# LOWER LIMB MOTOR FUNCTION FOR BODY ROTATION DURING BASEBALL PITCHING

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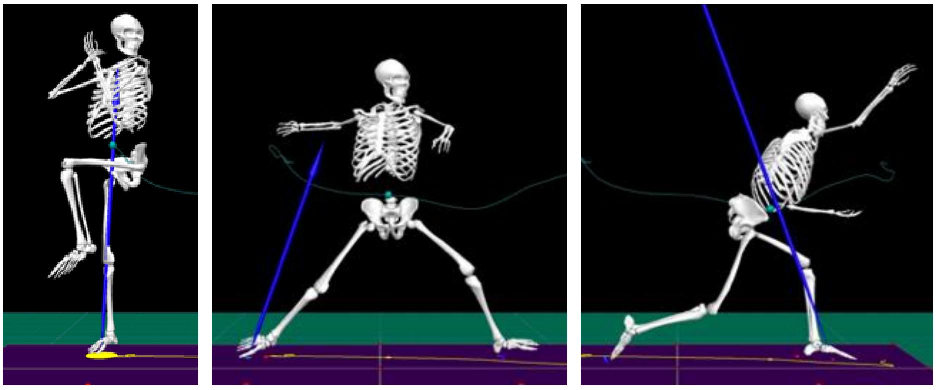
This study was conducted to clarify the mechanism of body rotation by the lower limbs in the baseball pitcher throwing motion. Twenty male overhead baseball pitchers participated in this study voluntarily. All participants threw three fastball pitches with maximal effort to a pitching net located in front of the pitcher. In all, 60 pitching motions were captured. An optical motion capture system and two force plates were used for kinematic and kinetic measurements. The ball speed at ball release, joint angles, joint moments and joint power in lower extremities, moment around the center of mass (COM), and body angular momentum about COM were derived. This study demonstrated that the body's angular momentum was acquired first around the Z axis (horizontal rotation), then around the X axis (vertical rotation), and finally around the Z axis after FFC. Hip joint moment was important for generating each rotation motion.

**KEYWORDS:** angular momentum, joint moment, moment around COM, rotational motion

**INTRODUCTION:** A high velocity of a pitched ball is an important point of evaluation for baseball pitchers. The pitching motion is a highly demanding athletic skill involving fine coordination of all parts of the body (Atwater, 1979). The lower limb mechanics are recognized as an integral part of the pitching motion (MacWilliams et al., 1998; Matsuo et al., 2001; Robb et al., 2010; Kageyama et al., 2015). The mechanism of the kinetics of the lower limbs during pitching has been assessed by measuring ground reaction forces (GRF). Elliot, Grove, and Gibson (1988) reported that the ability to drive the body over a stabilized stride leg is a characteristic of high-velocity pitchers. MacWilliams et al. (1998) reported the maximum GRF values in the pitching direction, respectively as 0.35 and 0.72 per unit of body weight for the pivot and stride legs. High-velocity ball pitchers can also generate greater momentum of the lower extremities than low-velocity ball pitchers (Kageyama et al., 2014). These findings indicate that greater GRF are necessary to throw a ball at high velocity. Those earlier studies assess the linear motion of the center of mass (COM) and the linear momentum of the body, but the mechanisms related to the rotational motion and the body momentum remain unknown. This study was conducted to clarify the mechanisms of body rotation by the lower limbs during a baseball pitcher's throwing motion.

**METHODS:** Twenty male overhead baseball pitchers (1.746 ± 0.064 m; 69.6 ± 10.4 kg; age, 21.2 ± 2.1 years) participated in this study voluntarily. Of them, 13 participants were right-handed; the other seven were left-handed. All participants denied any history of injury. Each threw three fastball pitches with maximal effort to a pitching net located in front of the pitcher. In all, 60 pitching motions were captured. An optical motion capture system (MAC3D; Motion Analysis Corp., Santa Rosa, California, 12 infrared cameras, sampling freq. 500 Hz) and two force plates (BP6001200; AMTI Inc., USA, sampling freq. 1 kHz) were used for kinematic and kinetic measurements. Reflective markers (12.5 mm diameter) were attached on the subject based on the Helen Hays marker set (Chappell et al., 2002). Two markers were attached on the ball to facilitate calculation of the speed at ball release. The GRF and three-dimensional coordinates of the laboratory were defined as follows: Y-axis, throwing direction; Z-axis, vertical axis; X-axis, third-base direction, perpendicular to the Y- and Z-axes. Following data collection, the motion and force data were examined further using motion analysis software (Visual3D; C-Motion, Inc.). The procedures used with that software first consisted of the development of a static model customized for each subject (Ford, Myer, and Hewett, 2007). Raw data were filtered using a fourth-order zero-lag Butterworth low-pass filter with a cut-off frequency of 6 Hz for the 3D marker trajectories and 18 Hz for force platform data. The 3D angles of hip, knee, and ankle joint were calculated according to the Cardan/ Euler rotation sequence X-Y-Z order (Cole et al., 1993). Kinematic and force platform data were used to calculate the joint moment (M) and power of each joint using inverse dynamics (Winter 1990). Both moments around the COM and body angular momentum about the COM were calculated to evaluate the degree of body rotation (Yeadon 1993). Kinetic data such as GRF, joint moments or powers were normalized as divided by body weight. The start and end of movement were defined respectively as lifting of the front leg (i.e. highest point of COM) and ball release (Figure 1). The derived signal data were time-normalized in this term. The mean and standard deviation of all 60 trials were obtained for signal data. The obtained biomechanical parameters in this study were the following: ball speed at ball release; joint angles, joint moments and joint power in lower extremities; moment around the COM; and body angular momentum around three axes of the laboratory coordinate system.



(a) Start (0%) (b) Front Foot Contact (FFC) (c) Ball release (100%)

**Figure 1: Time series of pitching motion.**

**RESULTS:** The average ball speed at release was 29.8 ± 2.0 m/s (107.5 ± 7.2 km/h). The body angular momentum about the COM is shown in Figure 2. The angular momentum around the Z axis (horizontal rotation) increased gradually from around 25%-time. A sharp increase was observed after front foot contact (FFC). The absolute value of the angular momentum around the X axis (vertical rotation) increased from around 70%-time. Of the three waveforms, the largest peak was that of data about the X axis, shown as * in Figure 2. The amount of change of the angular momentum around the Y axis was smaller than those of the other two. Figure 3 presents an illustration and time series data related to the rotating force of the body exerted by the pitcher. Figure 3(a) presents an illustration at 50%-time, free moment of pivoting leg is exerted at this time (Figure 3(d)), then the body was horizontally rotated. Figures 3(b) and 3(c) respectively present an illustration at the FFC and immediately after the FFC. Figure 3(b) shows that the GRF of the pivoting leg passes behind the COM. This phenomenon causes a moment around the COM (Figure 3(e)). The moment around COM (around X axis) began to increase from around 50%-time and peaked immediately before ball release (Figure 3(e)). Finally, after the FFC, GRFs act on both feet. Both action lines of these GRFs passed away from the COM (Figure 3(c)). A moment about the COM that causes the body to rotate counterclockwise acted in this phase (Figure 3(f)).
Time series of hip joint moments of both lower extremities are shown in Figure 4. From the start (0%) to FFC, extension moment (Figure 4(a)) and external rotation moment (Figure 4(c)) were observed in the hip joint of the pivoting leg. From about 50%-time to FFC, a sharp increase in the adduction moment was observed in the pivoting leg (Figure 4(b)). After FFC, extension M (Figure 4(a)), adduction M (Figure 4(b)), and internal rotation moment (Figure 4(c)) were observed in the front foot.

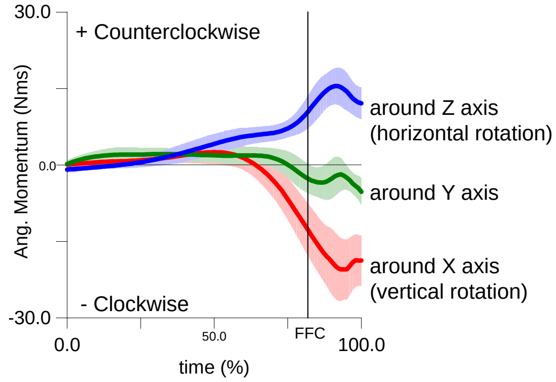



**Figure 2: Body angular momentum about the COM (mean ± SD).**

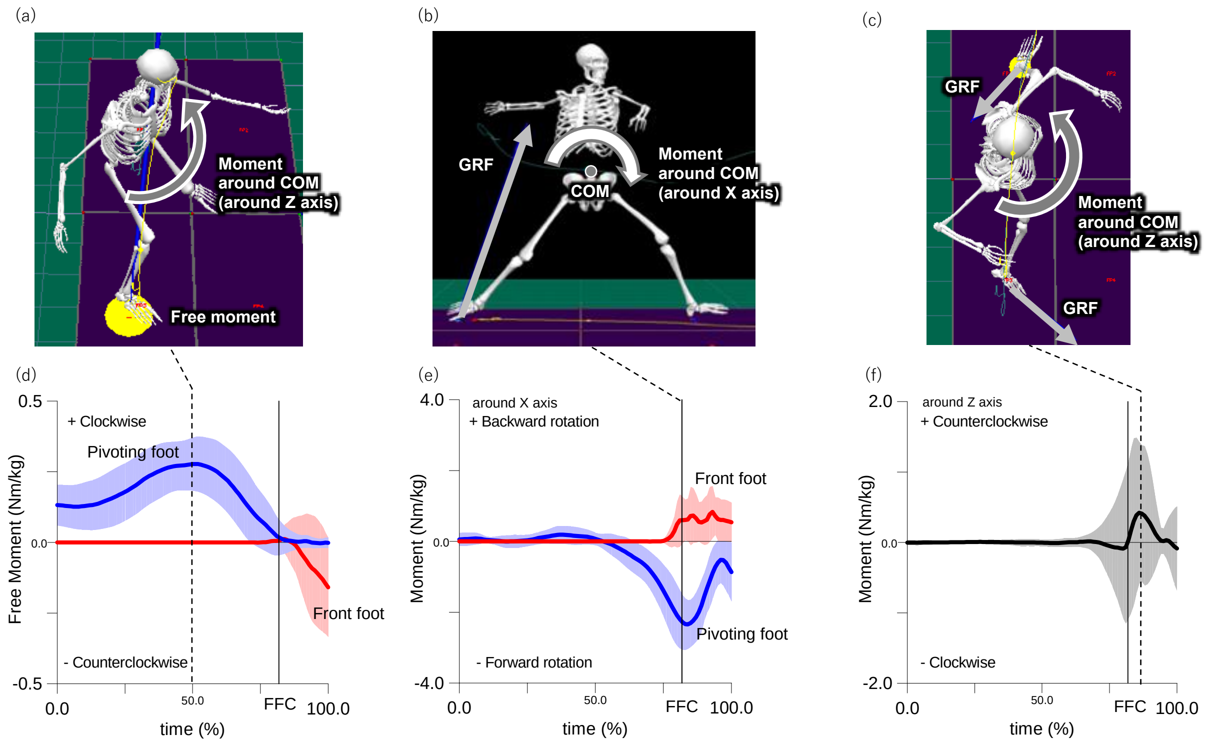



**Figure 3: Ground reaction force, free moment and moment around COM: (a)–(c) present characteristic scenes at 50%-time, FFC and immediately after FFC. (d)–(f) respectively show a time series of the free moment and moment around the COM. (mean ± SD). Figure (f) shows the resultant moment of the moments generated by the GRFs acting on both feet.**

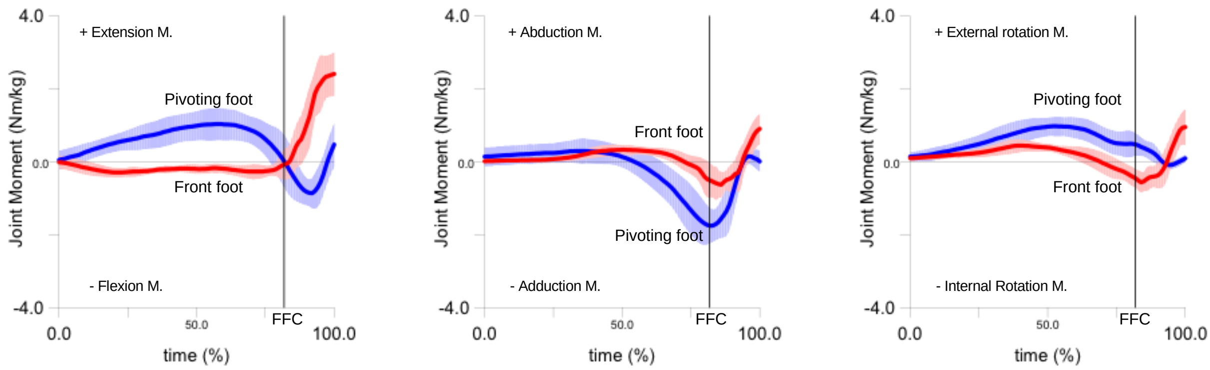



**Figure 4: Time series of hip joints moment: (a) extension / flexion M.; (b) abduction / adduction M.; (c) external rotation / internal rotation M. (mean ± SD).**

**DISCUSSION:** The angular momentum of the body during the pitching motion begins with rotation around the Z axis (Figure 2). This acquisition results from the free moment acting on the pivoting leg (Figure 3(a)), which was thought to be produced by external rotation M of the hip joint in the pivoting leg (Figure 4(c)). Then, the angular momentum around the X axis develops from around 70%-time (Figure 2). It is thought that this angular momentum was produced by the moment around the COM by pivoting leg (Figure 3(e)). At the same phase, the adduction M was exerted on the hip joint of the pivoting leg. It is considered that the angular momentum about the X axis was produced the action of the adduction M. After the FFC, the pitcher began to acquire angular momentum about the Z axis again (Figure 2). In this phase, the angular momentum increases rapidly. The body trunk and pelvis were greatly rotated to face the home base by ball release (Figure 1(c)). Rotation of the body might occur because of GRFs acting on both feet, thereby producing a force couple (Figure 3(c)). Previous studies have shown that the rotational speed of the trunk decreases with the curved ball pitching (Barrentine et al. 1998, Escamilla et al. 1998), but there is no report clearly describing the mechanism of generating the body rotation.

**CONCLUSION:** Results of this study clarified the mechanism of development of the body rotation motion during pitching motion of the baseball pitcher. Rotational motion was quantified by the angular momentum of the body. Results demonstrate that the body's angular momentum is generated first around the Z axis (horizontal rotation), then around the X axis (vertical rotation), and finally around the Z axis after FFC again. Hip joint M was shown to be important for generating each rotation motion.

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