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A Kinematic and Kinetic Comparison of Mound and Rocker Throws

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ABSTRACT

Background. The stride phase of the baseball throwing motion is an influential aspect in throwing performance as described in previously published literature. The Rocker drill is a constraint that is often used to change or improve baseball throwing performance throughout a wide range of settings, coaches, and training programs. Due to the lack of quantified and documented effects of the Rocker drill on throwing mechanics, this study aims to identify the

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resulting changes in performance, kinematics, kinematic velocities, and kinetics from the Rocker drill and a variation of the Rocker drill to determine which constraint may promote more effective mechanical changes.

Hypothesis. We hypothesize that the normal Rocker drill will have significantly different throwing arm, trunk, and lower body kinematic positions at front Foot Plant, maximum throwing shoulder external rotation, and Ball Release, as well as significantly different ball velocity, maximum kinematic velocities, and throwing elbow kinetics when compared to the “Foot-up” variation of the Rocker drill.

Methods. A total of 30 healthy baseball pitchers with collegiate or professional competition experience threw three to five regulation baseballs out of the “stretch” pitching position, the Rocker drill, and a less constrained, Foot-up variation of the Rocker drill as close to maximal intent as possible. Subjects wore retroreflective markers for use in kinematic measurements and ball velocity was measured with a Doppler radar device.

Results. Eleven statistically significant differences were found among the a priori tests conducted between the normal Rocker drill and the Foot-up Rocker drill. Ball velocity in the Foot-up Rocker was significantly greater than the normal Rocker (82.03 vs 79.53, p-value < 0.0001).Within the trunk kinematics category, the normal Rocker drill showed significantly greater trunk rotation angle at both Ball Release (BR) (111.90 vs 108.43, p-value = 0.0008) and Maximum External Rotation (MER) (98.76 vs 95.85, p-value = 0.0220) while the Foot-up Rocker showed significantly greater trunk lateral tilt at both Ball Release (33.86 vs 31.66, p-value = 0.0021) and Foot Plant (FP) (5.55 vs -0.13, p-value = 0.0222) as well as trunk forward tilt at BR (21.25 vs 16.85, p-value < 0.0001). Within the lower body kinematics category, the normal Rocker showed significantly greater front knee flexion at BR (41.71 vs 36.17, p-value = 0.0010), MER (49.51 vs 44.80, p-value = 0.0220) and FP (62.92 vs 51.04, p-value < 0.0001) while the Foot-up Rocker had significantly greater pelvis rotation angle at FP (38.25 vs 26.51, p-value = 0.0432). Within the kinematic velocity category, the Foot-up Rocker had significantly greater shoulder internal rotation angular velocity (4295.33 vs 4143.25, p-value = 0.0006).

Conclusion. This study aims to identify various mechanical and performance differences in the throwing motion between the Rocker drill and a less constrained, Foot-up variation of the Rocker drill. Ball velocity, trunk and lower body kinematics as well as kinematic velocities showed significant differences between the Rocker and the Foot-up variation of the drill. These results can be used by coaches and trainers to determine in which setting these drills may provide desired throwing motion adjustments.

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INTRODUCTION

The baseball pitching motion is initiated and heavily influenced by the stride and its various characteristics. A primary role of the stride is to position the lower half and trunk accordingly for the kinetic chain to perform effectively (Seroyer et al., 2010). There are aspects of momentum transfer in the throwing motion from the ground to the throwing arm which have exhibited relationships with stride characteristics (Ramsey, Crotin, & White, 2014). Further, these characteristics have exhibited significant relationships to throwing performance in terms of ball velocity (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Sgroi et al., 2015; Stodden et al., 2006; Werner, Suri, Guido, Meister, & Jones, 2008). Some researchers have gone further and concluded that performance measured by ball velocity has a causal relationship with how efficiently athletes "drive the body over a stabilizing front leg" and transfer momentum that is generated by the stride and push-off ground reaction forces (GRFs) "from the lower body to the throwing arm." (Elliott, Grove, & Gibson, 1988; Oyama & Myers, 2018). This relationship between the creation of linear momentum and transferring this energy to superior segments in the kinetic chain was also previously exhibited by observing a significant relationship between both drive leg medial force and stride leg breaking force with maximum shoulder rotation torque (Nicholson, Hulburt, Kimura, & Aguinaldo, 2019). Although methods of quantifying lower body kinematics and stride strategies have not been standardized, these various relationships between stride characteristics and important aspects of the throwing motion in kinematic and GRF investigations provide support for the importance of the lower body in an effective throwing motion.

The Rocker drill is a widely used training constraint in the baseball industry. Additionally, the authors' employer (Driveline Baseball Enterprises) has historically included this drill constraint as a method of improving athletes throwing performance. Despite the common implementation of the Rocker drill, its mechanical effects on the throwing motion have not been documented.

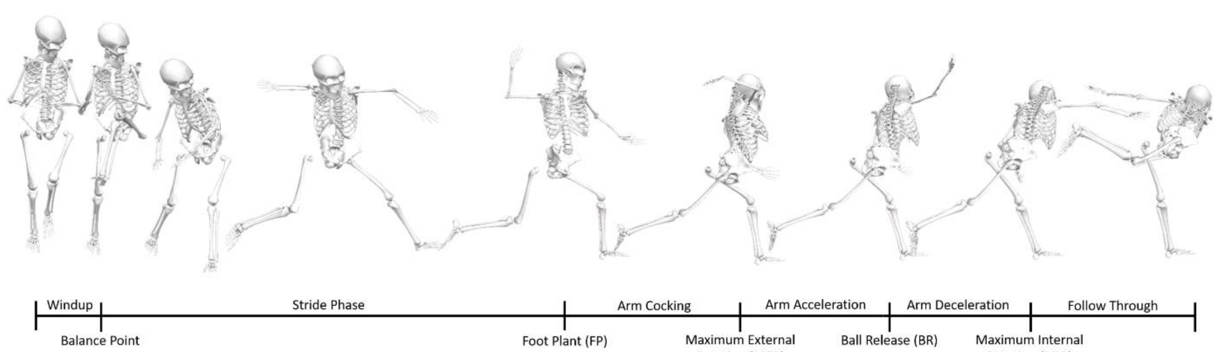

Figure 1. Phases and events in the pitching motion

In the normal Rocker drill, the lead leg of the thrower is spread out and planted in front of the athlete mimicking a lower body position like the pitching motion after Foot Plant (*Fig. 2A, 2B, 2C*). The athlete executes the drill by shifting their weight back and forth from their front leg to their back leg while keeping both feet planted on the ground. Because the athlete deliberately keeps their front foot on the ground and the front leg does not have a full range of motion to move throughout the delivery, lower half kinematics may be very different compared to those of a normal pitching motion where the pitcher strides and lands with their lead leg into Foot Plant. Through our observations, we hypothesized that the Rocker drill may promote inefficient lower half kinematic positions relative to the normal pitching motion, specifically with an increased front knee flexion and pelvis rotation angle. A less constrained variation of the Rocker drill where the foot can leave the ground and be replanted may provide an alternative solution to these issues as seen in *Fig. 2E*.

Figure 2. The Rocker drill (top) and the Foot-up Rocker variation (bottom)

It is unknown whether drills like the Rocker are effective in training baseball pitchers; alternatively, it is possible these drills promote movement into inefficient positions that reinforce poor mechanics during the pitching motion. The purpose of this study was to compare the normal Rocker drill to the Foot-up variation while referencing the normal pitching mechanics in order to evaluate its effectiveness as a throwing training drill.

METHOD

30 healthy pitchers with mean age, height, and weight of 23.5 ± 2.4 years, 73.9 ± 2.1 inches, and 209.3 ± 20.9 pounds, respectively, with collegiate or pro-level experience volunteered to participate in the study. Two of the throwers threw sidearm and seven were left-handed. Participants were provided with a verbal explanation of the study and asked to read and sign an informed consent prior to data collection. This study was approved by Hummingbird IRB, who granted ethical approval to carry out the study at the author's facilities (Hummingbird IRB #: 2018-82). Testing proceeded after the investigators received verbal confirmation of consent and obtained a witnessed legal signature from the athlete. Heights, weights, and ages of the participants were recorded before the beginning of testing.

Testing Procedure

Athletes were allowed as much time as needed to prepare and warm-up accordingly to throw at near maximum intent off the pitching mound. Once the subject was ready, they were fitted with 47 reflective markers in preparation for the motion capture data collection. Markers were attached bilaterally on the third distal phalanx, lateral and medial malleolus, calcaneus, tibia, lateral and medial femoral epicondyle, femur, anterior and posterior superior iliac spine, iliac crest, acromial joint, midpoint of the humerus, lateral and medial humeral epicondyle, midpoint of the ulna, radial styloid, ulnar styloid, distal end of index metacarpal, parietal bone, and frontal bone, as well as on the inferior angle of scapula, C7 and T10 vertebrae, the sternal end of the clavicle, and the xiphoid process.

Ball velocity was measured by a Doppler radar device (Applied Concepts/Stalker Radar, Richardson, TX, USA) for each trial. Additionally, for all trials, the three-dimensional positions of the reflective markers were tracked with a multi-camera motion-capture system, sampling at 240 Hz (Natural Motion/Optitrack, Corvallis, OR, USA). This motion-capture system contained a mixture of Prime 13 and Prime 13W cameras, totaling 15 cameras. These cameras were placed symmetrically around the capture volume, approximately 8–12 feet from the center of the pitching mound at varying heights. A total of six cameras were mounted on a truss system in front of the pitcher to avoid collisions.

The motion capture system was calibrated using Motive:Body software (Natural Motion/OptiTrack, Corvallis, OR, USA) and the ground plane was set; calibration was confirmed when the system showed one millimeter (mm) or less of mean three-dimensional error. Pitchers were instructed to throw three to five throws each from the stretch position (Mound), normal Rocker drill (Rocker), and Foot-up Rocker drill (Foot-up) at or near maximum intent as defined by typical in-game effort and ball velocity. The order was randomized for each participant. Fatigue was assumed to be negligible. Throws were made using a standard five-ounce (142 grams) regulation baseball off the mound to a strike zone target (Oates Specialties, LLC, Huntsville, TX, USA) located above home plate, which was 60 feet, 6 inches (18.4 meters) away.

Figure 3. Placement of motion tracking cameras for measurement of the participants' kinematics.

Joint centers of the model were estimated based on markers placed on the joint and local coordinate systems (Dillman, Fleisig, & Andrews, 1993). Position data were filtered using a 20 Hz fourth-order Butterworth low-pass filter, after which kinematics and kinetics were calculated in Visual3D (C-Motion Inc., Germantown, MD, USA). The model was scaled for body size, and inertial properties of the hand, forearm, and upper arm were based on cadaveric data (de Lava, 1996). The baseball was modeled as a 0.142 kg point mass at the metacarpal marker until the ball was released, while after release the mass was omitted from the model (Fleiseg, Diffendaffer, Aune, Ivey, & Laughlin, 2017). All kinematic and kinetic values were calculated using the International Society of Biomechanics (ISB) recommended model of joint coordinate systems (Wu et al., 2002).

In total, 20 kinematic and kinetic values (12 position, five velocity, and three kinetic) were calculated. Nine joint angles were calculated at the events of Foot Plant (FP), max external rotation (MER), and Ball Release (BR), including: elbow flexion, shoulder horizontal abduction, shoulder abduction, shoulder external rotation, trunk forward tilt, trunk lateral tilt, trunk rotation angle, pelvis rotation angle, and lead knee flexion. Additionally, maximum shoulder horizontal abduction, shoulder external rotation, and hip-to-shoulder separation were measured. Kinematic measures of the arm and lead knee were taken as their local joint angles, using local coordinate systems. Trunk and pelvis kinematic measures were measured in the global coordinate system. Five velocity parameters included maximum pelvis angular velocity in the axial direction, torso angular velocity in the axial direction, elbow extension angular velocity, shoulder internal rotation angular velocity, and lead knee extension angular velocity. Pelvis and torso angular velocities were measured as rotation in the global coordinate system. Elbow, shoulder, and lead knee velocities were calculated as the rate of change in the joint angle in expressed as °/second. Maximum elbow varus torque was calculated as a torque applied to the joint by the proximal segment onto the distal segment. Maximum elbow varus torque was also normalized to body weight and height, as well as to the pitch speed.

Statistical Analyses

The means of both the normal Rocker and Foot-up Rocker positions for the 30 subjects were compared across a series of a priori chosen biomechanical metrics with a series of paired T-tests. An $n - 1$ degree of freedom was used. These comparisons fell into six general biomechanical categories: throwing arm, trunk, and lower body kinematic positions, maximum kinematic positions, kinematic velocities, and joint kinetics. The only measurement which was not classified in one of the six above biomechanical categories was ball velocity of each respective pitch, and the same paired T-test was executed to compare the ball velocity means between normal Rocker and Foot-up Rocker conditions. To combat the possibility of family wise error rate that occurs in the context of multiple comparisons testing, a Holm method correction was applied in the context of each category, to adjust the p-values accordingly.

Results

Paired t-test comparisons were completed for the six main measurement categories. Mean ball velocities were significantly different between Rocker and Foot-up throws (Rocker: 79.5 ± 4.6 mph; Foot-up: 82.0 ± 4.9 mph; P-value < 0.0001; Mound: 83.9 ± 4.8 mph). Throwing arm kinematic positions exhibited no statistically significant mean differences (after the results were adjusted with Holm's method), with eight of the twelve Foot-up sample means being closer in absolute value to the mound kinematic positions than the Rocker. The mean and standard deviations of the kinematic positions during the Rocker, Foot-up, and Mound positions are found below in Table 1, along with the initial p-values and adjusted p-values.

Table 1

Throwing Arm Kinematic measurements at various events for Rocker, Foot-up, and Mound throws

Measurement (°)	Event	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Shoulder External Rotation Angle	FP	46.5 ± 38.7	63.3 ± 27.5	0.028	0.276	71.7 ± 24.1
	BR	89.1 ± 12.7	90.3 ± 12.4	0.234	0.936	88.0 ± 12.2
	MER	157.8 ± 20.5	164.8 ± 13.6	0.019	0.233	162.5 ± 14.0
Shoulder Horizontal Abduction Angle	FP	31.3 ± 21.0	33.7 ± 17.0	0.350	1.000	31.2 ± 14.9
	BR	2.2 ± 6.0	1.1 ± 6.3	0.025	0.270	1.6 ± 6.2
	MER	-3.0 ± 6.7	-2.7 ± 6.4	0.706	1.000	-2.1 ± 6.4
Elbow Flexion Angle	FP	98.9 ± 22.1	103.4 ± 16.0	0.074	0.669	105.2 ± 15.3
	BR	24.4 ± 5.4	24.9 ± 5.8	0.095	0.667	24.9 ± 5.8
	MER	73.8 ± 12.6	76.5 ± 12.2	0.105	0.527	76.6 ± 11.7
Shoulder Abduction Angle	FP	85.4 ± 9.2	87.8 ± 11.5	0.083	0.667	88.6 ± 10.9
	BR	83.9 ± 5.0	83.8 ± 5.4	0.899	0.899	84.1 ± 6.0
	MER	78.9 ± 7.9	78.1 ± 8.6	0.103	0.617	77.8 ± 8.0

Note. Throwing arm kinematics were compared at three events each: Foot plant (FP), ball release (BR), and throwing shoulder maximum external rotation (MER). Angle values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

Trunk kinematic positions showed five statistically significant differences between the Rocker and Foot-up metric means: the trunk rotation angle, trunk lateral tilt, and trunk forward tilt at BR, trunk rotation angle at MER, and trunk lateral tilt at FP. The mound position means were closer to the normal Rocker means in three of the five metrics (trunk rotation angle at MER and BR, and trunk forward tilt at BR), as displayed in Table 2.

Table 2

Trunk Kinematic measurements at various events for Rocker, Foot-up, and Mound throws

Measurement (°)	Event	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Trunk Forward Tilt Angle	FP	-11.8 ± 9.0	-11.4 ± 6.2	0.735	0.735	-11.9 ± 6.6
	BR	16.9 ± 11.9	21.3 ± 12.3	<0.001	<0.001*	18.3 ± 13.7
	MER	5.3 ± 8.8	6.8 ± 9.9	0.226	0.453	3.8 ± 10.8
Trunk Lateral Tilt Angle	FP	-0.1 ± 15.0	5.6 ± 13.7	0.004	0.022*	8.7 ± 11.4
	BR	31.7 ± 14.7	33.9 ± 14.1	<0.001	0.002*	32.7 ± 13.6
	MER	27.5 ± 14.4	28.8 ± 14.2	0.034	0.102	28.7 ± 13.3
Trunk Rotation Angle	FP	-4.7 ± 23.5	7.0 ± 19.1	0.033	0.130	12.1 ± 14.2
	BR	111.9 ± 11.4	108.4 ± 12.9	<0.001	<0.001*	110.6 ± 13.3
	MER	98.8 ± 11.6	95.9 ± 10.6	0.004	0.022*	97.7 ± 11.3

Note. Trunk kinematics were compared at three events each: Foot plant (FP), ball release (BR), and throwing shoulder maximum external rotation (MER). Angle values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

**Adj. P-value < 0.05*

Lower body kinematic positions showed four statistically significant differences between the Rocker and Foot-up metric means: front knee flexion at FP, MER, and BR, as well as pelvis angle at FP. The mound position means were closer to the Foot-up Rocker means in all four of these metrics, as displayed in Table 3.

Table 3

Lower Body Kinematic measurements at various events for Rocker, Foot-up, and Mound throws

Measurement (°)	Event	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Front Knee Flexion Angle	FP	62.9 ± 10.1	51.0 ± 8.1	<0.001	<0.001*	44.3 ± 7.5
	BR	41.7 ± 13.1	36.2 ± 16.1	<0.001	0.001*	38.2 ± 13.1
	MER	49.5 ± 13.5	44.8 ± 13.9	0.006	0.022*	44.2 ± 11.3
Pelvis Rotation Angle	FP	26.5 ± 21.9	38.3 ± 16.2	0.014	0.043*	42.1 ± 11.4
	BR	99.6 ± 9.0	98.4 ± 8.2	0.160	0.320	98.5 ± 8.9
	MER	91.8 ± 9.6	91.3 ± 8.4	0.539	0.539	91.8 ± 8.7

Note. Lower body kinematics were compared at three events each: Foot plant (FP), ball release (BR), and throwing shoulder maximum external rotation (MER). Angle values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

**Adj. P-value < 0.05*

Maximum kinematic positions showed no statistically significant differences between the Rocker and Foot-up metric means. The mound position means were closer to the normal Rocker means in one of the two metrics (hip-shoulder separation), as displayed in Table 4.

Table 4

Maximum Kinematic measurements for Rocker, Foot-up, and Mound throws

Measurement (°)	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Horizontal Abduction Angle	43.7 ± 18.5	43.9 ± 17.8	0.870	1.000	44.0 ± 18.2
Hip-Shoulder Separation	37.7 ± 11.6	38.2 ± 9.3	0.758	1.000	37.7 ± 10.1

Note. Reported horizontal abduction angles correspond to the participants throwing arm. Hip-Shoulder separation describes angle of the pelvis in reference to the axial direction of trunk rotation. Angle values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

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Kinematic velocities showed one statistically significant difference between the Rocker and Foot-up metric means: maximum shoulder internal rotation angular velocity. The mound position means were closer to the Foot-up Rocker means in both metrics, as displayed in Table 5.

Table 5

Kinematic Angular Velocity measurements at various points of interest for Rocker, Foot-up, and Mound throws

Measurement (°/s)	POI	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Shoulder Internal Rotation Angular Velocity	Max	4143 ± 470.9	4295 ± 465.5	<0.001	<0.001*	4298 ± 484.8
Throwing Elbow Extension Angular Velocity	Max	2088 ± 222.5	2108 ± 268.8	0.515	1.000	2179 ± 213.7
Front Knee Extension Angular Velocity	BR	326 ± 125.7	295 ± 118.7	0.031	0.156	237 ± 119.4
Front Knee Extension Angular Velocity	Max	333 ± 127.7	326 ± 126.7	0.605	1.000	257 ± 116.1
Pelvis Rotation Angular Velocity	Max	666 ± 121.4	662 ± 111.5	0.818	1.000	729 ± 98.7
Torso Rotation Angular Velocity	Max	1094 ± 117.0	1096 ± 106.2	0.888	1.000	1148 ± 107.8

Note. The POI column represents the point of interest in which the corresponding kinematic velocities were recorded; Two different points of interest were used: the maximum of the velocity measurement throughout the throw (MAX) and the value of the measurement at ball release (BR). Angular velocity values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

**Adj. P-value<0.05*

Kinetics showed no statistically significant differences between the Rocker and Foot-up metric means. The mound position means were closer to the Foot-up Rocker means in both kinetic metrics, as displayed in Table 6.

Table 6

Maximum absolute and normalized varus torques for Rocker, Foot-up, and Mound throws

Kinetics	Rocker	Foot-Up	P-value	Adj. P-value	Mound
Mph to Normalized Elbow Varus Torque (mph/%)	12.4 ± 3.3	11.5 ± 2.4	0.103	0.308	11.8 ± 2.5
Normalized Elbow Varus Torque (%)	6.9 ± 1.5	7.1 ± 1.5	0.159	0.319	7.3 ± 1.4
Absolute Elbow Varus Torque (Nm)	120.4 ± 32.4	122.4 ± 30.3	0.434	0.434	128.3 ± 31.9

Note. All kinetic values listed are the maximum of their respective measurement throughout the throw. Normalization of elbow varus torque was done by dividing its absolute value by subject body weight (mass times gravitational constant) and subject height, then converted to percent by multiplying by 100. The MPH to Normalized Elbow Varus Torque ratio is calculated by dividing each subject's average pitch velocity by their average maximum normalized elbow varus torque. Elbow joint kinetic values in each row were reported as the mean ± the standard deviation of their respective conditions (Rocker, Foot-up, Mound). P-values and adjusted p-values represent the results of paired t-test comparison of rocker and foot-up means.

Discussion

This study found significant differences between the normal Rocker drill and the Foot-up variation of the Rocker drill regarding upper and lower body kinematic positions (at FP, MER, and BR) maximum kinematic velocities, and throwing performance. These results supported four of six hypotheses of this study. No significant differences were found with upper body kinetics. Additionally, lower body kinematic positions during the Foot-up variation were closer to the lower body kinematic positions of a normal pitching motion compared to the normal Rocker.

The lower half of the pitching motion is the starting point for the kinetic chain to efficiently deliver a pitch. First, the lead leg strides into Foot Plant and initiates the kinematic sequence acting as a foundation for the kinetic chain. Inefficient positions following stride Foot Plant may cause a cascade effect up the chain and negatively impact the rest of the motion. Two specific kinematic positions at stride Foot Plant which we use to describe the characteristics of this kinetic chain initiation are lead leg front knee flexion and pelvis rotation angle (Z-axis). After stride foot contact, the lead leg serves as the base of support for the rest of the motion while we believe the role of the pelvis to open (rotate towards the direction of the thrown ball) early enough to initiate the rotational sequencing of the kinetic chain.

The ideal amount of lead leg knee flexion at this position is unknown. However, previous research has shown that isometric knee extension torque peaks at around 50 degrees of knee flexion and decreases with more flexion (Haffajee, Moritz, & Svantesson, 1972). In this study, during the normal pitching motion, athletes had an average of 44 degrees of front knee flexion at foot plant compared to 61 degrees of flexion in the Rocker drill. Alternatively, the Foot-up Rocker variation had 51 degrees of flexion. This trend was consistent at each event of the delivery when knee flexion was recorded. As the athlete strides down the mound, they generate linear momentum towards the plate that is transferred rotationally up the chain following the planting of the stride foot, requiring the generation of a braking force in the front leg to act as a fulcrum for rotation. It is possible that having increased knee flexion in the lead leg at this point could be compromising the athlete's ability to properly extend their lead leg, produce this braking force, and transfer linear momentum effectively, whereas a more extended knee position could be more advantageous. Since the Foot-up variation resulted in significantly less lead leg knee flexion than was observed in the normal Rocker, the Foot-up variation may promote more efficient transfer of momentum superiorly through the kinetic chain. This coincides with previously published research about the lead leg in the pitching delivery in which lead leg knee flexion at Foot Plant and at Ball Release were found to be significant variables related to pitching velocity (Werner et al., 2008).

Following the stride in the pitching motion, the pelvis rotates to face home plate, which is then followed by rotation of the trunk in the same direction. The timing of these two segments' rotation is an essential part of transferring energy to the throwing arm through the kinematic sequence (Fleisis, Barrentine, Escamilla, & Andrews, 1996). Improper timing of pelvis rotation can have a negative effect on the timing of trunk rotation by prohibiting efficient loading and unloading of superior segments in the kinetic chain and may continue impeding the timing sequence of the remaining segment rotation. Consequently, the position of the pelvis at Foot Plant is another kinematic measurement of interest in describing the facilitation of efficient sequencing and energy transfer in the throwing motion. During the Rocker drill, mean pelvis rotation angle at Foot Plant was 26 degrees while the mean for the Foot-up variation of the Rocker was 38 degrees. Pelvis rotation angle at Foot Plant during the normal pitching motion in the present study was 42 degrees. The decrease in pelvis rotation angle during the Rocker drill suggests that the pelvis was completing full rotation towards home plate too late in the throwing motion. This observed delay in pelvis rotation along with increased lead leg knee flexion during the Rocker drill could create sequencing issues and an inefficient transfer of energy throughout the rest of the throw. These unfavorable positions could also be reinforcing poor mechanics in other aspects of the throw. Further, there is reason to believe a causal relationship exists between the observed decreases in both lead leg knee flexion and pelvis rotation angle while executing the Rocker drill.

Although the interaction between front knee flexion and pelvis rotation at Foot Plant is mostly unknown, a weaker base and increased front knee flexion could inhibit pelvis rotation. Increased knee flexion often translates the front knee towards home plate which causes translation of the pelvis toward the plate. As mentioned above, the lead leg acts as the fulcrum of rotation for the pelvis, and the translation of this fulcrum could inhibit the pelvis's ability to rotate on time which affects the rest of the kinematic sequence as discussed above. This also supports the idea that an inefficient position at Foot Plant in one area of the body can create a cascade effect of inefficient positions elsewhere, further highlighting the importance of prescribing drills that do not compromise efficient throwing positions.

Despite the lack of significant differences in upper half kinematics between the Foot-up and the normal Rocker drill, when looking at trunk kinematics, five significant differences were observed: trunk forward tilt at Ball Release, trunk rotation angle at Maximum External Rotation and Ball Release, and trunk lateral tilt at Foot Plant and Ball Release. Trunk position is seen as a key factor in the kinetic chain of a pitcher's delivery and is responsible for transmitting energy generated from the lower half to the upper half and more distal parts of the body (Kibler, Press, & Sciascia, 2006). Additional research has found a strong correlation between trunk rotational velocity and throwing velocity (Young, 2014). During the Foot-up Rocker variation, trunk positions at Foot Plant for lateral tilt and rotation angle were more similar to the normal pitching motion than in the normal Rocker. Lateral trunk tilt was the only trunk position metric at foot plant that was significantly different. In the normal Rocker drill, the trunk was more upright at foot plant and did not exhibit the same mean lateral tilt (-0.13 degrees) that is seen at foot plant in normal pitching motion (8.73 degrees) and the Foot-up variation of the Rocker (5.55 degrees). Additionally, subjects were able to achieve significantly more forward trunk tilt and lateral trunk tilt at ball release in the Root-up Rocker compared to the normal Rocker, with both metrics being closer to the normal pitching motion compared to the Rocker drill. This indicates that the Foot-up variation of the Rocker may allow athletes to achieve more trunk range of motion into Ball Release compared to the normal Rocker drill. This could be a product of the Rocker drill creating inefficient lower half positions making it difficult for the athlete to properly move their trunk into proper positions through Ball Release. Previous research has shown that athletes with greater forward trunk tilt at Ball Release have displayed increased ball velocity compared to those with a more extended trunk at Ball Release, further suggesting the heightened benefit of executing the Foot-up variation instead of the normal Rocker (Werner et al., 2008).

The primary limitations of this study were the variability of drill technique between athletes and the labeling of the Foot Plant event. First, athletes were given the same instructions for drills during the motion capture session, but there were slight variations in technique outside the control of instruction. Any subject with a visible inability to execute the drill were removed from the study. This included instances where the athlete's lead foot came off the ground in the normal Rocker drill. Second, difficulties arose in labeling "Foot Plant" for the normal Rocker drill throws since the foot typically stays in contact with the ground during the drill. To control for this variance, Foot Plant was labeled when the lead foot reached a minimum position along the vertical axis. Future studies would benefit from using force plates to quantify the timing of this event by directly measuring the onset of ground reaction force due to the stride foot. This event detection method would reduce variability of this event label by allowing the same method to be used for all conditions.

Conclusion

Our hypotheses that trunk and lower body kinematic position, and kinematic velocity means are significantly different at FP, MER, and BR between the Rocker and the Foot-up variation of the Rocker drill were supported. However, we failed to reject the null hypothesis that throwing arm kinematic position and throwing elbow kinetic means were the same. This evidence suggests that the normal Rocker drill could be compromising important lower half positions around Foot Plant during the throwing motion and that the Foot-up variation may provide a more effective constraint for achieving desirable mechanical changes. Additionally, these effects of the normal Rocker drill on lower half mechanics may also be creating improper movements and positioning throughout the rest of the delivery. Coaches and trainers should use the results of this study to consider the specific effects of each constraint to ensure the constraints that are being used do, in fact, progress throwing mechanics.

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