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Neuromechanical Integration of Pelvic-Thoracic Rotation among Youth Baseball Throwers

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ABSTRACT

The kinetic sequencing involved in the overhead throw anticipates an orchestration of body movement in which the more proximal segments of the body initiate movement prior to the more distal segment. This investigation explored neuromuscular and kinematic characteristics associated with one aspect of this kinetic sequencing, pelvic-to-thoracic rotation. Neuromuscular activation was recorded using surface electromyography and kinematic data was acquired using 3D videography. Specific objectives included 1) to describe the maximum angulation between the pelvic and thoracic body segments ($X_{max\,angle}$), 2) to test the hypothesis that glove-side external oblique peak neuromuscular activation (GEOPA) occurs before $X_{max\,angle}$, 3) to test the hypothesis that throwing-side external oblique peak neuromuscular activation (TEOPA) occurs following $X_{max\,angle}$. Results show the mean $X_{max\,angle}$ to be 45.96 degrees (± 10.83). The time of mean GEOPA (2.3653 sec ± 0.9094) occurred following the time of mean $X_{max\,angle}$ (2.2793 sec, ± 0.9026, $p < 0.01$), thus refuting the first hypothesis. The time of mean TEOPA (2.3658 sec, ± 0.8978) occurred following the time of mean $X_{max\,angle}$ (2.2793 sec, ± 0.9026, $p < 0.01$), thus confirming the second hypothesis. Results suggest that youth baseball participants may not adequately utilize the core of the body to fully benefit from the optimal kinetic sequencing postulated within the literature.

Introduction

The sport of baseball has long held a significant place in American society. Approximately 5.7 million children below the 8th grade participate in youth league baseball programs each year [1]. It is an activity requiring repetitive overhead throwing that has been associated with throwing arm injuries [2, 3].

The kinetic chain model of throwing suggests that the safest, most optimal method of throwing requires a highly orchestrated

series of segmental movements throughout the body [4–9]. A summary of this kinetic chain model of throwing states, "…the utilization of the kinetic chain to generate and transfer energy from the larger body parts to the smaller, more injury-prone upper extremity. This kinetic chain in throwing includes the following sequence of motions: stride, pelvis rotation, upper torso rotation, elbow extension, shoulder internal rotation and wrist flexion. As each joint rotates forward, the subsequent joint completes its rotation back into a cocked position, allowing the connecting segments and musculature to be stretched and eccentrically loaded" [4].

The order in which each segment reaches its maximum angular velocity is described as the kinematic sequence and has been the subject of investigation. The presumed optimal kinematic sequence is, pelvis - trunk - arm - forearm - hand [7]. This optimal kinematic sequencing facilitates the distal arm acceleration to be driven primarily by the forces generated within the thorax and shoulder [10]. Previous research has documented that the kinematic sequencing between the pelvis and thorax commonly conforms to the expected. In one study it was determined that of the three most performed kinematic sequences for both curveball and fastball pitches, the pelvis was the first and the trunk the second segment to reach maximum angular velocity [7]. In another study the pelvis was the first segment to reach maximum angular velocity in 96 % of the trials whereas the thorax was the second segment to do so in 91 % of trials [8]. The exception to this involves either the thorax reaching maximum angular velocity before the pelvis or at the same time as the pelvis [7, 8]. This exception to the expected pelvis–trunk, kinematic sequence was revealed to occur in 60 % of the trials and was associated with greater maximum shoulder external rotation and greater force at the shoulder [9]. Altered kinetic sequencing of the pelvis-thorax is identified as a predisposing condition for pitch-related injury [11].

The importance of trunk rotation during an early stage of kinematic sequencing relates to the distribution of kinetic energy from a high mass segment to the relatively lower mass upper arm segment. Generation of this kinetic energy depends on the trunk moving through a large arc of motion with high angular velocity. The magnitude of axial rotation as "computed as the angle between the pelvis and the upper trunk in the transverse plane" has been reported among participants at various ages [12]. Axial rotation within the transverse plane among youth pitchers is reported to be 50.1 ° (± 6.9), among high school pitchers 54.9 ° (± 9.1), college pitchers 51.5 ° (± 8.2), and professional pitchers 49.9 ° (± 5.2) [13]. Similarly, the magnitude of axial rotation among professional pitchers is also reported to be 55 ° (± 6.0) and maximal trunk angular acceleration at 11,600 °/sec (± 3,100) [12]. Peak pelvic angular velocity is reported as 600 °/sec with a rotational duration of 0.03–0.05 seconds, whereas peak thoracic angular velocity reaches 1,200 °/sec with a rotational duration of 0.05–0.07 seconds [14].

To accomplish the necessary magnitude of motion and acceleration within the kinetic sequence involving axial rotation, a "coordinated concentric activation of pre-stretched oblique muscles" is desirable [12]. Examination of this assertion was conducted using surface electromyography in which the authors found that during the overhead throw, the glove-side external oblique muscle was activated before its contralateral antagonist [15]. It was concluded

that this sequence of activation is consistent with the thoracic rotation motions associated with the overhead baseball pitch [15].

Sufficient quality of instruction on the throwing motion potentially has a meaningful role in preventing childhood pitching injuries. This assumption is supported by a longitudinal study in which significant improvements were demonstrated within a constellation of pitching kinematics among children ranging between 9–15 years [16]. The authors of this longitudinal study conclude that pitching instruction should focus on motor development prior to puberty so that following puberty the focus can be safely transitioned to improving strength and power [16].

The purpose of this investigation is to explore the maximum magnitude of angulation of the thorax relative to the pelvis within the transverse plane ($X_{max\ angle}$) in a sample of youth league baseball players. We will also determine the sequence of peak neuromuscular activation for the bilateral external oblique muscles relative to the attainment of the $X_{max\ angle}$.

Hypotheses include: 1) peak activation for the glove-side external oblique (GEOPA) will occur prior to the attainment of the $X_{max\ angle}$; 2) peak activation for the throwing-side external oblique (TEOPA) will occur following the attainment of the $X_{max\ angle}$; and 3) GEOPA will occur before TEOPA.

Materials and Methods

Twelve male youth baseball players participated in this study, with a mean age of 13.97 years (± 1.81; range 11–16), an average height of 1.67 meters (± 0.14), and an average weight of 67.15 kg (± 29.30), respectively. All participants were right-hand dominant. On the day of testing none of the participants reported injuries that would interfere with their ability to throw comfortably (▶ Table 1).

This investigation was conducted according to the stipulated ethical standards in sport and exercise science research [17]. This investigation was also approved by the Human Subjects in Research Internal Review Board associated with the institution to which the lead author is associated. (▶ Table 2 provides the stage progression of the data collection process).

Confirmation of informed consent

Prior to arriving at the testing facility, subjects and their parent(s) or guardian(s) were provided an informed consent form explaining the purpose of the study and testing procedures, as well as other information that individuals need to understand prior to offering informed consent (parent(s)/guardian(s) and assent (children). Upon arrival, a member of the research team met with and discussed the study procedures with both the child and their representative. Opportunities for questions provided before the parent(s) or guardian(s) were asked to offer their informed consent on behalf of the child, and the children were asked to assent to participate in the study.

Physical measures of the subject

Participants were weighed and measured for height. Each participant was then asked which hand they preferred to throw with and if they were currently experiencing pain or injury anywhere in their body that might interfere with their willingness or ability to throw effectively.

▶ **Table 1** Descriptive characteristics of subject sample.

Sex	Number of Subjects	Age (yrs)	Weight (kg)	Height (m)
Male	12	13.97 ± 1.81	67.15 ± 29.3	1.67 ± 0.14

▶ **Table 2** Stage progression of data collection process.

Stage	Objective	Process
A	Confirmation of informed consent	Review of procedures and questions answered
B	Physical measures of the subject	Age, height, weight
C	Functional throwing warm-up	Ten minutes of slow progression of throwing.
D	Prepare digital recording cameras.	Six cameras, sampling rate 120 Hz.
		Arranged to encircle subject.
		Calibration of camera system relative to space.
E	Placement of shoulder infrared reflector markers	One on dorsum of right acromioclavicular joint.
		One on dorsum of left acromioclavicular joint.
F	Placement of pelvic infrared reflectors markers	One on the apex of the right iliac crest.
		One on the apex of the left iliac crest.
F	Placement of throwing-side recording sEMG electrodes.	Sampling at 1000 Hz
		Cleanse the skin using standard alcohol rub
		Self-adhering electrodes
		Affixed to skin overlying external oblique:
		1st: 2" medial to throwing-side apex iliac crest
		2nd: 1" medial and inferior to electrode 1
G	Placement of glove-side recording sEMG electrodes.	Sampling at 1000 Hz
		Cleanse skin using standard alcohol rub
		Self-adhering electrodes
		Affixed to skin overlying external oblique:
		1st: 2" medial to glove-side apex iliac crest
		2nd: 1" medial to and inferior to electrode 1
H	Preparation throwing	Five practice throws without recording.
I	Throwing trial	Five game intensity throws while recording.
J	Data preparation	Throws with full dataset retained for analysis.

Functional throwing warm-up

Each participant engaged in a slow progression of throwing to prepare for the demand of the throwing trial. This preparation stage lasted 10 minutes and started with short-distance, light throwing and progressed to increasing distance followed by increased throwing intensity.

Recording equipment and placement of infrared reflective markers

Kinematic data was collected using six video cameras, each using an infrared strobe and sampling at a frequency of 120 Hz (Opus510; Qualysis, Gothenburg, Sweden). Cameras were arranged so as to encircle the subject throughout each throw. Digitizing the transverse X-angle required placing two sets of two infrared reflector 12.5-mm diameter markers on each subject (Qualysis). For the first set of infrared reflectors, one reflector was affixed to the dorsum of the throwing-side acromioclavicular joint and the second reflector was affixed to the dorsum of the glove-side acromioclavicular joint. For the second set of infrared reflectors, one reflector was affixed to the skin overlying the apex of throwing-side iliac crest while the second reflector was affixed to the overlying skin of the glove-side iliac crest.

Placement of surface electromyography

The primary neuromuscular factor within this investigation is the time at which peak activation is achieved for both the glove-side and throwing-side external oblique musculature (GEOPA & TEOPA, respectively). Measurement of these neuromuscular factors was accomplished using surface electromyography (sEMG). Two sets of three sEMG self-adhesive electrodes were placed, each of which was 40.8 × 34 mm in size (Ambu Bluesensor M ECG; Ambu, Ballerup, Denmark). Prior to affixing these electrodes to the skin, the skin was cleansed using standard alcohol rubs. In each set of three electrodes, two electrodes were recording electrodes and the third served as a ground electrode. Recording electrodes were applied to the skin overlying the external oblique musculature. The more proximal recording electrodes were affixed at a location two inches medial to the apex of the iliac crest. The second recording electrode was affixed to the abdomen at a location one inch medial and obliquely inferior to the first. The ground electrodes were affixed to the skin overlying the most distal ipsilateral rib.

Preparation for throwing trial

Once the subject was positioned for throwing, at the center of the appropriately calibrated camera system, the subject was asked to throw a standard youth-rated baseball a distance of 40'. Each of the five throws was to be a fastball, thrown at "game intensity" with an effort to throw a strike pitch. This process was to allow the participant to become acquainted with the sensation of throwing under this unique condition. No recording was conducted at this stage.

Throwing trial

During the throwing trial stage, each participant was asked to throw five separate fastball pitches at game intensity at a distance of 40'. They were asked to attempt to throw a strike pitch each time. The participant was asked to wait between pitches until the recording equipment was initiated and given the instruction to begin.

Data preparation

Only the 39 throws in which a complete data set was acquired were retained for analysis. Data was then exported to a spreadsheet and

analyzed using a unique program written specifically for this investigation using Python.

Computing the X-angle as a function of time was accomplished by projecting the thorax vector and pelvic vector downward into a plane. Using the X and Y coordinates from both acromioclavicular reflectors, the vector defining the orientation of the thorax was calculated. Using the resulting X and Y coordinates from both iliac crest reflectors, the vector defining the orientation of the pelvis was calculated. The X-angle is determined by the dot product between these two vectors, namely, $ACCOS\ (\vec{AC} \bullet \vec{P}\ /\ |\vec{AC}||\vec{P}|)$ Attention was paid to the domain of the ACCOS function.

▶ **Fig. 1** depicts the X-angle from a superior orientation. Within this figure the orientation of the body segments represent a right arm dominant thrower nearing the end of the cocking phase. The term X-angle originates from the angle in the shape of an X formed by the inter-iliac crest line and the inter-acromioclavicular line.

Neuromuscular activity was processed through the BioMonitor ME6000 (Mega Electronics, New Brunswick, NJ, USA) at a sampling rate of 1000 Hz before wirelessly transmitting data to the Qualysis Tracker Manager software for subsequent analysis (Qualysis, version 2.12). Amplitude of neuromuscular activity was recorded at each sampling point throughout each throw. The time at which each of the external oblique muscles achieved its maximum electrical amplitude was recorded.

Initiation of kinematic and neuromuscular data collection was synchronized by employing the Qualysis trigger. This mechanism initiated both high speed videography and sEMG data sampling, ensuring that measures of neuromuscular activity and X-angle position represent two behaviors that occurred at the same moment. In order to ensure that each throw was set to a uniform timeframe, the pitch was considered initiated at the point of lead foot highest elevation. Data was filtered so that once the pitch was initiated, data collection time was set to zero and only data that was recorded after that point was considered.
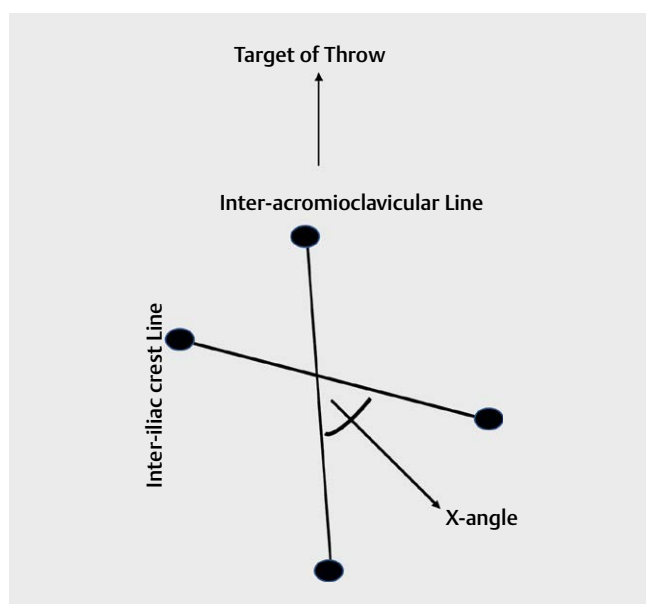
▶**Fig. 1** Illustration depicting the X-angle from a superior orientation.

Drawing upon the kinetic chain model of throwing [4], we theorized that optimal neuromechanical integration would be characterized by a distinctive sequence of peak neuromuscular activation relative to the attainment of the $X_{max\ angle}$. Specifically, it was expected that the glove-side external oblique peak activation (GEOPA) would occur prior to the attainment of the $X_{max\ angle}$, and the throwing-side external oblique peak activation (TEOPA) would occur after the attainment of the $X_{max\ angle}$ at the initiation of what is commonly referred to as the acceleration phase of throwing.

Statistics

Descriptive statistics were utilized in order to describe the subjects and the sample's mean height and weight and standard deviation. This category of statistic was also used to describe the sample's mean magnitude of the $X_{max\ angle}$ and standard deviation.

In order to test each of the hypotheses, the dependent sample t-test was utilized. This statistic facilitates determination of significant differences in time for sample mean time of GEOPA, sample time of TEOPA, and sample mean time of $X_{max\ angle}$.

Results

Examination of the X-angle revealed that the mean $X_{max\ angle}$ for the 39 total throws ranged from a minimum of 23.63 degrees to a maximum of 74.08 degrees. The mean $X_{max\ angle}$ was 45.96 degrees (±10.83) (▶**Table 3**).

Surface electromyographic data was analyzed to determine if there was a significant time differential between the time of GEOPA and the time of TEOPA. A dependent sample t-test demonstrated a non-significant difference between these measures, mean GEOPA (M = 2.3653 seconds, SD = 0.9094) and mean TEOPA (M = 2.3658 seconds, SD = 0.8978, t(38) = −0.0296, p > 0.01). The hypothesis stating that the GEOPA and TEOPA would occur at different moments within the throwing motion was refuted.

A second dependent sample t-test was utilized in order to evaluate the hypothesis that the GEOPA would occur prior to the attainment of the $X_{max\ angle}$. Results demonstrated a significant difference in time between these two points, mean GEOPA (M = 2.3653 seconds, SD = 0.9094) and time at $X_{max\ angle}$ (M = 2.2793 seconds, SD = 0.9026, t(38) = 4.4103, p < 0.01). However contrary to the hypothesis, within this sample it was revealed that the GEOPA occurred after the attainment of the $X_{max\ angle}$. Therefore this hypothesis was refuted.

To test the hypothesis specifying that the TEOPA would occur following the time at which the $X_{max\ angle}$ is attained was examined using a dependent sample t-test. Results demonstrated a significant difference between the time at which mean TEOPA occurred (M = 2.3658 seconds, SD = 0.8978) and the time at which the $X_{max\ angle}$ was observed (M = 2.2793 seconds, SD = 0.9026, t(38) = 6.2754, p < 0.01). This difference in time is in the expected direction and therefore this hypothesis was confirmed (▶**Table 4**).

Discussion

Within this investigation the mean $X_{max\ angle}$ was determined to be 45.96 ° (±10.83), which is very similar to the 50.1 ° (±6.9) previously reported for youth pitchers [13]. It is also similar in magni-

▶ **Table 3** Mean values and standard deviations for each dependent variable.

Maximum X-Angle	Time at GEOPPA	Time at TEOPPA	Time at maximum X-angle
45.96 ± 10.83 degrees	2.3653 ± 0.9094	2.3658 ± 0.8978	2.2793 ± 0.9026

▶ **Table 4** Results for three dependent sample t-tests. Time of peak point of activation glove-side and throwing-side external obliques (GEO PPA & TEO PPA). Time of maximum X-angle.

Measure	Mean Difference	Std. Deviation	Std. Error Mean	t-value	df	p (2-tailed)
GEOPPA – TEOPPA	−0.00006	0.1266	0.0203	−0.0296	38	p > 0.01
GEOPPA – Max X-angle	0.086	0.1218	0.0195	4.4103	38	p < 0.01
TEOPPA – Max X-angle	0.0866	0.0863	0.0138	6.2754	38	p < 0.01

tude when compared against the maximum angulation reported for high school pitchers 54.9° (± 9.1), college pitchers 51.5° (± 8.2), and professional pitchers 49.9° (± 5.2) and 55° (± 6) [12, 13]. While the magnitude of these angles are all rather similar, when viewed in light of the rather high deviations associated with these magnitudes, there does not appear to be a discernable improvement as pitching level rises.

Within this proximal-to-distal model of throwing, it is expected that prior to achieving throwing arm load position during the cocking phase, there would first be an independent angular motion of the pelvis followed by the thorax. To establish a maximal angulation between the pelvis and thorax requires glove-side external oblique muscular force to hold the thorax within the original position while the pelvis rotates toward the intended target. Results from this investigation suggest that children do not exhibit this level of refined motor control. Data presented here indicate that the GEOPA is achieved significantly after attainment of the $X_{max\,angle}$. The inability to coordinate maximum activation of the glove-side external oblique earlier in the pitch cycle indicates that the thoracic segment will retain its original stationary position briefly until the initial elongation of passive anatomic structures connecting these segments. High-magnitude muscle activation occurring earlier in the pitch cycle of the glove-side external oblique may serve to increase the magnitude of the $X_{max\,angle}$ by delaying the initiation rotation of the thoracic segment. By delaying this rotation, a greater pre-stretch of the throwing-side external oblique may facilitate higher resulting muscular forces acting to accelerate the thoracic segment through a greater arc of motion.

To achieve maximal thoracic angular velocity within the transverse plane, there must be a reciprocal contraction–relaxation cycle between the antagonistic external oblique muscles. Within this investigation this assumption was refuted. The difference in time for both GEOPA and TEOPA was non-significant and occurred following attainment of the $X_{max\,angle}$ as the thoracic segment initiated its angular rotation within the cocking phase. This indicates that the muscular force intended to facilitate the acceleration of thoracic rotation was inhibited by bilateral co-contractions of the external oblique muscles.

One purpose of organized youth league sporting activity must be to instruct participants in the skills and techniques that are required for safe and effective participation. Results of this investigation provide initial indication that children do not intrinsically possess the capacity for effective neuromechanical integration within the core of the body during the activity of throwing. We encourage youth league coaches, parents, physicians, and rehabilitation professionals to examine the ability of their athletes and patients to passively and actively rotate the thorax independently of the pelvis. Furthermore, we encourage youth league coaches and exercise professionals to integrate instruction so that optimal pelvo-thoracic rotation occurs prior to proximal arm acceleration. Finally, we urge additional future investigations that may illuminate this potential risk factor for throwing arm injury in sport.

Conflict of Interest

The authors declare that they have no conflict of interest.

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