Three-Dimensional Scapular Kinematics During the Throwing Motion

Kristin E. Meyer, Erin E. Saether, Emily K. Soiney, Meegan S. Shebeck, Keith L. Paddock, and Paula M. Ludewig

University of Minnesota

Proper scapular motion is crucial for normal shoulder mechanics. Scapular motion affects glenohumeral joint function during throwing, yet little is known about this dynamic activity. Asymptomatic subjects (10 male and 10 female), ages 21 to 45, were analyzed. Electromagnetic surface sensors on the sternum, acromion, and humerus were used to collect 3-D motion data during three trials of low-velocity throwing. Scapular angular position data were described for five predetermined events throughout the throw corresponding with classic descriptions of throwing phases, and trial-to-trial reliability was determined. ANOVA compared scapular angles across events. Subjects demonstrated good to excellent reliability between trials of the throw (ICC 0.74–0.98). The scapula demonstrated a pattern of external rotation, upward rotation (peak of approx. 40°), and posterior tilting during the initial phases of the throw, progressing into internal rotation after maximum humeral horizontal abduction. During the arm acceleration phase, the scapula moved toward greater internal rotation and began anteriorly tilting. At maximum humeral internal rotation, the scapula ended in internal rotation (55°), upward rotation (20°), and anterior tilting (3°).

Significant differences in scapular position (p < 0.05) were identified across the throwing motion. Scapular data identify events in the throwing motion in which throwers may be more susceptible to shoulder pathologies related to abnormal scapular kinematics.

Keywords: shoulder, biomechanics, motion analysis

Shoulder injuries among overhead athletes are a common occurrence. Throwing athletes are particularly susceptible owing to the complex mechanics of throwing—coordinated, high-velocity, multiple-joint interactions (Chambless et al., 2000; Dillman et al., 1993; Wasserlauf, 2003). Prevalence rates have been reported at up to 35% in young pitchers (Lyman et al., 2001, 2002; Wasserlauf, 2003). Common injuries include rotator cuff tendonitis and impingement, rotator cuff tears, glenohumeral instability, and labral pathologies.

A knowledge of normal and abnormal shoulder kinematics is believed to be essential for health professionals treating the athletic population. Although determining the actual cause-and-effect relationship is often difficult, a majority of shoulder injuries, pain, and decreased function are believed related to faulty mechanics (Fleisig et al., 1996a). During any upper extremity motion, the relationship between the humerus and scapula allows for optimal shoulder complex function. To produce elevation of the arm...
the scapula externally rotates, upwardly rotates, and posteriorly tilts (Figure 1), while the humerus externally rotates to maximize the subacromial space for clearance of the humeral head (Inman et al., 1944; Ludewig & Cook, 2000; McClure et al., 2001). In nonathletic populations, abnormal scapular motions, including decreased upward rotation and posterior tilting and increased internal rotation, have been identified in persons with shoulder pathology (Ludewig & Cook, 2000; Lukasiewicz et al., 1999; Ozaki, 1989). Proper scapular motion is crucial for normal shoulder mechanics; subsequently, the scapula is believed a major determinant of how the glenohumeral joint will function during the throwing motion (Kibler, 1998). Scapular motion abnormalities have the potential to produce shoulder pathology for individuals who frequently perform throwing activities (Kibler, 1998).

Although all overhand throwing athletes are susceptible to throwing injuries, analysis of throwing mechanics has been primarily focused on pitching (Andrews et al., 1999; DiGiovine et al., 1992; Dillman et al., 1993; Escamilla et al., 2002; Fleisig et al., 1996a, 1996b; Sakurai et al., 1993; Stodden et al., 2005). Normal shoulder mechanics during an overhand throw for football and javelin have also been described (Best et al., 1993; Fleisig et al., 1996b; Mero et al., 1994; Rash & Shapiro, 1995). However, quantitative data on shoulder mechanics during overhand throwing excluding pitching is limited. In particular, owing to past difficulties in directly measuring scapular motion, scapular movements during throwing have only been qualitatively described. Further, there is also a gap in the literature regarding data on females performing an overhand throw. Knowledge of scapular kinematics during

---

Figure 1 — Three-dimensional scapular motions. Modified and reprinted with permission from Ludewig, P.M., Functional shoulder anatomy and biomechanics. Solutions to Shoulder Disorders, HSC 11.1.1, LaCrosse, WI, Orthopedic Section, APTA, Inc, 2001.
an overhand throw is an important foundation from which to develop an understanding of how abnormal
scapular motion can contribute to shoulder injuries
in the throwing population.

The baseball pitch is typically divided into six
phases: wind-up, stride, arm cocking, arm accel-
eration, arm deceleration, and follow-through. The
stride, arm cocking, arm acceleration, and arm
deceleration phases likely have the highest potential
for injury because the humerus is elevated during
all of these phases (Fleisig et al., 1996a). Humeral
elevation necessitates proper scapular positioning to
maintain the subacromial space for clearance of the
humeral head and to provide stability for the gleno-
humeral joint (Glousman et al., 1998; Kibler, 1998;
Ludewig & Cook, 2000). Research has identified
abnormal scapular mechanics that have the potential
to contribute to throwing injuries (Ludewig & Cook,
2000; Lukasiewicz et al., 1999; Ozaki, 1989). The
high incidence of injuries among throwing athletes
suggests the need for a better understanding of
scapular motion and associated potential mechanical
sources of pathology.

The purpose of this study was to quantitatively
describe the three-dimensional motions of the
scapula during low-velocity overhand throwing. It
was hypothesized the scapula would first upwardly
rotate, posteriorly tilt, and externally rotate in early
phases of the throw, followed by anterior tilting,
internal rotation, and downward rotation in the
later phases. A secondary purpose was to provide
preliminary comparisons between male and female
throwers.

Methods

Subjects

There were 20 individuals, 10 females and 10 males,
who participated in this investigation. Subjects were
required to be at least 18 years of age, to have par-
ticipated at the varsity high school level of baseball
or softball, and to have continued in recreational or
competitive league play annually up to the time of
the study. Ages of participants ranged from 21 to
45 years (Table 1). All subjects threw right-handed,
except for two male subjects who threw left-handed.
The exclusion criteria prevented the participation of
subjects with a history of traumatic shoulder
injury, shoulder surgery, current shoulder pain
with throwing, or shoulder pain reproduced with a
clinical screening exam (Ludewig & Cook, 2000;
Magee, 2002).

Instrumentation

The Flock of Birds (Ascension Technology, Bur-
lington, VT) electromagnetic tracking device was
used to determine three-dimensional position and
orientation of sensors attached to each body segment
of interest. Each sensor contains three coils orien-
tated in a perpendicular arrangement with respect to
each other, creating local sensor axes. The associ-
ated Motion Monitor software (Innovative Sports
Training, Chicago, IL) calculates the position and
orientation of the receiver (sensor) relative to the
transmitter. The sampling rate for this investigation
was 100 measurements per second for each sensor.
For this study, three sensors (18 × 8.1 × 8.1 mm)
were attached to body segments and one sensor was
attached to a digitizing stylus. All nine measure-
ments (humerus, scapula, and thorax orientations)
were collected simultaneously. Reported accuracy
of the system is 0.50 degree (root mean square
[RMS]) regarding orientation and 0.20 cm regard-
ing position within a source-to-sensor separation
of 76.2 cm. To determine the onset of ball release
during the throw, a thin pressure-sensitive switch
(Interlink Electronics, Camarillo, CA) was used,
which recorded positive voltage when pressure was
present between the fingers and the ball and reduced
to zero when pressure was released.

Procedures

The subjects were informed of the purpose of the
study, procedures, and the risks and benefits
related to their involvement. Each subject signed

<table>
<thead>
<tr>
<th>Table 1 Subject Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Throwing (average days/week)</td>
</tr>
<tr>
<td>Throwing (average months/year)</td>
</tr>
</tbody>
</table>
a university-approved informed consent form prior to participation. Self-reported medical history, demographic data, and clinical screening examination data were collected to determine eligibility.

Three surface sensors were attached over the segments of interest. One sensor was taped with double-sided tape to the skin over the sternum just distal to the sternal notch. A second sensor was taped over the medial portion of the acromion at the junction with the scapular spine. A third sensor was attached to the posterior side of a thermoplastic arm cuff, which was placed around the distal humerus and secured with Velcro straps (Figure 2). Once the sensors were attached, landmarks on each body segment were palpated and digitized to set up anatomical coordinate systems for each sensor (Ludewig & Cook, 2000). Finally, the pressure-sensitive switch was taped to the second and third digits of the subject’s throwing hand. This switch allowed determination of ball release.

Each subject performed a series of low-velocity throws to warm up muscles, learn the appropriate rate of motion, and check the equipment setup. The subjects were asked to assume a stance that was comfortable for them and then to perform an overhand throw, aiming at a target, and to complete the throw from initiation to follow-through in about 2 s. This low velocity of throwing was chosen for two reasons. First, with a sampling rate of 100 Hz, this low speed would reduce the magnitude of changes in humeral position occurring between measured samples. Secondly, in pilot testing, high-velocity throwing frequently resulted in substantial cable movement artifact in the signal occurring at points in the throw where changes in direction of humeral motion occurred at the end of arm cocking and follow through. The target was a typical nylon pitching target (approx. 1.5 × 1.8 m) with an embedded “pocket” that was sized and placed as a strike zone. The target was placed at a distance of approximately 6 m from the subject. Subjects were asked to aim for the pocket, but throws were not discarded if they hit the backstop rather than the target. Because throwing rather than pitching was being tested and speed was below maximum, subjects did not perform a typical pitching windup or stride. Three repetitions of the throwing motion were collected for each subject.

Data Reduction

Local coordinate axes systems for each body segment (trunk, scapula, and humerus) were created using the digitized anatomical data points. The coordinate systems were developed using previously described landmarks and methods (Ludewig & Cook, 2000). The x-axis was defined as approximately medial/lateral, the y-axis approximately anterior/posterior, and the z-axis approximately superior/inferior with the subject in the anatomical position. Collectively, these three axes defined the cardinal planes for the trunk.

To define the axes of the scapula, the x-axis was defined in the plane of the scapula from the root of the scapula to the posterior/superior acromioclavicular joint. The y-axis was perpendicular to the plane of the scapula directed anteriorly. The z-axis was perpendicular to the x- and y-axes in a superior direction (Ludewig and Cook, 2000).
The humeral z-axis was defined from the estimated center of the humeral head (An et al., 1990) to the midpoint between the medial and lateral epicondyle directed superiorly along the long axis. The humeral y-axis was defined perpendicular to the z-axis and perpendicular to a line between the medial and lateral epicondyles, directed anteriorly. The x-axis was created by forming a perpendicular line to the y- and z-axes directed laterally (Ludewig and Cook, 2000).

Software mathematical transformations aligned the sensor axes to the anatomical coordinate axes (Ludewig & Cook, 2000). To describe internal/external rotation, upward/downward rotation, and anterior/posterior tilting or tipping of the scapula relative to the trunk, a z, y', x'' Cardan angle sequence was used (Karduna et al., 2000; Ludewig & Cook, 2000). To describe humeral horizontal abduction/adduction (plane of elevation), elevation angle, and long axis internal/external rotations of the humerus relative to the trunk, a z, y', z'' Euler sequence was used (Ludewig & Cook, 2000). To describe the elevation angle, horizontal abduction/adduction, and long axis internal/external rotations of the humerus relative to the scapula, a y, x', z'' Cardan angle sequence was used (Ludewig & Cook, 2000). Raw data were filtered using a Butterworth filter with a 6-Hz low-pass cutoff, based on subjects being instructed to throw at a speed of 2 s per throw, and the sampling rate of 100 Hz. Left-handed subjects’ data were collected in the same fashion and then converted to right-sided equivalency by multiplying x- and z-axis rotations by −1.

Events in the throwing motion (Figure 3) were determined as (1) initiation of humeral motion, (2) maximum humeral horizontal abduction relative to the trunk, (3) maximum humeral external rotation, (4) ball release, and (5) maximum humeral internal rotation. Instantaneous angular velocity of the humerus relative to the trunk was calculated during the throw as the first derivative of humeral angular position over time. Certain angular values (scapular upward rotation, humeral elevation) were multiplied by −1 so that the values were consistent with common clinical interpretation.

**Data Analysis**

The data collected during the subjects’ three over-hand throwing trials was analyzed for reliability and descriptive statistics, and to find the statistical effects of event in the throwing motion. The independent variables were the five events defined during the throw. The dependent variables were scapular motions of upward/downward rotation, anterior/posterior tilting, and internal/external rotation. All statistical calculations were completed using NCSS statistical software (Kaysville, UT). Reliability and descriptive statistics were calculated across subjects for each dependent variable and event, except that reliability was not determined for the first event (initiation of humeral motion).

Reliability was determined using a one-way mixed-model ANOVA with subjects as the factor. An intraclass correlation coefficient (ICC) was determined as (BMS − WMS) divided by [BMS × (k −

---

**Figure 3** — Events in the throwing motion were identified based on humeral motion and pressure switch data as (A) initiation of humeral motion, (B) maximum humeral horizontal abduction, (C) maximum humeral external rotation, (D) ball release, and (E) maximum humeral internal rotation.
Scapular Kinematics During Throwing

1) + WMS], where BMS was the between-subjects mean square term, WMS the within-subjects mean square, and \( k \) the number of trials (Fleiss, 1986; Portney & Watkins, 1993). From this one-way ANOVA, the standard error of measurement (SEM) was also determined as the square root of the WMS (Fleiss, 1986). Descriptive averages included the means and standard deviations across subjects, both averaged between genders and separated by gender.

A one-way ANOVA also was used to compare events in the motion of an overhand throw. Events were a within-subjects factor. In the presence of a significant event effect, follow-up pairwise comparisons with a Tukey–Kramer adjustment prevented alpha inflation. Maximum humeral angular velocity during throwing was assessed as a possible covariate by determining the relationship between maximum angular velocity of the humerus relative to the thorax at any event in the throw and each scapulothoracic angular variable using a Pearson correlation analysis for each event. Instantaneous humeral angular velocity was calculated by the Motion Monitor software from the continuous humerothoracic rotational displacement data. The maximum correlation between peak velocity and any scapular dependent variable was \( r = -0.05 \), with all \( p \) values > 0.05. Therefore, it was determined that there was no confounding of scapular angular position across events due to differing velocities across subjects, and an ANCOVA model was not necessary. Averaged across males, females, and overall, the highest humeral angular velocity (332, 320, and 326 deg/s respectively) occurred at maximum humeral external rotation.

### Table 2: Trial-to-Trial Reliability Statistics for the Throwing Motion

<table>
<thead>
<tr>
<th>Scapular motion</th>
<th>Maximum humeral horizontal abduction</th>
<th>Maximum humeral external rotation</th>
<th>Ball release</th>
<th>Maximum humeral internal rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal rotation</td>
<td>ICC* = 0.85</td>
<td>ICC = 0.95</td>
<td>ICC = 0.93</td>
<td>ICC = 0.98</td>
</tr>
<tr>
<td></td>
<td>SEM** = 6.8°</td>
<td>SEM = 4.0°</td>
<td>SEM = 4.5°</td>
<td>SEM = 2.3°</td>
</tr>
<tr>
<td>Upward rotation</td>
<td>ICC = 0.74</td>
<td>ICC = 0.95</td>
<td>ICC = 0.92</td>
<td>ICC = 0.79</td>
</tr>
<tr>
<td></td>
<td>SEM = 7.0°</td>
<td>SEM = 2.2°</td>
<td>SEM = 3.2°</td>
<td>SEM = 4.0°</td>
</tr>
<tr>
<td>Anterior tilting</td>
<td>ICC = 0.80</td>
<td>ICC = 0.91</td>
<td>ICC = 0.89</td>
<td>ICC = 0.90</td>
</tr>
<tr>
<td></td>
<td>SEM = 4.3°</td>
<td>SEM = 3.0°</td>
<td>SEM = 3.1°</td>
<td>SEM = 2.6°</td>
</tr>
</tbody>
</table>

*ICC-intraclass correlation coefficient = \( \frac{BMS - WMS}{BMS + (k - 1)WMS} \).

**SEM (standard error of measurement) = square root of WMS.

### Results

In general, the three trials of the throwing motion demonstrated good reliability (Table 2), with ICCs ranging from 0.74 to 0.98. The SEM values ranged from 2.2° to 7.0°. Descriptive statistics averaged across genders and separated by genders are presented in Figures 4 and 5. In general, the scapular patterns were similar across genders, with the largest separation between genders being 8° for scapular internal rotation at maximum humeral horizontal abduction.

As expected, after the initiation of humeral motion, the humerus was elevated relative to the trunk throughout all the events of the throw until maximum internal rotation (Figure 4). Maximum humeral horizontal abduction occurred early in the throwing motion, and maximum humeral external rotation occurred just before ball release. The scapular position at initiation of the throw was internal rotation in the plane of the scapula (approx. 40°; Figure 5). Maximum scapular external rotation occurred with maximum humeral horizontal abduction, and thereafter the scapula was progressively more internally rotated across the events. The scapula began in slight upward rotation, progressively upwardly rotated to a plateau of approx. 40° at maximum humeral external rotation, and then began to return to reduced upward rotation after ball release. Scapular tilting at the initiation of the motion was slightly anteriorly tilted. The scapula then progressively posteriorly tilted across events until reaching a peak at maximum humeral
external rotation, after which it began to move again toward anterior tilting at ball release until maximum humeral internal rotation. For all scapular variables, there were significant differences between events in the motion, which are summarized in Table 3.

**Table 3  Significant Event Differences**

<table>
<thead>
<tr>
<th>Event in throw</th>
<th>Scapular internal rotation different than events</th>
<th>Scapular upward rotation different than events</th>
<th>Scapular tilting different than events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Initial humeral movement</td>
<td>2,3,5</td>
<td>2,3,4,5</td>
<td>2,3,4</td>
</tr>
<tr>
<td>2: Maximum humeral horizontal abduction</td>
<td>1,4,5</td>
<td>1,3,4</td>
<td>1,3</td>
</tr>
<tr>
<td>3: Maximum humeral external rotation</td>
<td>1,4,5</td>
<td>1,2,5</td>
<td>1,2,5</td>
</tr>
<tr>
<td>4: Ball release</td>
<td>2,3,5</td>
<td>1,2,5</td>
<td>1,5</td>
</tr>
<tr>
<td>5: Maximum humeral internal rotation</td>
<td>1,2,3,4</td>
<td>1,3,4</td>
<td>3,4</td>
</tr>
</tbody>
</table>

**Discussion**

The clinical significance of analyzing the positions of the scapula across various events during a throw is examining potential implications for injuries. Past
research has described significant differences in scapular motions between healthy individuals and those with impingement syndrome during elevation of the arm, including reductions in posterior tilting and upward rotation and increases in internal rotation (Ludewig & Cook, 2000; Lukasiewicz et al., 1999; Warner et al., 1992). Less posterior tilting and upward rotation may decrease the subacromial space, thus decreasing the amount of space for rotator cuff tendon clearance during humeral elevation and increasing the risk of shoulder impingement (Kibler, 1998; Ludewig & Cook, 2000).

Knowing that scapular upward rotation and posterior tilting are important motions during an overhand throw, it is possible to speculate specific portions of the throwing motion that may place structures at risk for subacromial impingement. Using the five events mentioned earlier, for slow throwing, the arm is elevated below the traditionally described “painful arc” of motion at initial humeral position and maximal humeral internal rotation representing the beginning and ending points of the throw. Therefore, impingement is likely less of a concern during these events. The rotator cuff tendons pass beneath the coracoacromial arch and are most susceptible to subacromial impingement between 60° and 120° of humeral elevation (Flatow et al., 1994). The middle events in the throw, which include maximal humeral horizontal abduction, maximal humeral external rotation, and ball release, allow increased potential for subacromial impingement due to higher humeral elevation angles (Fleisig et al., 1996a). The results of this study indicated the average humeral elevation angles during these events were 49.5°, 83.4°, and 82.7° respectively. Typical pitching data report humeral elevation values of about 85–90° during these events, and continuing into maximum humeral internal rotation (Dillman et al., 1993). Scapular positioning into upward rotation and posterior tilting is crucial during these phases to maintain the subacromial space and reduce subacromial impingement risk (Kibler, 1998; Ludewig & Cook, 2000). Additionally, although the humerus is minimally elevated toward the end of the throw in slow throwing (maximal humeral internal rotation), there may still be substantial risk to the rotator cuff in higher velocity throwing due to the higher elevation angle measured in previous investigations during this event when throwing at higher velocities as well as high eccentric forces needed to decelerate the arm, and potential for superior translation of the humeral head (Fleisig et al., 1996a). Further, although this study evaluated healthy subjects, one might speculate that throwers with a tight posterior capsule may be at increased risk for impingement in the arm deceleration and follow-through phases if the scapula is pulled into extreme internal rotation, anterior tilting, and/or downward rotation by tight posterior capsule tissues (Kibler, 1998).

In addition to subacromial impingement, posterior superior or “internal” rotator cuff impingement has also been identified in the throwing population (Paley et al., 2000). In this condition, the posterior cuff structures and glenoid labrum are impinged between the externally rotating humerus and the posterior glenoid and glenoid labrum during the late arm cocking phase of throwing. This data suggests the scapula will maximally externally rotate or be most retracted during this phase of throwing. A lack of adequate scapular external rotation during maximum humeral horizontal abduction or maximum humeral external rotation would increase a thrower’s risk for posterior shoulder impingement.

Glenohumeral instability including anterior, inferior, and multidirectional instability is also a frequent problem in throwing athletes. There is evidence suggesting reduced upward rotation during arm elevation in subjects with inferior instability (Ozaki, 1989). Increased inferior instability has also been observed in cadavers in positions of decreased scapular upward rotation (Itoi et al., 1992). The greatest pathologic implication for throwers may be reduced scapular upward rotation during maximum glenohumeral external rotation and ball release, where humeral elevation and scapular upward rotation angles were of greatest magnitude. Interestingly, our subjects averaged 39° of scapular upward rotation at maximum humeral external rotation, whereas the humeral elevation angle averaged 83° at this same position of maximum humeral external rotation. In a study assessing scapular motions during humeral elevation in the scapular plane that used identical joint axis system descriptions (Ludewig & Cook, 2000), subjects averaged only 33° of scapular upward rotation for a 90° humeral elevation angle. This suggests normal throwing mechanics may require greater scapular upward rotation for a given level of humeral elevation. Such comparisons should be interpreted cautiously,
however, as differences between the populations and test conditions may affect the magnitude of scapular upward rotation reported.

Scapular internal rotation or protraction positions are also known to alter anterior shoulder stability (Weiser et al., 1999). Although in vivo data are not available demonstrating abnormal scapular internal/external rotation in throwers with instability, excess internal rotation is believed a potentially contributory mechanism to anterior instability and labral lesions (Kibler, 1998). Throwers are likely most susceptible to such an injury mechanism in arm deceleration and follow-through phases when shoulder destabilizing forces are high. The current investigation indicates average scapular internal rotation positions exceeding 50° in healthy subjects throwing at low velocities.

In the current study, the scapula of the throwing arm was in a position of 18° greater external rotation, 13° greater upward rotation, and 6° greater posterior tilting on average at maximum humeral horizontal abduction as compared with initial humeral motion. At maximum external rotation, the scapula was then upwardly rotated and posteriorly tilted an additional 14° and 8°, respectively, as compared with maximal horizontal abduction. The serratus anterior muscle demonstrates high electromyography (EMG) activation during the associated arm cocking phase of the throw (DiGiovine et al., 1992). The serratus anterior, as the only scapulothoracic muscle with the ability to contribute substantial torque to all three of the scapular component motions of upward rotation, external rotation, and posterior tilting, likely plays a critical role in this phase of the throw. In their EMG analysis of throwing athletes with anterior instability, Glousman et al. found a number of differences as compared with healthy subjects, including decreased serratus anterior EMG throughout the entire throwing motion, which likely reduces scapular control and contributes to development or progression of pathology (Glousman et al., 1998).

The scapular data in this study at ball release shows an average of 10° greater internal rotation, and 4° greater anterior tilting as compared with maximum humeral external rotation. Upward rotation is essentially unchanged at these two points in the throw. DiGiovine et al. found that all of the scapular muscles are highly active during this arm acceleration phase (DiGiovine et al., 1992). These muscles are believed to maintain the scapula as a stable fulcrum for the humerus during this high-velocity phase (DiGiovine et al., 1992). At maximal internal rotation, the scapula is further internally rotated 21°, downwardly rotated 20°, and anteriorly tilted 9° as compared with positions at ball release. While the rotator cuff muscles slow the humerus, the serratus anterior, trapezius, and rhomboids also demonstrate high EMG activity during this arm deceleration phase (DiGiovine et al., 1992), eccentrically contracting to restrict scapular protraction at the end of the throw.

Limitations arise during the course of any research. The sample population is one limitation of this study. The subject sample consisted of 10 men and 10 women. Subjects were from various backgrounds and playing positions. Positions ranged from catchers to pitchers to outfielders, all of whom may display different throwing mechanics. This may increase the between-subject variability. However, the data obtained affords greater generalizability with a more heterogeneous sample.

Subjects were instructed to throw below their maximum velocity (at about 2 s to complete the throw) in order for the instrumentation to record accurately, minimizing cable movement artifact and maximizing the available data for the sampling rate. Thus their motions may have been altered to compensate for a slower overhand throw, and the sampling rate and filter cutoff may have attenuated the peak motion recorded. Also, ball release was recorded via a pressure switch, which may have resulted in an early identification of ball release depending upon the nature of grip and ball release. However, we believe that the decreased velocity of the throw and other instrumentation factors still afforded an accurate description of the patterns of motion during the overhand throw, with reductions in the magnitude of motion one might expect in a maximum velocity throw. Peak humeral angular velocities of elite pitchers have been reported at greater than 6,000 deg/s. Despite these much higher velocities, instrumentation differences, and elite nature of pitching subjects investigated in much of the past work, our patterns and magnitudes of motion are quite similar during the throw to past data for humeral elevation and humeral horizontal abduction (Dillman et al., 1993; Fleisig et al., 1996a).

Data in the current study for maximum humeral external rotation (79°) was much less than reported in past research for full velocity pitching in elite
athletes (nearly 180°). This is in part due to previous methodologies not measuring all components of spinal and scapular motion, as well as not accounting for valgus opening at the elbow. Thus, the higher humeral external rotation values previously reported are a combination of spinal extension, posterior tilting of the scapula, and valgus opening at the elbow in addition to humeral motion. Further, high-level throwers often present with increased humeral external rotation range of motion related to humeral retroversion or anterior capsular laxity. The methodology of the current study measured humeral to trunk motion only in a mix of recreational and competitive throwers, and thus smaller values can be expected. However, our slow velocity of throwing likely also contributed to reduced external rotation as compared with the high velocity pitching literature. Finally, a surface humeral cuff also underrepresents the full magnitude of bone motion of the underlying humerus by as much as 9%, even for a slow velocity movement (Ludewig et al., 2002).

Finally, because surface sensors were used to track motion, potential skin motion artifact is a limitation of this study. Karduna et al. previously compared three-dimensional scapular motions described from bone fixed sensors to electromagnetic surface motion measures during dynamic arm motions in vivo, with small magnitudes (approx. 2° for tilting to 6° for upward rotation) of skin motion error during humeral elevation at or below 90° (Karduna et al., 2001). For humeral motion when comparing surface humeral cuff motion to bone fixed humeral motion during dynamic slow velocity internal and external rotation with the arm at the side, axial rotation RMS errors averaged 9% (Ludewig et al., 2002). For scapular plane abduction, humeral cuff skin slip errors ranged from 1.5° to 3.5°, with the highest error for axial rotation (Ludewig et al., 2002). In that investigation, each sensor was collected at 30 Hz. Skin slip in the current study may be greater with the throwing motion as compared with planar arm elevation. It should be noted, however, that high trial-to-trial reliability was demonstrated.

Despite these limitations, the objective of this study was to examine scapular mechanics during an overhand throw. Although previous studies have been conducted regarding throwing mechanics, none have measured three-dimensional scapular positions. The study was not designed to statistically compare genders during the throwing motion, as there was no previous variability data from which to base a priori power analyses. However, data from the current study allow determination of necessary sample sizes for any future studies intending to make such comparisons. Using judgment of a clinically meaningful difference of 5° and the variability present in this sample, about 50–80 subjects per group would be needed to have moderate power to detect differences between genders for scapular upward rotation and internal rotation, respectively. However, adequate power was present in this study with a sample size of 20 to detect gender differences of less than 6° for scapular tilting.

To decrease the incidence of throwing injuries, coaches and health care professionals must emphasize prevention through proper technique, balanced muscle strengthening, and training regimens. To prevent and rehabilitate these shoulder injuries, it is beneficial to have knowledge of scapular mechanics and the EMG activity of the scapular stabilizers during a throw. This study has provided new information regarding three-dimensional motions of the scapula during an overhand throw. The results of this study suggest that the movements and positions of the scapula during the throw may have implications for common shoulder pathologies. Understanding these throwing mechanics may help athletes, coaches, and rehabilitation specialists better prevent and treat throwing injuries.

Acknowledgments

This work was supported in part by an equipment grant from the Minnesota Medical Foundation.

References


