THE RELATIONSHIP BETWEEN ANGULAR MOMENTUM OF THE LOWER TRUNK AND SHOULDER JOINT FORCES DURING AN OVERARM THROW

Kevin Moore, Suzanne Konz, Mark Timmons, Steven Leigh

School of Kinesiology, Marshall University, Huntington WV, USA

The proximal-to-distal transfer of force through the kinetic chain in overarm throwing has well-established movements. The nature of the transfer of momentum from the lower trunk to the shoulder during an overarm throw remains to be determined. This study explored the association between angular momentum about the superior-inferior axis of the lower trunk and compressive and anterior shear forces at the shoulder in experienced baseball players as they made maximum effort throws from the outfield. We found no association between the maximum lower trunk angular momentum during the arm cocking phase and shoulder joint anterior shear force at ball release (r = 0.149, p = 0.244, 95% CI [0.165, 0.133]) or shoulder joint compressive force at ball release (r = 0.222, p = 0.149, 95% CI [0.226, 0.218]). Even experienced athletes may be inefficient at transferring momentum.

KEYWORDS: throwing, trunk, shoulder, angular momentum, shear.

INTRODUCTION: Baseball players try to optimize ball velocity while minimizing injury risk by moving efficiently. During the overarm throw, athletes utilize the kinetic chain to generate and transfer force from the lower body to the upper body in a proximal-to-distal sequence (Feltner & Dapena, 1989; Hirashima et al., 2008). The force transmission process begins with the generation of a ground reaction force between the push-off foot and the ground (MacWilliams et al., 1998). The push-off foot directs this ground reaction force in the anterior direction, where the landing foot then contacts the ground and supplements with additional ground reaction force. These transmitted ground reaction forces act on the lower extremities to increase their momentum (MacWilliams et al.,1998; Young et al., 1996). The anteriorly directed linear momentum is transferred through the lower trunk which rotates about a superior-inferior axis, generating angular momentum (Young et al., 1996). Since torque is the time derivative of angular momentum, there is a direct relationship between the increase in angular momentum of the proximal lower trunk and the rotational force (torque) of the corresponding distal shoulder joint (Hirashima et al., 2008; Oliver, 2014). Along the kinetic chain, trunk rotation movements are associated with greater shoulder torques (Hirashima et al., 2008; Oliver, 2014). Trunk flexion and rotation movements have also been identified as one of the key contributors to elbow torque and ball velocity, further exemplifying the trunk's association to movements of the throwing arm (Aguinaldo & Escamilla, 2019; Cohen et al., 2019).

The general sequence of movements of the kinetic chain for overarm throwing is well-established. The precise relationship between the change in angular momentum at the lower trunk and the force at the shoulder remains to be determined. Generating force in the large musculature of the lower body and transmitting it to the upper body should be more efficient than relying on the smaller or less stable upper extremities to develop and control throwing forces. The transfer of force from the lower body to the upper body occurs through the trunk, as the trunk transfers the force from the lower body to the shoulder via trunk rotation and flexion movements. Determining this key relationship of the kinetic chain for overarm throwing and evaluating its efficiency will help us better understand how overarm throwing athletes can optimize ball velocity while minimizing injury risk. The purpose of this study, therefore, was to explore the relationship between the maximum angular momentum of the lower trunk and the throwing shoulder joint resultant compressive and shear forces during the overarm throwing motion of baseball athletes. We hypothesized that there would be a negative correlation between the maximum angular momentum about the superior-inferior axis of the lower trunk (during arm cocking phase) and both the compressive, and anterior shear force at the shoulder joint (at ball release) during the baseball overarm throwing motion.

METHODS: Twenty-four experienced, male baseball players (age: 22.8 ± 3.6 years, height: 1.83 ± 0.07 meters, mass: 90.3 ± 13.9 kg, experience: 14.5 ± 4.2 years, 10 position players and 14 pitchers) were recruited to participate in this study, whose protocols were approved by the Marshall University IRB. Subjects were tested on a grass baseball field or indoor practice facility while wearing tight-fitting clothing. Following a self-selected warm-up protocol, each subject executed three maximum effort crow-hop throws with a regulation baseball from flat ground to a target located 36.58 meters (120') away to replicate a position player throw.

All throws were recorded with two Sony RX10iii video cameras (Sony, Tokyo, Japan) at 59.94 frames/second, one camera to the throwing arm side and one camera behind the subject. The angle between the optical axes of the two cameras was approximately 90°. A 36-point control object was positioned to define a capture volume and to calibrate the high-speed cameras' positions and orientations in reference to the capture volume. The control object consisted of four survey poles with nine points per pole of known measurements. A global reference frame was established in the capture volume so that X was forward (the throwing direction), Y was to the left, and Z was up.

Video from both 2-D camera views (back and throwing arm side) of the control object and all throwing trials were digitized with Vicon Motus software (Vicon, Oxford, UK). Thirty-six calibration coordinates were digitized on the four survey poles. Twenty-three anatomical landmark coordinates were digitized at the joints of each subject and ball. The 2-D anatomical landmark coordinates were time synchronized using three instants within the throwing motion (foot contact, max shoulder external rotation, and ball release). The 2-D anatomical landmark coordinates were converted to 3-D landmark coordinates using the Direct Linear Transformation procedure (Abdel-Aziz & Karara, 1971) and the calibration coordinates from the control object in MotionSoft software (MotionSoft LLC., Durham, NC, USA). Limb segment angles, angular velocities, angular accelerations, center of mass coordinates, center of mass accelerations, radius of gyration, lengths, and masses were calculated from the 3-D landmark coordinates and anthropometric data.

The inertia tensor of the lower trunk was computed as the product of 11.17% of the subject's mass and the radius of gyration, which was 58.7% of the segment length of the pelvis (deLeva, 1996). Using a custom MatLab script (Mathworks, Natick, MA), lower trunk angular momentum was calculated as the cross product of the inertia tensor and the angular velocity matrix of the lower trunk segment. The inverse dynamic technique was used to calculate shoulder joint forces from a three-link segment chain of the hand, forearm, and upper arm. The mass and acceleration of the baseball were used to calculate the force input for the distal end of the inverse dynamic equation (Hirashima et al., 2008). The proximal forces at the upper arm were resolved into shear and compressive components using the local reference frame of the upper trunk.

Bivariate correlations were computed using SPSS (IBM, Chicago, IL, USA) to determine the associations between the maximum angular momentum of the lower trunk during the arm cocking phase, the shoulder joint anterior shear force at ball release, and the shoulder joint compressive force at ball release. Statistical significance was set a priori as $\alpha = 0.05$.

RESULTS: There was no correlation between lower trunk maximum angular momentum during the arm cocking phase and shoulder joint anterior shear force at ball release ($r = 0.149$, $p = 0.244$, 95% CI [0.165, 0.133]) (Figure 1). There was no correlation between lower trunk maximum angular momentum during the arm cocking phase and shoulder joint compressive force at ball release ($r = 0.222$, $p = 0.149$, 95% CI [0.226, 0.218]) (Figure 2).

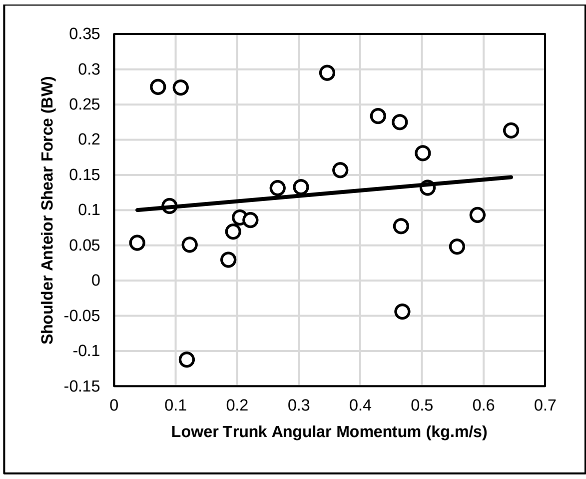

Figure 1: The relationship between lower trunk angular momentum and shoulder joint anterior shear force.

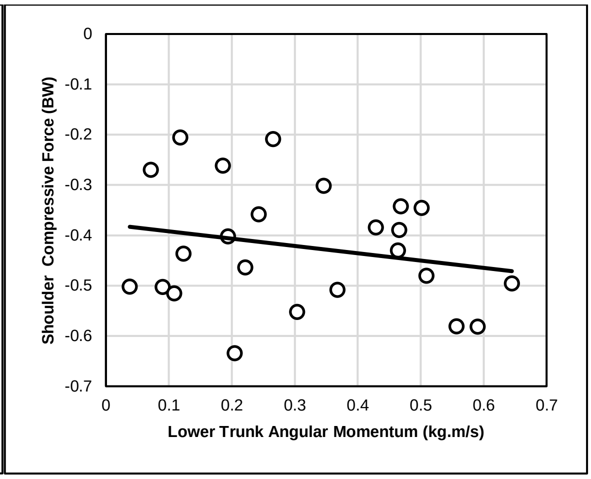

Figure 2: The relationship between lower trunk angular momentum and shoulder joint compressive force.

DISCUSSION: This study did not identify an association between the maximum angular momentum at the lower trunk during the arm cocking phase and the forces at the shoulder joint at ball release. One explanation for the lack of association found between the angular momentum at the lower trunk and the forces at the shoulder joint is the possibility that the subjects in this study were inefficient at transferring momentum between different body segments. It is possible for an athlete to generate a large amount of momentum using the lower trunk but transfer that momentum in a manner that is not directed toward the throwing shoulder. An inefficient transfer of momentum from the trunk to the shoulder can increase the force demand put on the shoulder (Seroyer et al., 2010; Young et al., 1996).
The timing sequence of different body segments is also very important. In the overarm throwing motion, the body segment should begin to move as the adjacent body segment reaches maximum velocity (Putnam, 1993). When the timing sequence is inefficient, it will affect the relationship between the lower trunk and shoulder. The subjects of this study may have moved with improper timing. Research has identified that professional players did not exhibit a large difference in torque at the upper trunk than lower-level athletes, but their timing was different, which occurred later in the arm cocking phase much closer to when the shoulder began to accelerate (Aguinaldo et al., 2007). The improper timing of trunk rotation reduces the transfer of momentum to the shoulder and increases the force applied to the shoulder (Oyama et al., 2014).
The kinetic chain sequence is supported by considerable research. The shoulder and upper arm alone cannot produce the force that is needed to throw a baseball at a high velocity (Fleisig et al., 1995; Roach & Lieberman, 2014). If the shoulder and arm cannot generate the force on their own, then it must come from somewhere else in the body. We examined the variables at discrete instants rather than considering the whole throwing motion and relative timing, which is a limitation of this study. Examining the variables throughout the entire throwing sequence, and determining where they occur in relation to one another, may provide a better representation of the kinetic chain relationship. The focus of this study was limited to baseball position player throwing (long toss throwing), which has some similarities to pitching, but may not be applicable as pitching is a different skill (Fleisig et al., 2011).

CONCLUSION: We did not identify a relationship between the angular momentum of the lower trunk and the resultant forces at the shoulder joint during the overarm throw. These results suggest that even experienced athletes can have inefficiencies in transferring momentum throughout the body. The use of discrete variables to characterize the sequential kinetic chain relationship may not be appropriate.

REFERENCES

Abdel-Aziz, Y. I., Karara, H. M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In *Proceedings of the ASP/UI Symposium on Close-Range Photogrammetry* (pp. 1-18). Falls Church, VA: American Society of Photogrammetry.

Aguinaldo, A. L., & Escamilla R. F. (2020) Induced power analysis of sequential body motion and elbow valgus load during baseball pitching, Sports Biomechanics, Feb 5;1-13.

Aguinaldo, A. L., Buttermore, J., & Chambers, H. (2007). Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics, 23*(1), 42-51.

Cohen, A. D., Garibay, E. J., & Solomito, M. J. (2019). The Association Among Trunk Rotation, Ball Velocity, and the Elbow Varus Moment in Collegiate-Level Baseball Pitchers. *The American Journal of Sports Medicine*, *47*(12), 2816–2820.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. Journal of Biomechanics, 29(9), 1223-1230.

Feltner, M. E., & Dapena, J. (1989). Three-dimensional interactions in a two-segment kinetic chain. Part I: general model. *International Journal of Sport Biomechanics, 5*(4), 403-419.

Fleisig, G. S., Bolt, B., Fortenbaugh, D., Wilk, K. E., & Andrews, J. R. (2011). Biomechanical Comparison of Baseball Pitching and Long-Toss: Implications for Training and Rehabilitation. *Journal of Orthopaedic & Sports Physical Therapy, 41*(5), 296-303.

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995). Kinetics of baseball pitching with implications about injury mechanisms. *American Journal of Sports Medicine, 23*(2), 233-239.

Hirashima, M., Yamane, K., Nakamura, Y., & Ohtsuki, T. (2008). Kinetic chain of overarm throwing in terms of joint rotations revealed by induced acceleration analysis. *Journal of Biomechanics, 41*(13), 2874-2883.

MacWilliams, B. A., Choi, T., Perezous, M. K., Chao, E. Y., & McFarland, E. G. (1998). Characteristic ground-reaction forces in baseball pitching. *American Journal of Sports Medicine, 26*(1), 66-71.

Oliver, G. D. (2014). Relationship between gluteal muscle activation and upper extremity kinematics and kinetics in softball position players. *Medical & Biological Engineering & Computing, 52*(3), 265-270.

Oyama, S., Yu, B., Blackburn, J. T., Padua, D. A., Li, L., & Myers, J. B. (2014). Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. *American Journal of Sports Medicine, 42*(9), 2089-2094.

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics, 26* Suppl 1, 125-135.

Roach, N. T., & Lieberman, D. E. (2014). Upper body contributions to power generation during rapid, overhand throwing in humans. *Journal of Experimental Biology, 217*(12), 2139-2149.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health, 2*(2), 135-146.

Young, J. L., Herring, S. A., Press, J. M., & Casazza, B. A. (1996). The influence of the spine on the shoulder in the throwing athlete. *Journal of Back and Musculoskeletal Rehabilitation, 7*(1), 5-17.