseball and softball players,[30] making comparisons with our work difficult.

When comparing HRVΔ across age groups, we found no differences, which indicated that HRVΔ was similar in tennis players between the ages of 14 and 25 years. These results were consistent with those of other explorations of HRV adaptations across the age spectrum of youth and young adults participating in asymmetric overhead sports. Struminger et al[30] reported no differences in HRVΔ measures when comparing youth (11- to 14-year-old athletes) and collegiate overhead athletes, including baseball, softball, and tennis athletes. Among youth and adolescent baseball players, Hibberd et al[4] demonstrated no differences in HRVΔ between 2 groups of high school players (14–16 years and 16–18 years). Similarly, Oyama et al[12] observed no changes in HRV of the dominant limb over a 1-year period in high school baseball players. Our findings provided further support that most torsional growth and adaptation happens before the teenage years.

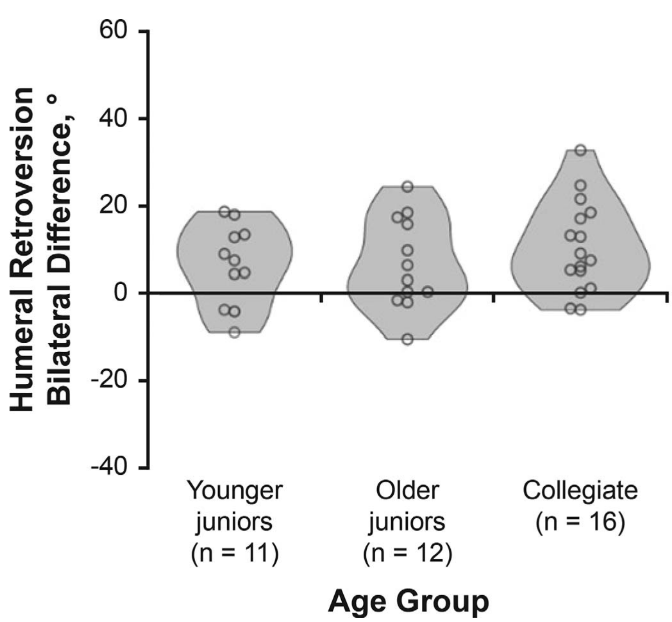

Figure 3. Violin plots with embedded data points depicting data distribution of humeral retroversion difference measures in each age group of tennis players. No differences were observed between groups.

Torsional and longitudinal growth of the humerus occurs mostly at the proximal humeral physis.[31] The derotational growth of the humerus takes place most rapidly before the age of 8 years, and this process continues at a slower pace until skeletal maturity, around age 16.[31] Although the degree of HRV is largely the result of genetic predisposition, secondary factors (eg, muscular forces and functional activities) during the years of skeletal growth have been suggested to alter the final degree of HRV.[32] The opposing torsional forces during the late cocking phase of the overhead throw or serve were theorized to be substantial enough to inhibit the normal antetorsional growth of the humerus in the skeletally immature athlete, and this was manifested as greater HRV measures in the dominant limb.[2] The age at which bilateral differences in HRV become evident in overhead athletes is around 11 years,[17] and differences have been seen in youth baseball players as young as 8 years.[3,4] Most participants (69%) in our study played no overhead-throwing or overhead-serving sport other than tennis, supporting the likelihood that the torsional forces experienced during tennis were substantial enough to affect the normal derotational growth of the humerus. Our results upheld the findings of Taylor et al,[26] who used biomechanical simulations and determined that the torsional forces experienced during the tennis serve were sufficient to affect the torsional growth of the humerus.

In contrast, we were unable to find long-term longitudinal studies that provided conclusive evidence of overhead throwing or overhead serving as causing the observed increase in dominant-limb HRV, the large degree of HRVΔ, or both, in overhead athletes. Rather, a natural amount of HRVΔ may be present in any given person, resulting in an inherent culling as individuals age such that those with greater HRV in the dominant limb remain in their sport.[10] No differences were detected across age groups in HRVΔ; however, the collegiate group displayed approximately 4° more HRVΔ than did both groups of junior players. Thus, future longitudinal studies are warranted to provide more conclusive evidence regarding the effect of overhead activities on the development of bilateral HRV asymmetry.

Numerous investigators[3,4,7,10,33] have discussed the influential role of HRV adaptations in the interpretation of clinical measures of shoulder ROM among overhead-throwing athletes, and our results revealed that tennis players were no exception. All 3 groups demonstrated a pattern of increased HRV in the dominant limb. However, substantial variability occurred in the amount of HRVΔ (range = 43°) in the overall sample, with values ranging from a −10.5° difference in 1 athlete (nondominant > dominant limb HRV) to a 32.8° difference in another athlete (dominant > nondominant limb HRV). These findings are not unique to tennis players, as other researchers have reported considerable variability within and between individuals of as much as 38°[10] and 90°.[32] It has been suggested that a shift in the dominant-side TAM to a more externally rotated position is attributable to an ipsilateral increase in HRV.[2] The shift can be substantial, but most overhead-throwing athletes maintain a TAM that is equivocal when viewed bilaterally.[34] Thus, any TAM deficits are considered to be pathophysiological adaptations of the soft tissues about the shoulder. Still, healthy tennis players often demonstrate substantial deficits in the TAM of approximately 9°.[22,23] Such TAM deficits in combination with the substantial HRV variance we noted offer further evidence that simple, clinical goniometric measures of rotational shoulder motion are inadequate for accurately differentiating between the bony and soft tissue adaptations that may contribute to motion deficits. Unfortunately, most clinicians are unable to prescribe directionally accurate ROM exercises because HRV measures using diagnostic imaging are not commonplace. Clinicians who have access to ultrasound and want to incorporate these HRV-corrected ROM measurements should refer to previously published studies for guidance.[7,33] Bearing in mind the limitations associated with basic goniometry, future studies are warranted to investigate new, clinically friendly methods that aid clinicians in identifying soft tissue contributions to motion deficits so that appropriate interventions can be prescribed to mitigate injury risk.

We identified several limitations to consider when interpreting our results. First, we used a cross-sectional design. Therefore, we were unable to definitively determine that the observed differences in HRV were in response to the torsional forces experienced during tennis participation. Second, we combined data from males and females in our sample of junior and collegiate tennis players. Others have demonstrated that both male and female overhead-throwing athletes display HRVΔ and the amount of HRVΔ is not affected by sex.[10] For our purposes, we were most interested in learning if tennis players displayed bilateral differences in HRV as seen in overhead-throwing athletes. Third, we did not include ROM measurements as part of this study, which limited our ability to examine the effects of HRVΔ measures on interpretations of clinical measures of rotational shoulder motion when screening for and implementing interventions to mitigate injury risk.

CONCLUSIONS

We identified greater measures of HRV in the dominant limbs of tennis players. Our results also suggested that HRV adaptations took place at an early age and most likely before age 14, as we observed no HRVΔ differences across the 3 age groups of junior and collegiate tennis players. These findings were consistent with those reported in previous studies[1,3,4,6,11,17] of other populations of overhead athletes. Nonetheless, the torsional loads on the humerus during tennis participation appeared to have affected the normal anteversion growth of the dominant-side humerus. Considering that tennis players demonstrate this bony asymmetry as well as the inherently large variability in HRV measures, clinicians should be cautious when screening for and implementing interventions for ROM deficits based on simple clinical measures. Additional research is needed to further explore the development of HRV adaptations in overhead athletes and their implications on both performance and injury risk.

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