Overarm Throwing Variability as a Function of Trunk Action

M. A. Urbin, David Stodden, and Glenn Fleisig

Individual body segment actions evolve during throwing skill development. Maximal trunk involvement is typically the last feature of the movement pattern to fully develop. The current study examined developmental levels of trunk action and the associated variability in the throwing motion. The throwing motions of children and adolescents were analyzed via motion capture and trunk actions were classified as exhibiting no rotation \((n = 7)\), blocked rotation \((n = 6)\), or differentiated rotation \((n = 11)\). Results indicated nonrotators exhibited greater variability than blocked-rotators in maximum humeral external rotation and humeral horizontal adduction angles at ball release; nonrotators also demonstrated greater variability than differentiated-rotators on these parameters, in addition to forward trunk tilt and elbow extension angle at ball release. Nonrotators produced more variable peak upper torso and humeral horizontal adduction angular velocities, as well as peak upper torso linear velocity, relative to differentiated-rotators. Blocked-rotators produced more variable peak pelvis, upper torso, and humeral horizontal adduction angular velocities, as well peak pelvis linear velocity, relative to differentiated-rotators. Nonrotators were less consistent relative to blocked- and differentiated-rotators in the time that elapsed from peak pelvis angular velocity to ball release. These results indicate that greater trunk involvement is associated with more consistent movement production.

**Keywords**: coordination, motion capture, motor development, motor control

The overarm throw is a kinetic chain of events that complies with the summation of speed principle (Bunn, 1972; Putnam, 1991). This principle holds that each body segment makes a contribution to the throwing motion that is not independent of other segments (Neal, Snyder, & Kroonenberg, 1991). In essence, angular momentum can be transferred through the skeletal linkage to the projectile when the timing of body segment rotations is effective. Though kinetic chain principles can be exploited when only two body segments are involved (Alexander, 1991; Chowdhary & Challis, 2001), a thrower’s ability to exploit these principles with all of the appropriate body segments is intimately tied to motor skill development (Alexander, 1991; Langendorfer & Robertson, 2002; Southard, 2002, 2009; Stodden, Langendorfer, Fleisig, & Andrews, 2006a,b).

Researchers have examined trends in throwing skill development using the component approach (Roberton & Halverson, 1984), which categorizes the action of individual segments in the overall spatiotemporal patterning of the throw. For example, the action of the trunk can be categorized as having no rotation or anterior-posterior sway, indicating a less developmentally advanced action. More developmentally advanced trunk actions can be characterized as having blocked or differentiated rotation of the pelvis and upper torso. Accordingly, these categorizations reflect a continuum of kinetic chain exploitation, providing insight into throwing skill development. Given the various combinations of segmental actions that can potentially appear during skill development, the component approach captures variations that may not be accounted for using a whole-body approach (Roberton, 1978). This approach has been used in analyses of both children and adult throwers (Roberton, Halverson, Langendorfer, & Williams, 1979; Williams, Haywood, & van Sant, 1998) and accounts for 85% of the variance in ball speed (Roberton & Konczak, 2001). Kinematic analyses have indicated that individual body segment actions classified with the component approach discriminate quantitative differences in the associated action (Stodden et al., 2006a, 2006b), suggesting that the component approach is a valid method for evaluating throwing skill development.

Longitudinal inquiring into throwing skill development using the component approach indicates there is considerable interindividual variation in the acquisition of a developmentally advanced movement pattern (Langendorfer & Robertson, 2002). Stated another way, there is no one common pathway observed in the progression of skill development. Nevertheless, the most developmentally advanced component trunk action tends to be
the last feature to appear and is thought to constrain the component action of more distal body segments. The kinetic chain is an open system of skeletally linked body segments with the trunk serving as the fixed base about which the more distal segments rotate (Southard, 2009). Therefore, from a theoretical standpoint, the action of the trunk should also have some impact on spatiotemporal fluctuations occurring late in the throwing motion.

Variability in the context of overarm throwing skill development is not well understood. Previous research has examined kinematic variability between baseball pitchers of different competition levels and found that youth pitchers tend to exhibit the greatest variability (Fleisig, Chu, Weber, & Andrews, 2009). A similar investigation of throwing techniques used by handball players with different training experience demonstrated that the magnitude of variability associated with the jump throw and standing throw without a run-up was similar among skill groups (Wagner, Pfusterschmied, Klous, Serge, & Müller, 2012). However, the low-skilled group was found to exhibit more variability during the standing throw with a run-up.

These studies provide meaningful insight into variability and its association with competition level and training experience, but they do not directly explain variability as it relates to differences in coordination that emerge as a function of skill development. The inclusion of individuals competing at different levels and with different training experience is generally a reflection of skill, but throwing skill development is not directly captured by these criteria. This view is supported by the trunk action exhibited by youth pitchers in the Fleisig et al. (2009) study. Though youth pitchers may be considered lesser skilled relative to higher competition levels (e.g., high school, collegiate, professional), the sample of youth league pitchers exhibited the most developmentally advanced trunk action (i.e., differentiated rotation). This observation underscores the arbitrary nature of competition level and experience as indexes of throwing skill development. A deeper understanding of skill-related trends in performance variability may be ascertained by establishing a link between variability in the throwing motion and valid measures of skill development. A deeper understanding of skill-related trends in performance variability may be ascertained by establishing a link between variability in the throwing motion and valid measures of skill development. Understanding whether intrtrial variation is influenced by the amount of trunk involvement is theoretically appealing for two reasons. First, a more skillful throwing pattern is characterized by more trunk involvement, whereas a less skillful pattern is characterized by less trunk involvement. Second, the action of the trunk is thought to constrain the component action of more distal body segments.

A sound theoretical framework in which to interpret trends in variability is as necessary as establishing such trends. For many years, developmentalists have argued that variability around a transition is a prerequisite for acquiring more evolved motor repertoires (Thelen & Corbetta, 1994). According to this view, a fully developed throwing motion is acquired through repeated production of different movement characteristics and experimenting with different musculoskeletal organizations (Goldfield, Kay, & Warren, 1993). However, in the context of a high-speed, whole-body movement such as maximal-effort overarm throwing, exploration may be limited to early movement characteristics involving the lower-extremities and trunk. Though the sequence of body segment rotations is not as sequentially distinct in a less developed throwing motion, the action of the trunk precedes the respective actions of more distal body segments. Since the trunk action can affect the inertial constraints of distal segments, exploration of different lower-extremity and trunk configurations also may influence the variability of these segmental trajectories. To address these possibilities, the current investigation analyzed the throwing motions of children and adolescents exhibiting different component trunk actions. It was hypothesized that throwers with greater trunk involvement would exhibit significantly less variability in positional, peak velocity, and temporal kinematic parameters relative to throwers with less trunk involvement.

Methods

Kinematic data were collected from the throwing motions of 24 children and adolescents in an indoor laboratory at the American Sports Medicine Institute, in Birmingham, Alabama. Each participant and his/her legal guardian provided informed assent and consent before participation. Next, 1.0-cm diameter reflective markers were placed bilaterally on the distal end of the third metatarsal, lateral malleolus, lateral femoral epicondyle, greater trochanter of the femur, lateral tip of the acromion, lateral humeral epicondyle, and ulnar styloid (Figure 1). A reflective marker was also placed on the radial styloid of the throwing hand. Participants were then guided through a dynamic stretch routine of the upper and lower extremities followed by a self-selected number of warm-up throws. Participants were instructed to throw “as hard as you can” for each throw to a framed net (2 m length × 2 m width) approximately 18 m away. Reducing the distance between the net and some of the children participants was necessary to provide a more developmentally appropriate task constraint.

Twelve adolescents with pitching experience (M age =13.3 ± 1 years; all male) threw baseballs (mass = 150 g, diameter = 6.3 cm) from a mound. The remaining participants (M age =7.2 ± 2.4 years; 8 female, 5 male) lacked experience throwing a baseball from a mound. Therefore, these participants threw tennis balls (mass = 63 g, diameter = 6.0 cm) from flat ground. Previous research has indicated there are minimal differences in kinematics characteristics of the throwing motion when throwing balls of different masses (Fleisig et al., 2006) and throwing from a mound or flat ground (Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews, 2011). In addition, according to motor learning principles, task novelty is associated with increased performance variability (Fitts & Posner, 1967). Therefore, it was necessary to scale task constraints to ensure that ball mass and throwing surface were typical for adolescents and developmentally appropriate for
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612.0x792.0

children. These conditions were held constant across all of the throws analyzed for each participant.

Six synchronized cameras (Motion Analysis, Corp Santa Rosa, CA) tracked the reflections of markers at a frequency of 240 Hz. The orientation of each camera was optimized to capture the entire throwing motion. Raw coordinate data were digitally filtered with a 13.4-Hz Butterworth low-pass filter. Positional and peak velocity kinematic parameters were calculated based on previously described procedures (Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998). Ball speed was recorded from a radar gun (JUGS Inc. Tulatin, OH). These parameters were chosen because they are performance-related features of the throwing motion (Barrentine, Fleisig, Whiteside, Escamilla, & Andrews, 1998; Fleisig et al., 2009; Stodden, Fleisig, McLean, & Andrews, 2005; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001). Three of the four positional kinematic parameters were referenced at the time of ball release: forward trunk tilt relative to the horizontal plane, elbow extension angle, and humeral horizontal adduction angle. The remaining positional parameter was the maximum angle of humeral external rotation. Ball speed and eight velocity parameters were examined, including peak angular and linear velocities of the pelvis and upper torso, as well as peak angular velocities of humeral horizontal adduction, humeral internal rotation, and elbow extension associated with the throwing arm. In addition, the time between peak pelvis angular velocity and ball release was calculated.

The trunk action for each throw was analyzed qualitatively via sagittal- and rear-view digital video recordings (60 Hz) of the throwing motion. Trunk action was scored by two independent raters with the developmental sequence for the component trunk action of the overarm throw (Roberton & Halverson, 1984). Level 1 was recorded if no trunk twist preceded the arm movement, or if there was flexion/extension of the trunk (i.e., non-rotator). Level 2 was recorded if the pelvis and upper torso simultaneously rotated in the throwing direction as one unit (i.e., blocked-rotator). Level 3 was recorded if the pelvis rotated in the throwing direction while the upper torso simultaneously rotated away from the throwing direction (i.e., differentiated-rotator). Interrater and intrarater objectivity was established using the proportion of agreement adjusted for chance (Safrit & Wood, 1995). The kappa coefficient for interrater and intrarater objectivity was $k = 0.92$ and $k = 0.96$, respectively. Participants were grouped according to trunk action for data analysis: nonrotators ($n = 7$, $M$ age = 6.4 ± 2.1 years; 7 females; height = 120.8 ± 15.3 cm; mass = 26.2 ± 7.6 kg); blocked-rotators ($n = 6$, $M$ age = 8.1 ± 2.6 years; 5 males, 1 female; height = 131.5 ± 12.1 cm; mass = 28.1 ± 5.7 kg); differentiated-rotators ($n = 11$, $M$ age = 13.3 ± 1.0 years; 11 males; height = 169.1 ± 10.2 cm; mass = 54.9 ± 9.1 kg). Qualitative analyses indicated that trunk developmental level remained constant across each of the five throws for all participants.

For each participant, the standard deviation of each parameter was calculated to provide an index of the overall magnitude of variability and entered into analysis. The use of five trials is consistent with previous research examining variability between throwers on similar kinematic parameters (Fleisig et al., 2009). Multivariate analysis of variance (MANOVA) was used to evaluate variability between groups on kinematic positional and velocity parameters. Correlation matrices of parameters contained in each MANOVA indicated correlations were between .2 and .7. Thus, the assumption of multicollinearity was not violated. Pillai’s trace was the test statistic used because it is the most conservative test, and it is robust when sample sizes are small (Tabachnick & Fidell, 2001). Bonferroni (two-tail) post hoc tests were used to correct for multiple comparisons. Analysis of variance (ANOVA) was used to examine variability in the overall time between stride-foot contact and ball release. Significance for all analyses was set at the .05 level.

**Results**

The MANOVA for kinematic positional parameters was significant [$F(8, 38) = 4.030, p = .002, \eta^2 = .459$]. Descriptive statistics for positional parameters are contained in Table 1. All four parameters contributed significantly to the model: forward trunk tilt angle at ball release.
\[ F(2, 21) = 4.472, p = .024, \eta^2 = .299 \]; elbow angle at ball release \[ F(2, 21) = 11.718, p < .001, \eta^2 = .527 \]; humeral horizontal adduction at ball release \[ F(2, 21) = 33.264, p < .001, \eta^2 = .760 \]; and maximum humeral external rotation \[ F(2, 21) = 21.668, p < .001, \eta^2 = .764 \]. Bonferroni post hoc test indicated: nonrotators were more variable than differentiated-rotators in forward trunk tilt angle at ball release \( p = .022 \), elbow angle at ball release \( p < .001 \), humeral horizontal adduction angle at ball release \( p < .001 \), and maximum humeral external rotation \( p < .001 \). In addition, nonrotators were more variable than blocked-rotators in humeral horizontal adduction at ball release \( p < .001 \) and maximum humeral external rotation \( p = .001 \).

The MANOVA for kinematic peak velocity parameters was significant \[ F(16, 30) = 8.269, p < .001, \eta^2 = .815 \]. Descriptive statistics for peak velocity parameters are contained in Table 2. Post hoc tests indicated that the following parameters contributed significantly to the model: peak pelvis angular velocity \[ F(2, 21) = 10.514, p = .001, \eta^2 = .500 \]; peak pelvis linear velocity \[ F(2, 21) = 3.820, p = .038, \eta^2 = .267 \]; peak upper torso angular velocity \[ F(2, 21) = 16.044, p < .001, \eta^2 = .604 \]; peak upper torso linear velocity \[ F(2, 21) = 4.835, p = .019, \eta^2 = .315 \]; and peak humeral horizontal adduction angular velocity \[ F(2, 21) = 11.582, p < .001, \eta^2 = .524 \]. Bonferroni post hoc test indicated: blocked-rotators were more variable than differentiated-rotators \( p = .001 \) in peak pelvis angular velocity; differentiated-rotators were less variable than nonrotators \( p < .001 \) and blocked-rotators \( p = .022 \) in peak upper torso angular velocity; differentiated-rotators were less variable than nonrotators \( p = .001 \) and blocked-rotators \( p = .015 \) in peak humeral horizontal adduction angular velocity; blocked-rotators were more variable than differentiated-rotators \( p = .042 \) in peak pelvis linear velocity; nonrotators were more variable than differentiated-rotators \( p = .008 \) and differentiated-rotators \( p < .001 \).

### Table 1 Mean and Mean Standard Deviation for Positional Parameters by Trunk Action

<table>
<thead>
<tr>
<th></th>
<th>No rotation</th>
<th>Blocked rotation</th>
<th>Differentiated rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward trunk tilt (°)</td>
<td>17.4 ± 6.4*</td>
<td>5.0 ± 4.4</td>
<td>32.9 ± 2.5</td>
</tr>
<tr>
<td>Elbow extension angle (°)</td>
<td>91.7 ± 20.7*</td>
<td>84.5 ± 11.9</td>
<td>37.3 ± 3.0</td>
</tr>
<tr>
<td>Horizontal add (°)</td>
<td>35.4 ± 15.6†</td>
<td>32.1 ± 4.7</td>
<td>10.2 ± 1.3</td>
</tr>
<tr>
<td>External rot (°)</td>
<td>142.6 ± 14.2*†</td>
<td>148.4 ± 5.2</td>
<td>179.9 ± 2.4</td>
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</tbody>
</table>

* Significant difference relative to differentiated rotation.
† Significant difference relative to blocked rotation.

### Table 2 Mean and Mean Standard Deviation for Peak Velocity Kinematic Parameters by Trunk Action

<table>
<thead>
<tr>
<th></th>
<th>No rotation</th>
<th>Blocked rotation</th>
<th>Differentiated rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis (m/s)</td>
<td>0.5 ± 0.1</td>
<td>1.1 ± 0.2*</td>
<td>2.0 ± 0.1</td>
</tr>
<tr>
<td>Upper torso (m/s)</td>
<td>0.9 ± 0.3*</td>
<td>1.2 ± 0.2</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Pelvis (°/s)</td>
<td>202.5 ± 48.1</td>
<td>473.7 ± 70.0*</td>
<td>606.5 ± 26.0</td>
</tr>
<tr>
<td>Upper torso (°/s)</td>
<td>391.0 ± 93.5*</td>
<td>780.5 ± 64.6*</td>
<td>1037.6 ± 28.2</td>
</tr>
<tr>
<td>Humeral hor. adduction (°/s)</td>
<td>383.9 ± 129.7*</td>
<td>532.7 ± 105.6*</td>
<td>551.3 ± 41.5</td>
</tr>
<tr>
<td>Elbow extension (°/s)</td>
<td>1281.9 ± 204.9</td>
<td>1573.3 ± 131.3</td>
<td>2224.8 ± 119.6</td>
</tr>
<tr>
<td>Humeral internal rotation (°/s)</td>
<td>2293.7 ± 484.3</td>
<td>3580.5 ± 360.0</td>
<td>6928.8 ± 517.8</td>
</tr>
<tr>
<td>Ball (m/s)</td>
<td>8.2 ± 0.9</td>
<td>13.1 ± 1.0</td>
<td>28.8 ± 0.5</td>
</tr>
</tbody>
</table>

* Significant difference relative to differentiated rotation.
† Significant difference relative to blocked rotation.
Accordingly, the intent to throw at a specific percentage of throwing coordination (Southard, 2002; 2009) and percentages of maximum effort influences the stability of maximum may act as a control parameter that induces change in the movement pattern. Participants in the current study were instructed to throw at maximum effort. The increased variability in each primitive form of trunk rotation, therefore, may reflect an exploration of different strategies to increase trunk involvement and, in turn, maximize ball speed. If this view is accurate, the results of the current study indicate there may be an ordered, serial transition from no rotation to blocked rotation followed by blocked rotation to differentiated rotation. In essence, the transition from no rotation to blocked rotation may be characterized by increased variability in the linear and angular velocities of the pelvis. Differentiated trunk rotation is achieved when the performer acquires the ability to forcefully rotate the pelvis allowing the upper torso to lag behind. The variability blocked-rotators exhibit in peak pelvis linear and angular velocity also may explain the variability that results in peak upper torso angular velocity later in the kinetic chain as upper torso movement becomes more dependent on pelvis movement.

Just as the angular acceleration of the pelvis causes the upper torso to lag behind when trunk rotation is differentiated, lag is also observed in the action of the humerus relative to the upper torso (Hong, Cheung, & Roberts, 2001). As such, kinematic characteristics of the upper extremity segments are influenced by the angular velocity of the upper torso and the motion-dependent inertia of upper extremity mass (Stodden et al., 2006b). Differentiated-rotators were significantly more consistent in producing peak humeral horizontal adduction angular velocity relative to both nonrotators and blocked-rotators. However, nonrotators were more variable in the humeral horizontal adduction angle at the time of ball release relative to both blocked- and differentiated-rotators. The fact that blocked-rotators were not more variable than differentiated-rotators in this regard, despite exhibiting more variability in the peak velocity of this joint action, is a curious finding. A similar finding was observed in elbow extension angle at ball release. Though nonrotators exhibited greater variability in this angle at ball release, there were no group differences in the variability of peak elbow extension angular velocity. Collectively, these findings suggest that variations in rotational velocities of

<table>
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<tr>
<th>Table 3 Mean and Mean Standard Deviation for the Time Elapsing Between Peak Pelvis Angular Velocity and Ball Release by Trunk Action</th>
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</thead>
<tbody>
<tr>
<td>No rotation</td>
</tr>
<tr>
<td>Peak pelvis angular velocity—ball release (msec)</td>
</tr>
</tbody>
</table>

* Significant difference relative to differentiated rotation.
† Significant difference relative to blocked rotation.

Discussion

The purpose of this study was to examine the magnitude of variability in various kinematic features of the throwing motion as a function of trunk involvement. The findings indicate that greater trunk involvement is associated with more consistent movement production, supporting the overall hypothesis. For clarity, the differences observed between groups in the throwing parameters analyzed will be discussed in the order they appear during the throwing motion.

Pelvis and upper torso linear velocities are the initial source of momentum in the throwing motion that can augment the angular velocities of the pelvis and upper torso if the timing of each rotation is effective. Results of the current study indicate that differentiated-rotators were more consistent in producing these peak velocities. Nonrotators exhibited greater variability in peak linear and angular velocities of the upper torso. Blocked-rotators were more variable in generating peak linear and angular velocities of the pelvis, as well as upper torso angular velocity. The coexistence of increased variability in the linear and angular velocities of the same trunk segment in each respective form of trunk rotation may be accounted for by the physics associated with the throwing motion and theory surrounding motor skill development.

Differentiation of the trunk action is due to the initial rotation of the pelvis and the combined mass of the upper torso and throwing arm resisting angular motion in throwing direction. The forceful rotation of the pelvis in the throwing direction as the upper torso rotates away causes the trunk musculature to be eccentrically loaded. This dynamic loading promotes storage and recovery of elastic energy as the upper torso rotates in the throwing direction (Stodden et al., 2006a). The results of the current study suggest this form of trunk rotation is associated with more consistent movement production. A thrower’s ability to exhibit differentiated trunk rotation is a developmental phenomenon, and instability in coordination signals a transition into a more evolved movement pattern (Goldfield et al., 1993; Thelen & Corbetta, 1994). Previous research has demonstrated that performing throws at different percentages of maximum effort influences the stability of throwing coordination (Southard, 2002; 2009) and ball speed (Urbin, Stodden, Boros, & Shannon, 2012). Accordingly, the intent to throw at a specific percentage of maximum may act as a control parameter that induces change in the movement pattern.
the trunk induced variability in the velocity of this joint action without affecting variations in its position at the time of ball release.

Differentiated-rotators were more consistent in achieving maximum humeral external rotation compared with both nonrotators and blocked-rotators. Relatively greater kinetic energy is transferred to the upper extremity when the trunk action is maximized. Greater energy transfer contributes to the extreme range of motion at the glenohumeral joint in elite level throwers (≥180°; Werner, Fleisig, Dillman, & Andrews, 1993) and is produced via high inertial loading characteristics of the forearm when the elbow is flexed at approximately 90° (Escamilla & Andrews, 2009). Thus, the passive mechanisms stemming from more trunk involvement may lead to more consistent maximum humeral external rotation.

Nonrotators were more variable in forward trunk tilt angle at the time of ball release. Increased ball speed is associated with greater trunk tilt in elite-level throwers (Stodden et al., 2005). Though it could be argued that negative acceleration of the pelvis upon stride-foot contact causes the trunk to flex passively, there is likely some active shortening of the trunk musculature leading to more tilt. Minimal data are available on trunk muscle activity patterns during the throwing motion. However, the existing data indicates that the rectus abdominis musculature reaches its peak activity just before ball release (Hirashima, Kadota, Sakurai, Kudo, & Ohtsuki, 2002). It is, therefore, possible that the variability of forward trunk tilt at the time of ball release in the differentiated-rotators is not exclusively associated with the passive mechanisms attributed to the previously discussed parameters.

Finally, nonrotators were significantly more variable than both blocked- and differentiated-rotators in the overall time from peak pelvis angular velocity to ball release. This finding suggests that when the trunk is more involved in the throwing motion, more energy is transferred up the kinetic chain, resulting in greater temporally stability of upper torso and distal joint rotations. These findings appear compatible with previous research that indicates less-developed throwers exhibit greater variability in the upper torso and distal joint rotations. These findings in the throwing motion, more energy is transferred up the kinetic chain reaching its peak activity just before ball release (Hirashima, Kadota, Sakurai, Kudo, & Ohtsuki, 2002). It is, therefore, possible that the variability of forward trunk tilt at the time of ball release in the differentiated-rotators is not exclusively associated with the passive mechanisms attributed to the previously discussed parameters.

In conclusion, the findings of the current study indicate that maximal trunk involvement is associated with more consistent movement production. Trunk involvement occurs on a continuum that may not be fully captured by the three ordinal classifications used in the current study. However, these classifications represent the general developmental progression of a thrower’s ability to dynamically integrate the trunk in the throwing motion. The enhanced consistency associated with a more developmentally advanced trunk action appears to be linked to the passive transfer of momentum stemming from greater trunk rotation. From a performance perspective, focusing on the development of trunk action may be advantageous for promoting the integration and consistency of distal body segment actions that occur late in the kinetic chain (Stodden, 2006).

References


Erratum: Urban, Stodden, & Fleisig (2013)

In Table 2, nine values were incorrectly listed. The first two rows (Pelvis, Upper torso) and the last row (Ball) listed incorrect values in three columns (No rotation, Blocked rotation, Differentiated rotation). The correct values have now been placed. In Table 3, the unit was incorrectly listed as m/s and should be msec. Additionally, the three values contained erroneous zeros. All items have been corrected.