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Comparison of Shoulder Range of Motion, Strength, and Playing Time in Uninjured High School Baseball Pitchers Who Reside in Warm- and Cold-Weather Climates

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Investigation performed at the Mayo Clinic, Rochester, Minnesota

Background: There is an assumption that baseball athletes who reside in warm-weather climates experience larger magnitude adaptations in throwing shoulder motion and strength compared with their peers who reside in cold-weather climates.

Hypotheses: (1) The warm-weather climate (WWC) group would exhibit more pronounced shoulder motion and strength adaptations than the cold-weather climate (CWC) group, and (2) the WWC group would participate in pitching activities for a greater proportion of the year than the CWC group, with the time spent pitching predicting throwing shoulder motion and strength in both groups.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: One hundred uninjured high school pitchers (50 each WWC, CWC) were recruited. Rotational shoulder motion and isometric strength were measured and participants reported the number of months per year they pitched. To identify differences between groups, *t* tests were performed; linear regression was used to determine the influence of pitching volume on shoulder motion and strength.

Results: The WWC group pitched more months per year than athletes from the CWC group, with the number of months spent pitching negatively related to internal rotation motion and external rotation strength. The WWC group exhibited greater shoulder range of motion in all planes compared with the CWC group, as well as significantly lower external rotation strength and external/internal rotation strength ratios. There was no difference in internal rotation strength between groups, nor a difference in the magnitude of side-to-side differences for strength or motion measures.

Conclusion: Athletes who reside in cold- and warm-weather climates exhibit differences in throwing shoulder motion and strength, related in part to the number of months spent participating in pitching activities. The amount of time spent participating in pitching activities and the magnitude of range of motion and strength adaptations in athletes who reside in warm-weather climates may make these athletes more susceptible to throwing-related injuries.

Keywords: glenohumeral joint; rotational motion; rotator cuff; throwing; youth athlete

The popularity of baseball among youth athletes is tremendous. During the 2008-2009 academic year, more than 470 600 male high school students played for their high school teams.[31] This makes baseball one of the most popular high school sports among male students in the United States. Despite nationwide popularity, there is the anecdotal perception that youth baseball athletes who live in warm-weather climates spend more time participating in baseball activities than their peers who grow up in a cold-weather climate. If there is a difference in the volume of baseball activities, this may affect the physical development of the throwing arm and result in unique clinical presentations for athletes of the same age but from different geographic regions.

The repeated stresses associated with pitching induce soft and osseous tissue adaptations in the thrower's shoulder.[6,13,29,39] Humeral head retroversion of the dominant limb has been described in the throwing athlete. Defined as the acute angle in a medial and posterior direction between the axis of the elbow joint and the axis through the center of the humeral head,[25,38] increases in humeral retroversion allow the articulating surfaces of the humeral

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head and glenoid to remain in contact as the shoulder externally rotates.[20,25] This osseous adaptation also allows the shoulder to achieve a greater degree of external rotation before the humeral head is constrained by the anterior capsule.[20,25] A decrease in scapula upward rotation has been described in pitchers compared with positional players.[51] Multiple mechanisms have been implicated as contributors to altered scapula kinematics in this population, including muscle fatigue, lower trapezius muscle weakness, and increased laxity of the inferior glenohumeral ligament. Kibler[22] proposed that a decrease in upward scapula rotation may compromise glenohumeral stability and promote an increase in anterior humeral translation. Thrower's laxity refers to the increase in capsular mobility of the anterior and inferior glenohumeral ligaments.[3,52] Andrews and Mazoue[3] have reported that this excessive capsular mobility is a consequence of repeated throwing, referring to it as acquired laxity. Although the increase in anterior glenohumeral translation may be appreciated during clinical examination, Borsa et al[7,8] have reported greater posterior than anterior glenohumeral capsular laxity. Thus, while it appears there are capsular adaptations in response to repetitive throwing, there is no agreement regarding the precise nature of these adaptations. Collectively, however, these adaptations indicate that the throwing shoulder of the baseball athlete is not comparable with the nonthrowing limb.

To aid clinicians with interpretation of their evaluations and determine return-to-play readiness after injury, numerous studies have been performed in an effort to define normal presentation of the throwing shoulder in the uninjured baseball athlete. Shoulder motion adaptations are predictable. There is a shift in rotational range of motion (ROM) that includes an increase in external rotation, and a corresponding loss of internal rotation in the throwing shoulder relative to the nonthrowing shoulder,[6,9,21,29,46,51] resulting in nearly symmetrical total rotational motion (internal + external rotation) on bilateral comparison.[51,52] Rotator cuff strength adaptations consistently include greater internal rotation strength in the throwing arm compared with the nonthrowing arm.[1,9,12,15,17,19,49] External rotation strength has predominantly been described as symmetrical on bilateral comparison,[1,9,12,15,16,46] with 2 investigators reporting weakness of the external rotators in the dominant shoulder compared with the nondominant shoulder.[19,49] The increase in internal rotation strength in the absence of a corresponding gain in the external rotator musculature is quantified by calculating the ratio of external/internal rotation strength. Clinical recommendations indicate the strength of the external rotators should be between 66% and 75% of the internal rotators[49,52] to maintain a healthy glenohumeral joint.

The majority of studies characterizing the uninjured thrower's shoulder have been performed in adult populations (ie, collegiate and professional levels). Trakis et al[46] were among the first investigators describing both shoulder strength and motion adaptations in adolescent pitchers. The investigators evaluated a total of 23 high school–aged pitchers for the study including 12 athletes with a history of throwing-related arm pain and 11 individuals with no history of arm injury. Trakis et al[46] reported that the characteristic shift in rotational ROM typically described in older athletes was also present in this cohort of adolescents. For the group, there was an increase in external rotation of 11° and loss of internal rotation of 13° in the throwing shoulder. There was no difference bilaterally for total ROM, or the ratio of external/internal rotation strength, between pitchers with and without a history of throwing-related pain. Pitchers with a history of pain did, however, have greater relative strength of the internal rotators and lower supraspinatus and middle trapezius strength compared with players without prior pain. Trakis et al[46] concluded that throwing-related pain in this population may be due to the inability of weakened posterior shoulder musculature to tolerate the stress imparted on it by adaptively strengthened propulsive muscles (ie, internal rotators). Furthermore, Trakis et al[46] proposed strength imbalances may precede any total ROM loss as the first step toward future pathologic changes in pitchers. Results from the investigation by Trakis et al[46] provide insight into normal adaptations occurring in youth pitchers and adaptations in the youth athlete that may be useful in identifying individuals with an increased injury risk.

It is possible that athletes growing up in warm-weather climates may have more pronounced changes in shoulder motion and strength than athletes from a cold-weather climate as a consequence of year-round participation in baseball activities. Determining whether there is a difference in the normal presentation of the throwing shoulder in athletes from warm- and cold-weather climates may aid with the interpretation of clinical evaluation of these athletes, and potentially aid in identifying athletes who are at risk for a throwing-related injury. Accordingly, the purpose of this study was to characterize the shoulder ROM and strength of uninjured high school–aged baseball pitchers from divergent climates. We recruited athletes from Minnesota to represent pitchers from a cold-weather climate. Athletes from California and Arizona represented pitchers from warm-weather climates. We hypothesized that individuals from the warm-weather climate would exhibit more pronounced throwing-arm motion and strength adaptations than athletes from a cold-weather climate. We also hypothesized that athletes from the warm-weather climate would report participating in pitching activities for a greater proportion of the calendar year than athletes from the cold-weather climate, with the amount of time spent participating in baseball activities predicting throwing shoulder motion and strength.

MATERIALS AND METHODS

Participants

The study sample consisted of 100 uninjured male high school baseball pitchers. The data for these individuals were randomly drawn from a larger athlete pool, and reanalyzed to answer a different question. The participants consisted of volunteers who were recruited from high schools,

TABLE 1
Participant Characteristics

	Warm Climate Mean (Range)	Cold Climate Mean (Range)	*P* Value
Age at time of testing, y	16 (14-18)	17 (14-18)	<.01[a]
Weight, kg	77 (54-101)	75 (54-106)	.36
Height, m	1.8 (1.7-1.9)	1.8 (1.6-2.0)	.68
Age began pitching, y	10 (6-14)	10 (6-14)	.11
Number of years pitching	7 (3-13)	6 (3-11)	.35

[a]Statistically significant ($P < .05$).

summer leagues, instruction academies, and showcase attendees. To be eligible for study participation, athletes were required to be between 14 and 18 years of age, have pitched competitively for the past 3 consecutive years, be participating in baseball activities without restrictions, and have no current arm injury or complaints of pain. A QuickDash Sports Score of ≤10% was required to confirm participants were not limited in baseball participation secondary to symptoms related to the throwing arm. A physical examination of both upper extremities was conducted by either a board-certified sports physical therapist (W.J.H.) or a fellowship-trained orthopaedic surgeon (K.M.K.) to confirm the absence of injury to either arm. Individuals were ineligible for study participation if they did not meet all participation criteria. Participant consent and parental assent were obtained before testing began. The research protocol was approved by the Mayo Clinic Institutional Review Board.

Fifty pitchers each were recruited in the cold-weather group (Minnesota) and the warm-weather group (California, Arizona). Mean monthly high temperatures for regions from which athletes in Arizona and California resided range from 67° to 107°F and 53° to 92°F, respectively. Neither the recruitment regions in Arizona nor California have an average high temperature below 50°F. Mean monthly high temperatures for regions in Minnesota from which athletes were recruited range from 11° to 83°F, with 6 months per year having a high temperature below 50°F. The mean age for the entire group at the time of testing was 16 years (range, 14-18 years); the age at the time of initiating pitching activities, 10 years (range, 5-14 years); and total years experience as a pitcher, 6 years (range, 3-14 years). Mean weight for the group was 76 kg (range, 54-106 kg) and mean height was 1.8 m (range, 1.6-2.0 m). There were no differences between groups for the age at which subjects began pitching ($P = .11$), total years pitching ($P = .35$), height ($P = .68$), or weight ($P = .36$). Participants from the cold-weather group (mean, 17 years; range, 14-18 years) were on average 1 year older than those from the warm-weather group (mean, 16 years; range, 14-18 years; $P < .01$) (Table 1).

Procedures

Testing was performed during the athlete's off-season with at least 1 day of rest from throwing. Study participants performed a 5- to 10-minute warm-up consisting of stretching, jogging, and short-toss activities before initiating testing. Passive shoulder internal and external ROM and shoulder internal and external strength of the throwing limb were then tested in the thrower's position (ie, 90° abduction). The order of ROM and strength testing was randomized.

Range of Motion Testing. Passive shoulder ROM was conducted in a standardized order, including external and then internal rotation at 90° of abduction. All tests were conducted with participants supine and a towel roll positioned under the humerus to align the upper arm in a neutral position (humerus level with acromion process).[30,32-36] Shoulder ROM was measured with a standard, long-arm goniometer with a bubble level secured to the stationary arm to assist with device alignment.[29,30] Measurements were performed using standard goniometric techniques as defined by Norkin and White.[36] The axis of the device was aligned with the olecranon, the moving arm parallel to the forearm in alignment with the ulnar styloid process, and the reference arm perpendicular to the floor.

A single examiner was responsible for all ROM testing. The examiner stabilized the glenohumeral joint by placing the palm of 1 hand on the anterior aspect of the shoulder over the clavicle, coracoid process, and humeral head.[48] The examiner then took the athlete's arm through a full arc of motion until an end point was reached. The trial-to-trial testing error was less than 5°. End of motion was defined as a cease of motion or when scapular movement was appreciated.[30] An assistant positioned the goniometer and recorded the end-point shoulder angle. The examiner and participant were blinded to performance results. Two trials were taken for each motion of interest, with the average used for analysis.

Strength Testing. Glenohumeral internal and external rotation muscle strength was tested in a standardized order, including external rotation followed by internal rotation in 90° of abduction. Maximum voluntary isometric muscle force was measured with a hand-held dynamometer (Commander PowerTrack II, JTECH Medical, Salt Lake City, Utah) using a break test. The validity and reliability of upper extremity strength assessment with hand-held dynamometers has been established.[10,28,45] The measurement range of the unit was 1 to 56 kg, with a manufacturer-reported mechanical precision of 99%. One examiner performed all strength assessments when testing cold-weather athletes and a second examiner performed all strength assessments when testing warm-weather athletes. An assistant recorded the peak isometric force for each trial. Both the examiner and the athlete were blinded to the results. Testing error (between and within testers) was less than 2.5 kg.

Strength testing was performed with participants seated, and the hips and knees in 90° of flexion with the trunk unsupported. The dominant arm was positioned in 90° of abduction and neutral rotation. An assistant stabilized the humerus during testing to ensure appropriate positioning and to minimize participants' attempts to compensate or substitute. Athletes were allowed to use their contralateral limb to grasp the sitting surface for added stability. The point of force application was just proximal to the dorsal surface of the wrist for external rotation and the volar surface of the wrist for internal rotation testing. Participants performed 1 submaximal practice trial before testing. Two test trials, each approximately 5 seconds in length, were performed for both internal and external rotation with a 30-second rest between trials to minimize the influence of fatigue. The average of the 2 trials was used for the analysis.

Pitching Volume

Participants were asked to record the number of months per year in which they participated in pitching activities during the 3 years prior to study participation. Pitching activities included participation in seasonal leagues, high school teams, camps, traveling ball, showcases, and pitching lessons.

Data Analysis

Two-sample t tests were performed to identify differences between groups. This included a comparison of ROM and strength in the dominant and nondominant limbs. To capture the magnitude of adaptations that had occurred in the throwing limb, side-to-side differences in motion and strength were compared between groups. The average number of months participating in pitching activities for the 3 years preceding study participation was also compared between groups. For ROM, variables of interest included passive internal and external rotation, and total rotational motion (internal + external rotation). For strength, variables of interest included peak internal and external rotation force normalized to body weight, and the ratio of external to internal rotation force. Linear regression analysis was performed to determine the influence of the number of months participating in baseball activities (3-year average) on throwing limb shoulder motion and strength for each group. All statistical analyses were performed with commercially available software (SPSS Inc, Chicago, Illinois). An a priori α level was established at $P \leq .05$.

RESULTS

When comparing the magnitude of side-to-side differences in motion across groups, there were no differences. The warm-weather group exhibited an 11° gain (standard deviation [SD], 12.3°) and the cold-weather group a 12° gain (SD, 12.4°) in external rotation in the dominant arm compared with the nondominant arm (P = .959). There was an internal rotation loss of 15° in the warm-weather group (SD, 12.7°), and 11° loss (SD, 12.5°) in the cold-weather group for the dominant limb compared with the nondominant limb (P = .284). Total motion was 4° less on the dominant limb compared with the nondominant limb for the warm-weather group (SD, 12.8°), while the cold-weather group exhibited no side-to-side difference (SD, 15.1°) in total motion for each limb (P = .263). Based on these means and standard deviations, post hoc analysis indicated this sample size yielded a power of greater than 90% for identifying 10° side-to-side differences in ROM within participants, and 79% for 5° differences.

Between groups, there were significant differences in throwing limb rotational motion. The warm-weather climate group exhibited 8° greater external rotation than the cold-weather climate group ($P < .01$) (Figure 1A). Internal rotation motion was also greater in the warm-weather group compared with the cold-weather group (P = .043) (Figure 1B) by an average of 5°. Total rotational motion was consequently greater in the warm-weather climate group compared with the cold-weather climate group by an average of 13° ($P < .01$) (Figure 1C).

The magnitude of side-to-side differences in strength did not differ across groups. The side-to-side difference in external rotation strength was less than 1% for the warm-weather group (mean, 0.7%; SD, 0.02%) (dominant < nondominant), with the cold-weather group exhibiting no difference in external rotation strength between limbs (SD, 0.03%) (P = .168). The magnitude of the gain in internal rotation strength in the dominant shoulder relative to the nondominant shoulder was again less than 1% for the warm-weather group (mean, 0.3%; SD, 0.01%), while the cold-weather climate group demonstrated internal rotation strength values that were 1.6% higher on the dominant limb compared with the nondominant limb (SD, 0.01%) (P = .284). The ratio of external/internal rotation strength was 8% lower in the dominant shoulder relative to the nondominant shoulder in the warm-weather group (SD, 0.26%) and 9% lower in the cold-weather group (SD, 0.17%) (P = .614). Based on these means and standard deviations, post hoc analysis indicated this sample size yielded a power of greater than 90% for identifying a 1% side-to-side difference in strength.

Between groups, there were significant differences in dominant arm rotational strength. The cold-weather climate group exhibited significantly greater external rotation strength ($P < .01$) (Figure 2A), as cold-weather pitchers were on average 3% stronger than warm-weather pitchers. There was no difference in internal rotation strength between the 2 groups (P = .98) (Figure 2B). The ratio of external to internal rotation strength was significantly greater in the cold-weather group, as pitchers from this group exhibited an average rotational strength ratio that was 18% greater than the warm-weather climate pitchers ($P < .01$) (Figure 2C).

There was a significant difference between groups for the number of months per year that athletes participated

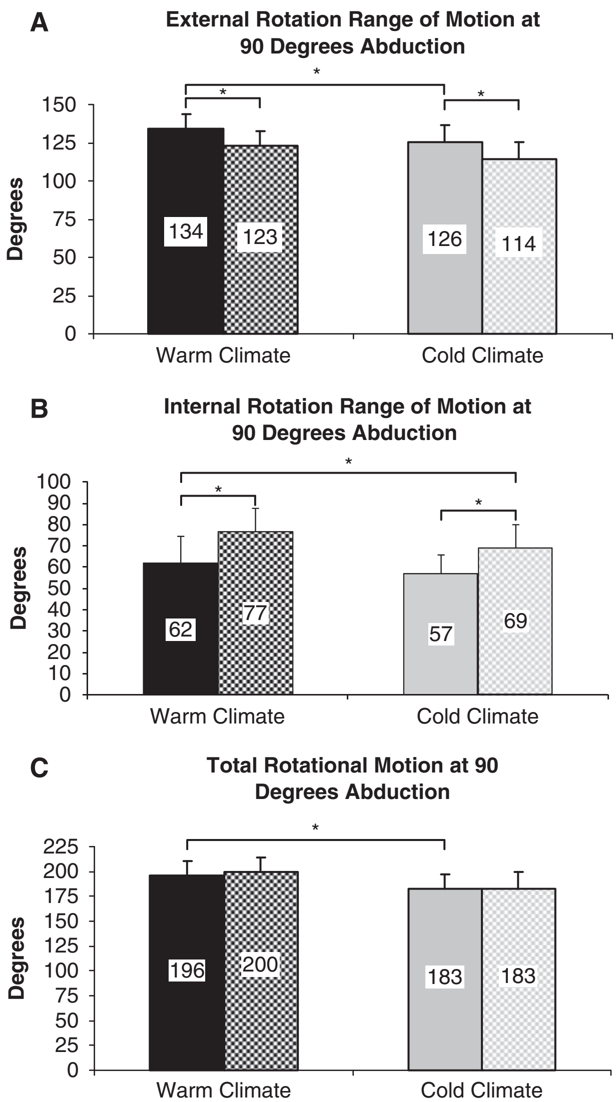

Figure 1. Range of motion for athletes from the warm-weather (solid black, dominant; hashed black, nondominant) and cold-weather (solid gray, dominant; hashed gray, non-dominant) groups for external rotation (A), internal rotation (B), and total motion (C). Mean values are reported within the thick vertical bars; thin vertical bars represent the standard deviation. Statistical significance at $P < .05$ is denoted by an asterisk (*).

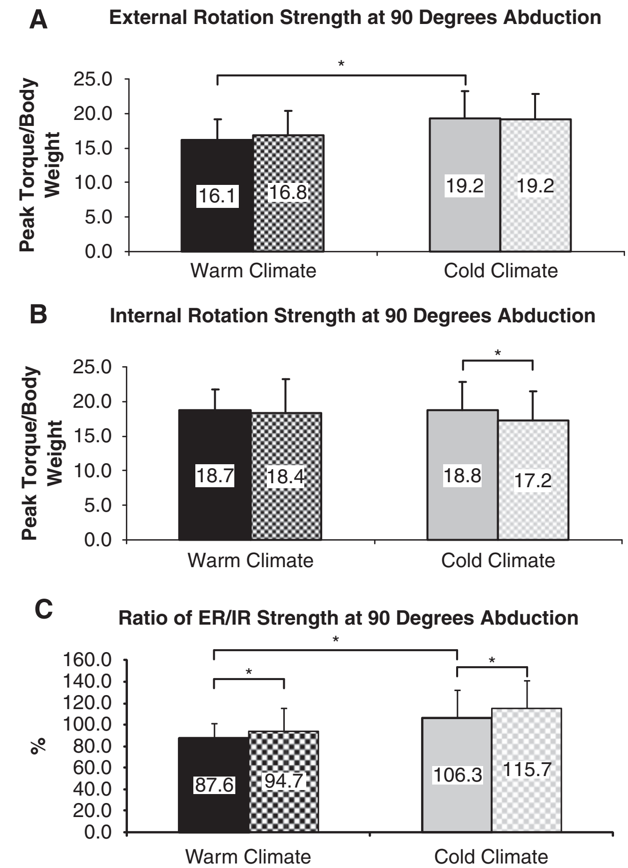

Figure 2. Strength for athletes from the warm-weather (solid black, dominant; hashed black, non-dominant) and cold-weather (solid gray, dominant; hashed gray, non-dominant) groups for external rotation (A), internal rotation (B), and external/internal strength ratios (C). Mean values are reported within the thick vertical bars; thin vertical bars represent the standard deviation. Statistical significance at $P < .05$ is denoted by an asterisk (*).

in pitching activities. Individuals from the warm-weather group were involved in pitching activities for an average of 9 months per year (range, 2-12 months), compared with an average of 6 months for the cold-weather group (range, 3-10 months) ($P < .01$). The average number of months participating in pitching activities was inversely related to internal rotation motion and external rotation strength in the warm-weather group, as greater time spent pitching was associated with less internal rotation (R^2 = .085, P = .05) and external rotation strength (R^2 = .085, P = .05) (Table 2). There were no other motion or strength measures predicted by time spent pitching in the warm-weather group (external rotation motion, P = .33; total motion, P = .25; internal rotation strength, P = .10; external/internal rotation strength ratio, P = .99) (Table 2). Time spent in pitching activities was not predictive of any motion or strength measures for the cold-weather group (external rotation motion, P = .29; internal rotation motion, P = .67; total motion, P = .28; external rotation strength, P = .41; internal rotation strength, P = .94; external/internal rotation strength ratio, P = .90) (Table 2).

DISCUSSION

Side-to-side asymmetry in the uninjured overhead athlete during clinical examination is an expected finding. The magnitude of shoulder ROM adaptations in the throwing limb compared with the nonthrowing limb in uninjured athletes is surprisingly consistent across skill levels and

TABLE 2
Influence of Number of Months Pitching on Throwing Shoulder Motion, Strength[a]

	R^2	P Value
Warm-weather group		
External rotation ROM	.021	.330
Internal rotation ROM	.085	.050[b]
Total motion	.029	.250
External rotation strength	.085	.050[b]
Internal rotation strength	.060	.100
External/internal strength ratio	<.001	.990
Cold-weather group		
External rotation ROM	.027	.290
Internal rotation ROM	.004	.670
Total motion	.028	.280
External rotation strength	.016	.410
Internal rotation strength	<.001	.940
External/internal strength ratio	.002	.900

[a]ROM, range of motion.
[b]Statistically significant ($P \leq .05$).

ages. External rotation gain in the dominant shoulder has ranged from 8.8° to 11° in studies of high school,[46] collegiate,[42] and professional[52] baseball athletes, while internal rotation loss in the dominant arm has ranged from 8.5° to 13° in these cohorts.[42,46,52] The sum of rotational motion has consistently been equal (within 10°) on bilateral comparison.[42,46,52] Results from the current investigation are in agreement with these earlier reports, as both groups in this study exhibited a comparable amount of external rotation gain (11°, 12°) and internal rotation loss (12°, 15°) in the dominant arm, with total motion within 4° on bilateral comparison. These results, and earlier work characterizing shoulder motion in the uninjured athlete, question the cumulative effect of pitching on the magnitude of shoulder ROM adaptations in physically mature athletes.

Athletes who reside in climates with short or mild winters have the opportunity to play outdoor sports yearround. It is therefore not surprising that the athletes in this study who resided in a warm-weather climate reported participating in baseball activities for a significantly greater portion of the year than the individuals who resided in a region with typically lengthy, severe winters. The amount of time an athlete dedicates to pitching activities is clinically significant, as many injuries in baseball are believed to be a result of cumulative microtrauma associated with throwing.[2,29,51,52] Based on work by Olsen et al,[37] the 10 months per year spent pitching increases the injury risk for athletes from the warm-weather climate fivefold compared with playing patterns of uninjured athletes. The investigators surveyed the pitching practices of adolescent pitchers, including 95 who had previously undergone shoulder or elbow surgery and 45 who had never experienced a significant pitching-related injury. Olsen et al[37] reported individuals who spent more than 8 months per year pitching were at approximately 5 times increased risk for injury requiring surgery. This finding prompted the authors to suggest youth pitchers may require more than 3 months of active rest (ie, not throwing) each year to minimize their risk for serious injury. Although athletes in the current study were uninjured, our results indicate that athletes who reside in warm-weather climates may be at increased risk for injury secondary to excessive time dedicated to pitching during a calendar year. The increased injury risk for athletes from the warm-weather group is further supported by the inverse relationship between the number of months pitching and internal rotation ROM, and external rotation strength, in these athletes. Significant internal rotation motion loss[30,47] and external rotation muscle weakness[11] have each been associated with throwing arm injury in the baseball athlete. Future studies will be necessary, however, to determine if there is a difference in injury rates based on athlete residence, and the association between ROM, strength, and injury risk.

Work by Meister et al[29] indicates pitching during skeletal immaturity is a meaningful factor affecting ROM in the throwing shoulder. In a study of 294 baseball athletes aged 8 to 16 years, Meister et al[29] reported internal rotation loss in the dominant limb that was 9° greater in 16-year-olds compared with 8-year-olds, and external rotation gain of 10° in the oldest group compared with 7° in the youngest group. Peak changes in ROM were seen at ages 11 to 13 years. It would thus appear that pitching during years of rapid growth has the greatest potential to affect vulnerable tissues, including humeral head orientation and capsular laxity, which both have the potential to contribute to alterations in ROM. Because the current investigation did not include athletes under the age of 14 years, we cannot provide insight into differences in ROM adaptations or playing habits in skeletally immature athletes from different climates. We do, however, agree with the suggestion by Meister et al[29] that longitudinal studies are necessary to determine the degree of adaptive change in shoulder motion that is optimal with respect to both performance and injury prevention in baseball athletes of all ages.

Shoulder motion of the dominant limb was not comparable between athletes from warm- and cold-weather climates. Athletes from the warm-weather group exhibited greater ROM in all planes compared with the cold-weather group. These differences were both statistically and clinically (>5°) significant.[51] Visual inspection indicates athletes from the warm-weather group also had clinically significantly greater ROM in the nondominant limb compared with cold-weather athletes. Thus, the 2 groups had comparable side-to-side differences in motion while having differences in dominant limb ROM. The presence of greater bilateral ROM suggests there may be more athletes from warm climates who have been self-selected to excel in baseball. That is, athletes with greater shoulder mobility secondary to congenital capsular laxity are more likely to have early success in overhand athletics that encourages them to persist in these activities.[6,29] There are previous studies that support the presence of self-selection among pitchers. Many investigators have documented that pitchers exhibit greater external rotation than do position players.[6,21,50] Increased capsular laxity in the baseball pitcher has also been described.[6] This greater shoulder motion has been deemed necessary for the excessive motion required to cock the arm during the throwing motion. Potential deleterious consequences of greater global shoulder motion include increased demands on the rotator cuff musculature to maintain dynamic glenohumeral stability.

We found no difference in the magnitude of rotator cuff strength adaptations for the 2 groups. Athletes from both groups exhibited an increase in internal rotation strength in the dominant arm. In contrast, external rotation strength was symmetrical in athletes from the cold-weather group, and slightly lower in the dominant limb compared with the nondominant limb for the warm-weather group. The absence of an increase in external rotation strength that corresponds with internal rotation strength gains may be a consequence of the different types of muscular contractions during pitching, as the external rotators contract eccentrically during follow-through to decelerate the arm. The presence of greater internal rotation strength without a corresponding increase in external rotator strength resulted in lower external to internal strength ratios in the throwing arm compared with the nonthrowing arm for both groups. There were differences in strength when comparing the dominant limbs of the warm- and cold-weather groups. The warm-weather group had significantly lower external rotation strength and external/internal strength ratios than the cold-weather group. The external rotators play a critical role in maintaining a healthy glenohumeral joint. These dynamic stabilizers promote joint stability as the inherently unstable shoulder undergoes tremendous ranges of motion and forces during pitching.[52] Weakness in this muscle group, or imbalance of the external rotators relative to the internal rotators, may be an indication of compromised neuromuscular contributions to dynamic joint control.

It should be noted, however, that relative to normative data of uninjured athletes, the warm-weather climate group did demonstrate good strength. Based on studies of isokinetic muscle performance, a ratio of external to internal rotation strength of 66% to 75%[49,52] is considered normal in uninjured athletes, and external rotation strength normalized to body weight is considered normal in the range from 18% to 23% in the dominant arm of uninjured professional athletes.[52] One potential explanation for the remarkable difference in strength ratios reported in this study compared with previous reports is the mode of muscle contraction that was performed. Athletes in this study were asked to perform a maximum isometric contraction. Knapik et al[23] reported differences in muscle torque production based on the type of contraction being performed, with the greatest torque production during isometric conditions compared with either isotonic or isokinetic testing methods. Physiologically, the mechanism underlying strength production is quite different based on the type of contraction performed. Strength assessed during an eccentric contraction is greatest secondary to internal muscle force production as the muscle is forcibly lengthened, which stresses the elastic components of the contractile structure.[26] Isometric testing conditions result in greater force production than high-speed isokinetic or eccentric testing as there is more time for cross-bridge formations, one of the primary contributors to force production, to be completed.[26] Previous work assessing isometric rotator cuff strength in baseball athletes has resulted in external to internal rotation strength ratios comparable with results we have reported. Using similar methods, the ratio of external/internal rotation strength described by Donatelli et al[15] and Magnusson et al[27] ranged from 83% to 108%. While high-speed isokinetic strength testing does provide insight into functional muscle performance, it is possible that external rotation strength deficiencies are a consequence of the testing mode and do not precisely capture the strength production capabilities of this muscle group. Future studies that define the range of normal isometric strength values in the baseball athlete may be necessary to complement isokinetic databases. The trend of lower external rotation strength with greater time spent pitching for warm-weather athletes in this study does suggest, however, that the continuation of existing playing patterns may place these athletes at risk for injury secondary to external rotator muscle weakness.

The negative effect of time spent pitching on external rotation strength for the warm-weather group is evident by the inverse relationship of these 2 measures. It is likely the repeated eccentric muscle contractions that the external rotators experience as they attempt to slow the arm during follow-through are contributing to physiologic muscle adaptations and negatively affecting muscle strength. Yanagisawa et al[53] collected T2-weighted images of the rotator cuff muscles in 6 amateur pitchers at different time intervals after pitching. The investigators reported elevated T2 levels associated with an increase in intramuscular water content in the supraspinatus and external rotators 48 hours after pitching and suggested this may be attributed to short-term muscle damage associated with eccentric muscle contractions during pitching.[53] These results support the practice of multiple days off between pitching bouts to facilitate full muscle recovery.

Although not statistically significant, external rotation strength of the nondominant limb was lower in the warm-weather group compared with the cold-weather group. This explains why we identified similar side-to-side differences in strength for the 2 groups in the presence of significant differences in dominant limb strength. We can only speculate regarding the cause of bilateral shoulder strength differences in the 2 groups. Fatigue, pain, and local tissue swelling are all potential factors contributing to incomplete muscle recruitment and weakness,[4,5,14,18,43] and all may potentially result from extended pitching outings. The presence of incomplete external rotator muscle activation is supported by findings reported by Reinold et al,[40] who described greater external rotation force production in postoperative patients who had performed strengthening augmented by neuromuscular electrical stimulation compared with patients who performed only voluntary strengthening exercises. If the activation failure is a consequence of central nervous system function, this would affect both limbs. This has been documented in patients with knee injury, who have demonstrated bilateral quadriceps activation failure during strength assessment.[24] Measurement of muscle activation in the shoulder has not, however, been performed in a patient population, and has only recently been described in a cohort of uninjured college students.[44] Future studies that assess voluntary activation during strength testing may provide tremendous insight into external rotation weakness, and the causes of this weakness, in the baseball athlete.

There are limitations associated with this study. We sampled a limited number of regions to capture the effect of climate on playing patterns and throwing shoulder adaptations. It is unknown whether athletes worldwide adapt their playing habits as a consequence of their residential climate. Another study limitation was related to the difficulty in obtaining accurate retrospective data in regard to chronologic variables such as number of pitches thrown and number of innings pitched. Consequently, we elected to use months per year participating in pitching activities as a surrogate measure of pitching volume. Despite a significant difference in number of months pitched based on geographic location, further dissection of pitch counts and types of pitches thrown may further define the origin of changes in ROM and strength. Additionally, athletes from the cold-weather group were on average 1 year older at the time of testing than athletes from the warm-weather group. Years of experience as a pitcher and the age at which individuals began pitching did not, however, differ between groups. Differences identified between groups were therefore not a consequence of playing experience. It is possible, though, that older athletes may have different tissue characteristics that could influence motion and strength values compared with their younger counterparts. Another potential study limitation was the timing of our testing. Pitchers were tested during their off-season to capture them during a normal state of functioning. We requested that the pitchers refrain from throwing for 24 hours before being tested. However, as Reinold et al[41] have indicated, alterations in ROM may persist for more than 1 day. Despite this, we believe that our measurement protocols were consistent between the groups, providing valid strength and ROM data. Finally, there are other factors that may have affected shoulder adaptations in these athletes that were not captured in this study. Most notably, participation in a baseball-specific training program for the upper extremity may have affected strength and motion. We do not believe, however, that participation in a training program would be significantly affected by the residential climate. Future studies that prospectively capture athlete play and training patterns will be necessary to provide insight into the effect of upper extremity exercise and clinical shoulder presentation, as well as the effect of exercise on injury risk.

CONCLUSION

To our knowledge, this is the first study to document clinical characteristics and playing patterns in athletes from warm- and cold-weather climates. We determined that athletes who reside in warm climates pitch more months per year than athletes from a cold climate. We also identified relative weakness of the external rotators in warm-weather athletes compared with their peers who live in cold climates. Furthermore, there was a negative relationship between months spent pitching and internal rotation motion and external rotation strength in the warm-weather group. These adaptations and the association with the amount of time athletes from a warm climate spend participating in pitching activities suggest these athletes are a previously unrecognized, vulnerable population in terms of their injury risk.

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