Descriptive analysis of kinematics and kinetics of catchers throwing to second base from their knees

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Abstract

In order to decrease the amount of time that it takes the catcher to throw the ball, a catcher may choose to throw from the knees. Upper extremity kinematics may play a significant role in the kinetics about the elbow observed in catchers throwing from the knees. If relationships between kinematics and kinetics exist then the development of training and coaching instruction may help in reduced upper extremity injury risk. Twenty-two baseball and softball catchers (14.36 ± 3.86 years; 165.11 ± 17.54 cm; 65.67 ± 20.60 kg) volunteered. The catchers exhibited a less trunk rotation (5.6 ± 16.2°), greater elbow flexion (87.9 ± 21.4°) and decreased humeral elevation (71.1 ± 12.3°) at the event of maximum shoulder external rotation as compared to what has previously reported in catchers. These variables are important, as they have previously been established as potential injury risk factors in pitchers, however it is not yet clear the role these variables play in catchers’ risk of injury. A positive relationship between elbow varus torque during the deceleration phase and elbow flexion at MIR was observed ($r = 0.609$; $p = 0.003$). Throwing from the knees reduces a catcher’s ability to utilize the proximal kinetic chain and this may help to explain why their kinematics and kinetics differ from what has previously been presented in the literature.

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1. Introduction

The literature has yet to describe the mechanics of a catcher throwing to second base from the knees, however catchers throwing from the squat have been examined briefly (Fortenbaugh et al., 2010; Plummer and Oliver, 2013a,b; Sakurai et al., 1994). Fortenbaugh et al. (2010) found catchers throwing to second base had a shorter stride length, open foot position, closed foot angle, and reduced pelvis-trunk separation angle at foot contact as well as excessive elbow flexion during arm cocking and less forward trunk tilt at ball release than pitchers’ throwing long toss the same distance. Though the stresses about the shoulder and elbow were similar, the catchers had significantly less ball velocity. Thus leading the authors to suggest that catchers have a less efficient throwing motion than other position players. In addition, Plummer and Oliver (2013a) examined the kinematics and kinetics of catchers throwing to second base and reported pelvis-trunk separation to be less than those reported by Fortenbaugh et al. (2010). Additionally, greater upper extremity segmental velocity and early pelvis rotation was displayed by the younger catchers (Plummer and Oliver, 2013a). Thus it was speculated that increased upper extremity segmental velocity and early pelvis rotation may increase the risk of injury in youth catchers due to altered kinetic chain sequencing. Though injury prevention is of great concern in baseball pitchers, the limited data concerning the position of catcher’s has not allowed for further investigation into the catcher’s injury susceptibility.

When attempting to throw out a stealing base runner the catcher may throw from a squatted position or from the knees. Many times the method in which the catcher chooses to utilize is dictated by where the pitch is located. It is the catcher’s ultimate goal to catch the pitch, transfer the ball from glove to throwing hand, and release the ball as quickly as possible in attempt to beat a runner progressing to second base. Base runners are often taught to steal when a pitch is in the dirt. A pitched ball in the dirt results in the catcher having to drop to the knees to block the ball, grasp the ball, and then perform the throw to second base. Consequently allowing the runner more time to successfully steal the base. In order to decrease the amount of time that it takes the catcher to throw the ball, a catcher may choose to throw from the knees. As and a result the catcher may then rush and or alter their mechanics thus possibly resulting in greater stress being placed on the upper extremity, specifically the elbow.
The human body is depicted as a kinetic chain in that segments function interdependently of each other to produce a desired movement. Proper sequencing during the overhead throwing motion is essential to limit the forces acting on the shoulder and elbow that may lead to injury (Burkhart et al., 2003; Plummer and Oliver, 2013a). The dynamic movement of the overhead throwing motion relies on the interaction of a series of structural and functional components of the neuromuscular system. The interaction of these components must allow for adequate pelvic and scapular stability and mobility for efficient shoulder movement. Therefore dynamic movement efficiency is dependent upon postural stability, strength, flexibility, and movement patterns of the entire kinetic chain (Sewick et al., 2012). The majority of force generation in overhead throwing is produced, in the lower extremity, through the legs and trunk and then funneled through the glenohumeral joint and on to the ball (Kibler, 1995, 1998). Sequential functioning of the lower extremity and trunk allow for the maximum force transfer to the upper extremity in throwing, and the lack of lower extremity force generation leads to injury within the shoulder as the body attempts to create the force in the upper extremity (Burkhart et al., 2003). In attempt to maximize ball speed when throwing, the movement should start with the more proximal segments (hips, pelvis and trunk) and progress to the more distal segments (shoulder, elbow, and wrist) (Bunn, 1972; Putnam, 1993).

Kibler has determined that the lower extremity (legs, hip, trunk) generates 54% of total energy during a tennis serve, thus emphasizing the importance of the proximal segments during dynamic movement (Kibler, 1995). When a catcher throws from the knees, the major force producer of the kinetic chain, the lower extremity, is altered. Therefore the force that is typically generated from foot contact is now eliminated. It is hypothesized that the alteration of the lower extremity, as when a catcher throws from the knees, could result in a disruption of kinetic chain sequencing and eventually contribute to injury. To the authors’ knowledge there are currently no data concerning injury susceptibility in catchers. Therefore it was the primary purpose of this study to quantitatively describe the kinematics and kinetics of catchers throwing from the knees. After quantifying the mechanics of catcher’s throwing from their knees, we additionally sought to examine the relationship between elbow kinetics and upper extremity kinematics of catchers throwing from the knees. It was hypothesized that catchers throwing from the knees would display decreased humeral elevation and increased elbow kinetics compared to the recommended kinematics and kinetics reported in the literature.

While freedom from injury within the past six months was one of the criteria for selection none of the participants reported that they had ever suffered an injury to their throwing arm. They also did not report any pain or stiffness in their upper extremity following extensive throwing sessions. Testing was conducted in a gym inside the University’s Sports Medicine and Movement Laboratory. The University’s Institutional Review Board approved all testing protocols. Prior to data collection all testing procedures were explained to each participant and their parent(s)/legal guardian (s) and informed consent and participant assent was obtained.

2.2. Procedures

The MotionMonitor™ (Innovative Sports Training, Chicago, IL) synced with electromagnetic tracking system (Track Star, Ascension Technologies Inc., Burlington, VT) was used to collect data. The electromagnetic tracking system has been validated for tracking humeral movements, producing trial-by-trial interclass correlation coefficients for axial humerus rotation in both loaded and non-loaded condition in excess of 0.96 (Ludwig and Cook, 2000). With electromagnetic tracking systems, field distortion has been shown to be the cause of error in excess of 5° at a distance of 2 m from an extended range transmitter (Day et al., 2000), but increases in instrumental sensitivity have reduced this error to near 1° prior to system calibration and 2° following system calibration (Day et al., 2000; Ludwig and Cook, 2000; Meskers et al., 1999, 1998). Thus prior to data collection, the current system was calibrated using previously established techniques. Following calibration, magnitude of error in determining the position and orientation of the electromagnetic sensors within the calibrated world axes system was less than 0.01 m and 3° respectively.

Participants had a series of 11 electromagnetic sensors [Track Star, Ascension Technologies Inc., Burlington, VT] attached at the following locations: (1) seventh cervical vertebra (C7) spinous process; (2) pelvis at sacral vertebrae 1 (S1); (3) deltoid tuberosity of the throwing arm humerus; (4) throwing arm wrist, between the radial and ulnar styloid processes; (5) acromioclavicular joint of the throwing arm (6–7) bilateral shank centered between the head of the fibula and lateral malleolus; (8–9) bilateral lateral aspect of the femur (Oliver, 2013; Oliver and Keeley, 2010a,b; Wu et al., 2002, 2005) and (10–11) bilateral third metatarsal of the foot. Student researchers who were trained in the application techniques applied the sensors. Sensors were affixed to the skin using PowrFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA) to ensure the sensors remained secure throughout testing. Following the application of the sensors, an additional sensor was attached to a stylus and used for digitization following previously established guidelines (Oliver, 2013; Oliver and Keeley, 2010a,b; Wu et al., 2002, 2005). Participants stood in anatomical position during digitization to guarantee accurate bony landmark identification. The medial and lateral aspect of each joint was digitized and the midpoint of the two points was calculated to determine the joint center (Oliver, 2013; Oliver and Keeley, 2010a,b; Plummer and Oliver, 2013a,b; Wu et al., 2002, 2005). A link segment model was developed through digitization of joint centers for the ankle, knee, hip, shoulder, thoracic vertebrae 12 (T12) to lumbar vertebrae 1 (L1), and C7 to thoracic vertebra 1 (T1). The spinal column was defined as the digitized space between the associated spinous processes, whereas the ankle and knee were defined as the midpoint of the digitized medial and lateral malleoli, medial and lateral femoral condyles, respectively. The shoulder and hip joint centers were estimated using the rotation method. This method of calculating a joint center has been reported for the as providing accurate positional data (Huang et al., 2010; Veeger, 2000). The shoulder joint center was calculated from the rotation between the humerus relative to the scapula and the hip joint center was from the rotation

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of the femur relative to the pelvis. The rotation method was implemented with the joint stabilized and then passively moved in 10 positions in a small circular pattern (Huang et al., 2010). The variation in the measurement of the joint center had to have a root mean square error less than 0.003 m in order to be accepted.

Table 1

<table>
<thead>
<tr>
<th>Segment</th>
<th>Axis of rotation</th>
<th>Angle of rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>Z</td>
<td>Flexion [+]/Extension [+]</td>
</tr>
<tr>
<td>Rotation 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation 2</td>
<td>X</td>
<td>Left Lateral Tilt [-]/Right Lateral Tilt [+]</td>
</tr>
<tr>
<td>Rotation 3</td>
<td>Y</td>
<td>Right Rotation [+]/Left Rotation [-]</td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation 1</td>
<td>Y</td>
<td>Humeral Plane of Elevation [0 = Abduction; 90 = Flexion]</td>
</tr>
<tr>
<td>Rotation 2</td>
<td>X</td>
<td>Humeral Elevation</td>
</tr>
<tr>
<td>Rotation 3</td>
<td>Y</td>
<td>Shoulder Internal Rotation [+]/Shoulder External Rotation [-]</td>
</tr>
<tr>
<td>Elbow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation 1</td>
<td>Z</td>
<td>Flexion [+] /Hyperextension [+]</td>
</tr>
<tr>
<td>Rotation 2</td>
<td>X</td>
<td>Carrying Angle</td>
</tr>
<tr>
<td>Rotation 3</td>
<td>Y</td>
<td>Pronation [+] /Supination [+]</td>
</tr>
</tbody>
</table>

Prime ['] and double prime ["] notations represent previously rotated axes due to the rotation of the local coordinate system resulting in all axes within that system being rotated. Rotation about X axis also results in rotation of both Y and Z axes resulting in a new system of X', Y', Z'.

Table 2

| Descriptive kinetic data of catchers throwing to second base from the knees. Mean (SD). |
|-----------------------------------|---------------------------------|---------------------------------|
| Coasting                          | Acceleration                    | Deceleration                    |
| Elbow varus torque (N/m)          | 1.98 (13.47)                    | 16.85 (29.13)                   | 7.31 (20.03)                   |
| Normalized elbow varus (N/m/BW)   | 0.22 (2.11)                     | 2.61 (4.76)                     | 0.95 (2.88)                     |
| Elbow proximal force (N)          | 103.43 (81.82)                  | 55.25 (46.00)                   | 2380.60 (265.00)               |
| Normalized elbow proximal force (N/BW) | 16.21 (11.91)             | 55.25 (46.00)                   | 2380.60 (265.00)               |
| Humerus velocity (/s)             | 1407.70 (216.04)                | 1624.80 (321.96)                | 2380.60 (265.00)               |
| Forearm velocity (/s)             | 1635.00 (186.14)                | 2497.40 (731.20)                | 2582.20 (431.20)               |

Phases: Coasting (KC–MER); Acceleration (MER–BR); Deceleration (BR to MIR).

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Type I error rate was set a priori at $p < 0.05$ and each event of throwing was analyzed independently.

### 3. Results

#### 3.1. Kinematics and kinetics

Descriptive kinematic data (Fig. 2) and kinetic parameters (Table 2) are presented. The trunk was rotated to the right ($5.6 \pm 16.2^\circ$) at MER and as the motion progressed to BR and MIR the trunk was rotated more to the left of their desired target ($-14.0 \pm 17.6^\circ$ and $-14.8 \pm 20^\circ$, respectively). Maximum humeral elevation was obtained at BR and was $84.0 \pm 15.3^\circ$. Maximum elbow flexion was obtained ($87.9 \pm 21.4^\circ$) at MER and then the elbow moved into extension as throwing progressed. Elbow varus torque ($16.8 \pm 29.1$ N/m) as well as elbow proximal force ($343.84 \pm 314.22$ N) were greatest during the acceleration phase.

#### 3.2. Correlations

The correlations between kinematic variables and elbow kinetics are presented in Table 3. A positive relationship between elbow varus torque during the deceleration phase and elbow flexion at MIR was observed ($r = 0.609; p = 0.003$). This correlation indicates that as elbow varus torque increased throughout the deceleration phase, there was greater elbow flexion at the event of MIR. The strength of this significant correlation can be classified as strong.

### 4. Discussion

When catchers throw to second base from the knees, to try to get a stealing base runner out, they may be negatively altering their throwing mechanics. The position of the trunk at MER was $5.6 \pm 16.2^\circ$ indicating that catchers were positioned with their trunk facing to the right of second base, or rotated toward throwing arm side. Then as the throw progressed into BR and MIR the trunk continued to rotate toward the non-throwing arm. These data are in agreement with previous reports by Plummer and Oliver (2013a) of catchers throwing from the stance. Plummer and Oliver (2013a) have postulated that early pelvic rotation (toward the non-throwing arm) might lead to kinetic chain dysfunction resulting in greater upper extremity segmental velocities due to the upper extremity compensating for lost energy. Ideal...
kinetic chain sequencing involves trunk rotation progressing toward the target during throwing as opposed to facing the target early in the motion. When catchers throw to second base from the knees their ability to generate force from the lower extremity is likely hindered and other body segments must compensate. The throwing arm must try to reproduce the forces necessary to perform the throw with limited assistance from the proximal segments of the kinetic chain.

Examining upper extremity kinematics, this study revealed that the catchers displayed decreased humeral elevation angles \( (84.0 \pm 15.3^\circ) \) than have previously been reported \((\text{Oliver et al., 2010; Keeley et al., 2012; Plummer and Oliver, 2013a})\). The decreased humeral elevation is of concern as it has been documented that decreased humeral elevation is an injury predictor \((\text{Davis et al., 2009})\). Additionally, it has been reported that the ideal position of the humerus, for reducing joint torques and maximizing functional stability, is 90° \((\text{Matsuo et al., 2006; McFarland, 1990})\). For the current study, it was hypothesized that humeral elevation would be less than the recommended 90° in catchers throwing from the knees. This hypothesis proved true as at MER, humeral elevation was less than 90°. When compared to the humeral elevation reported in other overhead throwing motions, the humeral elevation observed in catchers throwing from the knees is decreased (Table 4). Pitchers have an advantage over catchers in that they can take their time in their wind-up to produce a maximal effort throw to the target. Catchers are at a competitive disadvantage because they have to receive the pitch while also accounting for the movement of the base runner before performing a throw to second base. Based on these results it is speculated that in an attempt to have a quicker ball release the catchers may rush their throwing mechanics resulting in decreased humeral elevation.

Elbow kinetics in the current study were low compared to previous pitching literature \((\text{Fleisig et al., 1995, 1999; Fortenbaugh et al., 2010})\). One explanation is that the reported elbow flexion in the current study was much greater \((87.9 \pm 21.4^\circ)\) than what is typically observed during pitching. The increased elbow flexion is to position the wrist close to the ear throughout the cocking phase; which is a common mechanical technique taught to catchers \((\text{Fortenbaugh et al., 2010})\).

Table 3

<table>
<thead>
<tr>
<th>Kinematic Data</th>
<th>Catching from Knees</th>
<th>Catching from MIR</th>
<th>(p) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk rotation</td>
<td>5.6 ± 16.2°</td>
<td>9.8 ± 22.3°</td>
<td>0.07</td>
</tr>
<tr>
<td>Humeral elevation</td>
<td>84.0 ± 15.3°</td>
<td>111.4 ± 17.8°</td>
<td>0.01</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>87.9 ± 21.4°</td>
<td>76.4 ± 34.4°</td>
<td>0.06</td>
</tr>
<tr>
<td>Varus torque (Nm)</td>
<td>1.98 ± 13.47</td>
<td>10.0 ± 13°</td>
<td>0.008</td>
</tr>
<tr>
<td>Elbow proximal Force (N)</td>
<td>103.4 ± 81.2</td>
<td>51 ± 10</td>
<td>0.009</td>
</tr>
</tbody>
</table>

*Indicates significance at \(p < 0.05\).

Table 4

<table>
<thead>
<tr>
<th>Current study (a)</th>
<th>Plummer and Oliver (2013a)(b)</th>
<th>Keeley et al. (2010)(b)</th>
<th>Oliver et al. (2010)(b)</th>
<th>Fleisig et al. (1995)(b)</th>
<th>Fleisig et al. (1996)(b)</th>
<th>Fleisig et al. (1999)(b)</th>
<th>Werner et al. (2002)(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk rotation</td>
<td>5.6 ± 16.2°(a)</td>
<td>-5.92 ± 15.92°(b)</td>
<td>100.7 ± 7.9°(b)</td>
<td>99 ± 17°(b)</td>
<td>64 ± 12°(b)</td>
<td>95 ± 12°(b)</td>
<td>109 ± 33°(b)</td>
</tr>
<tr>
<td>Humeral elevation</td>
<td>84.0 ± 15.3°(a)</td>
<td>111.4 ± 17.8°(b)</td>
<td>100.7 ± 7.9°(b)</td>
<td>99 ± 17°(b)</td>
<td>64 ± 12°(b)</td>
<td>95 ± 12°(b)</td>
<td>109 ± 33°(b)</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>87.9 ± 21.4°(a)</td>
<td>76.4 ± 34.4°(b)</td>
<td>100.7 ± 7.9°(b)</td>
<td>99 ± 17°(b)</td>
<td>64 ± 12°(b)</td>
<td>95 ± 12°(b)</td>
<td>109 ± 33°(b)</td>
</tr>
</tbody>
</table>

\(a\) Catchers.
\(b\) Pitchers.

* Kinetics are not normalized to allow for comparisons to be made across studies.
5. Conclusion

Understanding the kinematics and kinetics associated with catchers throwing from the knees is critical for developing conditioning and rehabilitation programs that can be utilized by baseball and softball catchers. Reducing the contributions of the lower extremity when throwing from the knees, catchers lose the ability to utilize the proximal kinetic chain. The proximal kinetic chain segments serve to generate force and the upper extremity may then compensate by generating increased forces to maintain the velocity of the throw. Strengthening exercises that focus on the entire lumbopelvic-hip complex can help to provide a stable base of support for the pelvis and trunk (Oliver et al., 2010), helping to control the rate of timing of segmental rotation of the trunk when catchers throw from the knees. Additional, exercises that require coordinated activation of the trunk and upper extremity may be beneficial for catchers to perform to help prevent altered kinetic chain sequencing (Mcmullen and Uhl, 2000; Sciascia and Cromwell, 2012). More longitudinal epidemiological data are needed to better assess the effects on throwing from the knees on injury rates.

Conflict of interest

The authors have no conflict of interest to report.

References


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