Kinematic Motion of the Windmill Softball Pitch in Prepubescent and Pubescent Girls

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Abstract

Oliver, GD, Dwelly, PM, and Kwon, Y-H. Kinematic motion of the windmill softball pitch in prepubescent and pubescent girls. J Strength Cond Res 24(9): 2400–2407, 2010—This study examined the joint motions and movement patterns of the kinetic chain in the ballistic skill of performing the windmill pitch. Seventeen healthy girls who were currently playing competitive fast-pitch softball volunteered for the study. Subjects were instructed to perform 5 successful fastball windmill style deliveries. We selected 1 pitch for analysis based on the velocity, accuracy, and subjects’ input. Kwon3D motion analysis package (Visol., Inc., Seoul, Korea), with 6 digital camcorders placed at 60° apart was used for analysis. Raw data were interpolated using a frequency of 60 Hz and then smoothed using Butterworth low-pass second-order filter with a fixed cut-off frequency of 6 Hz. The subjects were divided into groups based on skill level: novice, intermediate, and advanced. Sequential progression of kinematic variables that resulted in increased throwing velocity and the contribution each segment (upper arm, forearm, and hand) possessed toward ball velocity with descriptive statistics and path analysis were assessed. There was evidence of sequentiality among the arm segments in the intermediate and advanced groups. The patterns of the shared positive contributions made by each of the limb segments were similar among the 3 groups of participants. The novice group tended to rely on more of the upper arm and forearm than the other 2 groups. From this study, it is evident that all emphasis should not be placed on the shoulder, but training and conditioning methods should focus on the entire kinetic chain including the torso and the full arm segment, not just the shoulder in an attempt to gain the greatest velocity while performing the 360° arc of the windmill softball pitch.

Key Words velocity, sequentiality, mechanics

Introduction

In 1995, fast-pitch softball was the largest team sport in the USA, with over 35 million participants (13). According to a report from all 5 governing bodies of fast-pitch softball, there were more than 2 million female adolescents between the ages of 12 and 18 competing in fast-pitch softball during 2003 (13). The fast-pitch softball game is strategically controlled by pitchers, similar to that of baseball. Despite the similarities between the pitching game of softball and baseball, there are notable differences; the mound in baseball vs. no mound in softball, to the management of the pitchers. Softball pitchers throw a higher number of innings and have limited recovery time, compared to the baseball pitchers. Example, softball pitchers may pitch as many as 10 games during a weekend tournament with each game having 7 innings to equate to approximately 1,500–2,000 pitches in a 3-day period (14). These factors come at the cost of a significant number of time-loss injuries in windmill softball pitchers (6).

The rate of injury can be reduced through factors such as improved pitching biomechanics. Powell and Barber-Foss have reported that girls sustain a significantly higher injury rate with softball than do boys participating in baseball (9). The only literature available on injury prevalence in fast-pitch softball indicated that 50% of the pitchers in the 1989 College World Series had a time-loss injury during the season (6). Loosli et al. recommended that the pitching mechanics be evaluated because of the high incidence of injury (6). Young (13) and elite (16) fast-pitch softball pitchers exhibit elbow and shoulder loads that are similar to those found in baseball pitching.

The pitching motion is a full kinetic chain activity that transfers energy from the pelvis and torso and releases into the upper extremity and on to the ball (5). The maximum amount of ballistic energy is applied to the ball, when all body segments are coordinated, which results in the greatest velocity produced at ball release. Therefore, when the velocity of the windmill pitch is a major contributor to the outcome of a game, the sequential activation is of major interest. In baseball pitching, energy is transferred through the trunk, then sequentially onto the smaller segments of the upper extremity (3,5,7,12). Werner et al. (14) reported there are excessive distraction forces at the shoulder of the softball pitcher similar to those found in baseball. Thus, if the
research is discussing inferences of joint forces being compatible across the sports (14), then the issue of sequentiality should be addressed. Therefore, the primary purpose of this study was to examine the joint motions and movement patterns of the kinetic chain in the windmill pitch. The secondary purpose was to investigate differences between advanced and novice pitchers’ movement patterns, sequential progressions, and segmental contributions. We primarily wanted to descriptively assess the kinematics of the windmill softball pitch, and secondly, we hypothesized that the more skilled softball pitcher would exhibit significantly different movement patterns, sequential progressions, and segmental contributions than the less skilled or novice softball pitcher.

METHODS

Experimental Approach to the Problem
We used a nonexperimental observational 3-group comparison design. The 3 groups were defined as novice, intermediate, and advanced. We defined “novice” as pitchers with 1 year or less of experience pitching competitively, “intermediate” as 2–3 years of competitive pitching experience, and “advanced” as 4 or more years of competitive pitching experience or currently pitching at the collegiate level. Each participant followed the same protocol, using a single test session without an intervention or treatment.

A path multiple regression analysis was also performed to assess in the explanation of sequential progression of kinematic variables that result in an increased throwing velocity to determine the contribution of each segment (upper arm, forearm, and hand) to the contribution of ball velocity. To compare the results of the path analysis across the 3 different skill levels, the investigators used a repeated-measures analysis of variance (ANOVA) with post hoc analysis. To understand the relationships between trunk and upper arm; upper arm and forearm; and forearm and hand at the point of ball release the investigators performed Pearson correlations. The investigators used SPSS 11.5 for Windows (SPSS, Chicago, IL, USA) statistical package to analyze data.

Subjects
Seventeen healthy girls who were currently playing competitive fast-pitch softball volunteered for the study. Demographic information is presented in Table 1. We included only right-handed pitchers who were injury-free. Before participation, subjects were informed of all possible risks and signed a consent form approved by Texas Woman’s University Institutional Review Board. For the subjects who were minors at the time of data collection, their parent signed the consent form before testing.

Procedures
Testing Procedures. Subjects were instructed to wear a dark colored tank top, spandex shorts, and tennis shoes to the testing site, the Biomechanics Laboratory at Texas Woman’s University, Denton, TX. Subjects were to arrive to the biomechanics laboratory prepared as if they were throwing a game that afternoon, meaning each subject performed her regular pregame routine before arrival; thus, fatigue was negated. After all measurements were completed, 19 1-cm reflective markers were placed on strategically placed over anatomical landmarks on the joints of the trunk and upper extremity to facilitate 3-dimensional kinematic analysis of the windmill softball pitch. Reflective marker placements are presented in Table 2. From the primary point coordinates,

### Table 1. Demographic mean ± SDs for advanced, intermediate, and novice groups.

<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>Jump (in.)</th>
<th>Wingate power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced</td>
<td>21.2 (0.8)</td>
<td>169.4 (1.9)</td>
<td>77.4 (12.5)</td>
<td>16.4 (3.0)</td>
<td>128.7 (17.0)</td>
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<tr>
<td>Intermediate</td>
<td>15.0 (2.1)</td>
<td>154.5 (23.1)</td>
<td>66.1 (8.4)</td>
<td>15.2 (2.8)</td>
<td>95.5 (20.4)</td>
</tr>
<tr>
<td>Novice</td>
<td>11.5 (2.4)</td>
<td>150.0 (12.5)</td>
<td>47.0 (16.4)</td>
<td>11.3 (2.8)</td>
<td>38.4 (20.0)</td>
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</tbody>
</table>

### Table 2. Reflective marker placement for digitizing the windmill softball pitch.

(R) Third metacarpal
Wand (proximal and distal markers)
(R) Medial elbow
(R) Lateral elbow
(R) Anterior shoulder
(R) Posterior shoulder
(L) Anterior shoulder
(L) Posterior shoulder
Supra sternal notch
C7
Sacrum
(R) ASIS
(L) ASIS
(R) Greater trochanter
(L) Greater trochanter
(R) Great toe
(R) Heel
(L) Great toe
(L) Heel
secondary points were computed. The secondary points identified were joint centers (right, left hip, wrist, elbow, upper arm, right shoulder, and left shoulder). Anthropometric measurements (height and weight) were recorded for each participant using the modified Hanavan method (4).

The 19 points selected for primary digitizing were chosen because the focus of the analysis was on the trunk and pitching arm segments: trunk, right upper arm, right forearm, and right hand. The secondary points determined joint centers of the hip, wrist, elbow, and shoulder. The hip joints were defined through the Tylkowski (11) method through the identification of the right anterior superior iliac spine (ASIS), left ASIS, sacrum and inter ASIS distance. A wand positioned in line with the wrist joint center with a near and far marker was used to determine the joint center of the wrist (see Figure 1).

A wand was mounted on a band that was placed around each participant’s wrist. The wand projected from the center of the dorsal side of the wrist on the pitching arm. The wand was 12.7 cm (5 in.) in length with a reflective marker on the proximal and distal end of the wand. The wand’s proximal marker was 5 cm from the dorsal surface of the wrist. To determine the joint center using a wand, it was assumed that the joint center lie on the line defined by 2 markers fixed to the wand. The 2 markers affixed to the wand were the proximal wand marker and the distal wand marker. The joint center could be obtained from equation 1.

\[
    n = (r_{np} - r_{fp})/|r_{np} - r_{fp}|; r_{jc} = r_{np} + D_n (1)
\]

For the prediction of joint center equation, the \( r \) is a position vector, and \( n \) is a unit vector of the vector drawn from the far point (fp) to the near point (np). Determining the joint center
through use of a wand requires 3 inputs (2 markers and the near-point-to-joint-center distance). The near-point-to-joint-center distance was required to compute the joint center using the wand. The right elbow was defined as the midpoint of the right lateral epicondyle and the right medial epicondyle. With the 2 points of the lateral epicondyle and medial epicondyle of the elbow defined, the midpoint was computed to represent the joint center of the elbow. The right shoulder joint was located based on the elbow joint and a point on the shoulder-elbow axis (upper-arm point). The upper-arm point was defined as the far marker, whereas the elbow joint was defined as the near marker in the wand method. The upper-arm length (distance between the elbow and the shoulder) was used to locate the joint center.

Before each data collection session, cameras were calibrated by videotaping a control object. The control object, a cube that contained 36 control points, was placed over the pitching area. All trials were performed within the area occupied by the control object. The camera conditions were maintained throughout the rest of the data collection session. The digital video camcorders were connected to SMPTE time code generators (HORITA RM-50/TG, Mission Viejo, CA, USA), which were connected to 6 Mini DV VCRs (Panasonic AG-DV1000, Secaucus, NJ, USA), which were attached to a video switcher system (Panasonic Video Switcher WJ-SW208). The video switcher system (Panasonic Video Switcher WJ-SW208) allowed for viewing all 6 cameras. The SMPTE time code generator recorded a mark in the field of view for each camera for synchronization. Video images were recorded by the 6 Mini DV VCRs (Panasonic AG-DV1000) and then captured to a CD through the use of a Hewlett Packard Pavilion N5405B notebook computer with an IEEE 1394 Firewire PCMCIA video capture card and Adobe Premiere 6.5 digital video capturing software.

Global and local reference frames determined the 3-dimensional coordinates. The global right-handed orthogonal reference frame was fixed to the control object in the direction of motion $X_g$, $Y_g$, and $Z_g$ were used to define the global reference frame. $Y_g$ was in the direction of the throw toward the target. $X_g$ was perpendicular to $Y_g$ in a horizontal direction, whereas $Z_g$ was vertical.

<table>
<thead>
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<th>Table 3. Tukey post hoc results by group (advanced [$n = 5$], intermediate [$n = 6$], and novice [$n = 6$] groups) for ball, wrist, elbow, and shoulder velocities on hand velocity.</th>
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</thead>
<tbody>
<tr>
<td>Dependent variable</td>
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<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Ball velocity</td>
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<td>Wrist velocity</td>
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<td>Elbow velocity</td>
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<td>Shoulder velocity</td>
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*$Represents significant difference between groups at $p < 0.01.$
To establish a mathematically functional model, 4 Cartesian coordinate systems were established (Figure 2). The axis systems were segmentally based within each segment. These anatomical based axis systems defined motion in the trunk, shoulder, elbow, wrist, and hand. The bony landmarks represented by the reflective markers were used to construct the right-handed orthogonal reference frames. To determine the local anatomical reference frame, a minimum of 3 non-collinear points had to be defined relative to the segment. The trunk, pelvis, upper arm, forearm, and hand reference frames were defined. The trunk was defined proximally by the right and left hips and distally by the right and left shoulders. The local reference frame of the trunk was defined, by positions of the right and left shoulders (see Figure 3). The axis was defined as the $Z$ and $X$ with the origin of the trunk center of mass relative to the global reference frame along the $XYZ$ axis. Motion about the $Z$ and $X$-axes of the local reference frame of the trunk were rotation and forward and lateral bending, respectively. The reference frame of the right upper arm was defined distally by the right elbow and proximally by the right shoulder. The local reference frame axis setup of the right upper arm was defined by the positions of the right medial and lateral elbow (see Figure 4). Axes were defined as negative $Z$ and $X$, which defined the motion about the shoulder. The negative $Z$ and $X$-axes had their origin at the right upper-arm’s center of mass relative to the reference frame of the trunk on the $XYZ$ axis. Movement about the negative $Z$-axis was internal/external rotation, whereas movement about the $X$-axis of the upper arm was defined by flexion and extension. The relative orientation of the upper arm to the trunk was computed to quantify upper arm motions. The reference frame of the right ulna defined the right elbow. The reference frame of the right ulna was defined by the positions of the right medial and lateral elbow and wrist.

![Figure 6](image-url) Shoulder, forearm, trunk, and wrist angular velocity (first derivative orientation angle) sequencing just before ball release (at marker 100) for A) advanced ($n=5$), B) intermediate ($n=6$), C) and novice ($n=6$).
The negative Z and X-axes with the origin of the right ulna’s center of mass defined the frame. The right ulna’s reference frame was relative to the global reference frame on the X1Z axis. The relative orientation of the forearm to the upper arm defined the motion at the elbow. Flexion and extension of the elbow defined the motion about the X-axis, whereas motion along the Z-axis was defined by internal and external rotation.

The reference frame of the right radius defined the joint motion at the right wrist. The proximal and distal wand markers that were located perpendicular to the wrist joint defined the reference frame of the right radius. The negative Z and negative Y-axis with an origin of the right radius relative to the right ulna determined the local reference frame. Movement was defined as pronation and supination about the Z-axis. In addition to the reference frame of the right radius defining the wrist, the reference frame of the right hand also assisted in defining the right wrist. The body vector of the right hand and the positions of the proximal and distal wand defined the axis setup. The negative Z- and negative Y-axes relative to the right radius determined the local reference frame of the hand.

After marker placement, each subject warmed up for a minimum of 10 minutes before the data collection began but did not commence until the subject was ready to throw with maximum effort. Subjects were instructed to perform 5 successful fastball windmill style deliveries using an official softball (12-in. circumference, 6 oz.). A successful pitch was considered one that contacted the targeted strike zone, a 20 × 20 in. area taped on a mat 40 ft away, was deemed satisfactory by the subject and was reported within their velocity range of actual game performance. After 5 successful pitches were thrown, we selected 1 pitch for analysis based on the velocity, accuracy, and subjects input. Kwon3D motion analysis package (Visol., Inc., Seoul, Korea), with 6 digital camcorders placed at 60° apart was used for the analysis. Raw data were interpolated using a frequency of 60 Hz and then smoothed using Butterworth Low-Pass second order filter with a fixed cut-off frequency of 6 Hz.

**Sequencing of Segments.** Simultaneity is the shared contribution of the segments, whereas the percent of shared positive contribution (SPC) between adjacent segments is the time both segments contribute positively divided by the time the last segment contributed positively. The SPC of the trunk minus the upper arm, the SPC of the upper arm minus the forearm, and the SPC of the forearm minus the hand were assessed. The period of positive contribution for the body was considered to be the interval that at least 1 segment was involved in positive contribution. If all segments underwent positive contribution, the segmental motion is simultaneous. Sequentiality is appropriately defined when 1 segment reached its peak or maximum angular velocity and then hundreds of a second later another segment reached its maximum.

**Results**

It was the purpose of our study to examine the joint motions and movement patterns of the kinetic chain during the windmill pitch between different levels and to investigate differences between advanced and novice pitchers’ movement patterns, sequential progressions, and segmental contributions. We hypothesized that the more skilled softball pitcher would exhibit significantly different movement patterns, sequential progressions, and segmental contributions than the less skilled or novice softball pitcher. The 1-way ANOVA revealed a significant difference between groups for linear velocity of the ball \[F(2,14) = 16.23, p < 0.01\] and for the wrist \[F(2,14) = 16.28, p < 0.01\]. Tukey post hoc results are presented in Table 3.

There was evidence of sequentiality among the arm segments in the advanced and intermediate groups (Figure 6A and B, respectively). Intermediate and advanced groups displayed proximal to distal sequencing of segments in the arm segment; however, they did not display the same proximal to distal sequencing in the trunk. In the advanced and intermediate groups the trunk did not reach its maximum angular velocity until ball release. The novice group failed to display a proximal to distal trend (Figure 6C). During the windmill pitch, sequentiality of the upper extremity is not observable until immediately before ball release.

The patterns of the SPC made by each of the limb segments were similar among the 3 groups of participants (Figure 7). The
novice group tended to rely on more of the upper arm and forearm than the other 2 groups. The novice group’s percent contribution displayed the inability of the participant to accelerate each segment in turn so that the succeeding segment lags behind, providing the final segment maximal speed.

**Discussion**

The purpose of this study was to describe the joint motions and movement patterns of the kinetic chain in the ballistic skill of performing the windmill softball pitch. Such information provides a more comprehensible understanding for the development of training programs for windmill softball pitchers. The results of this study show a definite sequence of proximal to distal segmental motions that are distinctive among the intermediate and advanced windmill softball pitchers. Even though the novice windmill softball pitchers did display characteristic sequentiality among segments, it was not a proximal to distal sequence. The results from the novice group are indicative of a lack of segmental progression when compared to the intermediate and advanced groups. Optimal, the larger more proximal segments reach their peak angular velocities, followed by the next distal segment and eventually ending with the furthest distal segment reaching its maximal velocity. Supported by this case, the wrist/hand stabilized just before ball release. However, because of the natural phenomenon of the whipping motion of the windmill softball pitch, the sequentiality of the segments was not evident until hundreds of a second before ball release.

For all 3 groups, the results indicated that the shoulder (upper arm segment) lost angular velocity before ball release; this is in agreement with the findings of previous studies where it has also been reported that during whole-body motions where a peak velocity is desired by the hands, such as in throwing, the properly timed stopping actions of each segment in sequence from foot to hands produces the best results (1,8). The results also are in agreement with those of Atwater (2) who stated that during the over arm throw, the body segments accelerates “in turn.” The distal segments gained acceleration from the proximal segments, and as the proximal segments reached peak acceleration, the distal continued to accelerate while the proximal segments slowed.

The majority of human movement that involves accelerating the distal end to project an object usually shows the sequential pattern at the beginning of the acceleration of the limb and continuing throughout the movement (15). However, the sequentiality occurred within a very short time period just before ball release in this study. Upon examining the motion of the windmill softball pitch, the arm approaches full extension while moving through the 360° arc. The pitcher extends the upper extremity for the whipping motion and then transfers the energy to the more distal segment within hundreds of a second before ball release.

This study also revealed the sequentiality of proximal to distal segments in their contributions to ball velocity. Among all groups, the hand was distinguished as allowing for the greatest contributory role in ball velocity. The advanced group specifically demonstrated the hand as contributing 62% of the ball velocity. The hand contributions were followed by the forearm, upper arm, and trunk. This finding is in agreement with Atwater (2) who stated “as each segment accelerated in turn, the succeeding segment first lagged behind, then acquired the speed of the segment moving it, and then accelerated to reach an even greater speed, while the proceeding segment decelerated.” Biomechanically, the forearm was slowing while the hand was increasing in velocity just at ball release. Even though the shoulder and upper arm reach their peak velocities at stride foot plant, their role in the prediction of ball velocity is still important. As Putnam (10) stated, even though the more proximal segments of the shoulder and upper arm do not make large kinematic contributions to the distal end speed at the instant of release, their motion histories are such that they make it possible for the distal end to achieve a high speed.

**Practical Applications**

From this study, it is evident that all emphasis should not be placed on the shoulder, but training and conditioning methods should focus on the entire kinetic chain including the torso and the full-arm segment, not just the shoulder in an attempt to gain the greatest velocity while performing the 360° arc of the windmill softball pitch. Focus should be placed on the velocity production about the forearm, wrist, and hand motion vs. trying to increase the velocity about the shoulder. In doing this, it is imperative that we concentrate on building a solid foundation of the supporting musculature supporting the trunk, shoulder, and elbow. Pitchers are at great risk of injury when instructed poorly, especially if the kinetic chain is not developed and used. Training and conditioning methods should focus on the entire kinetic chain when working with windmill softball pitchers. No matter what the age is, there should be a proximal to distal transfer of energy. Energy should be developed in the legs, trunk, shoulder elbow, and wrist. Instructing the proper technique early is paramount for performance enhancement and injury prevention. Thus, all training should be developed in the core and then extended outward to the most distal segment.

**References**


