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LINEAR AND ANGULAR CONTRIBUTIONS TO BALL VELOCITY IN THE DELIVERY MOTION AMONG VARIOUS LEVELS OF BASEBALL INFIELDER

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The purpose of this study was to investigate the linear and angular contributions to ball velocity of the delivery motion among junior high school (group J), high school (group H), and collegiate (group C) baseball infielders by using 3D videography. A total of 54 infielders were asked to throw a baseball quickly and accurately with full effort. Our results indicated that the ball velocity increased with progression in player level (group J, 28.3 m/s; group H, 31.8 m/s; group C, 33.2 m/s). Angle and height of ball release were significantly larger in group J than in groups H and C. Contributions of the forward and upward translations of the body to the ball velocity were, respectively, 6% and 10−15%, with the rest due to the rotations of the body. These results indicate that the rotations of the body are crucial for the increase of ball velocity.

KEY WORDS: kinematics, development, 3D videography.

INTRODUCTION: The goal of a baseball infielder's throw is to catch with a running approach a baseball that has been hit by the batter, and then deliver it as quickly and accurately as possible to other fielders (Figure 1). Most previous studies on the baseball throwing motion have concentrated on the pitching motion (Fleisig et al., 1999; Sakurai et al., 1993; Matsuo et al., 2001; Stodden et al., 2001; Feltner & Dapena, 1986; Miyanishi et al., 1996). We know of no studies that deal with the kinematics of the delivery motions of position players and with the variation of those motions through various levels of player development.
The general motion of a rigid body can be described as a combination of translation and rotation. Thus, the absolute velocity of the ball is determined by the sum of the velocity of the centre of mass (CM) of the thrower (or, more exactly, of the thrower-plus-ball system) relative to the ground and the velocity of the ball relative to the CM. Dapena & Anderst (1997) studied the throwing motions of elite discus throwers from this point of view, and found that the contributions of the forward and upward translations of the body to the velocity of the discus were, respectively, 10% and 6%, with the rest due to the rotations of the body. The purpose of this study was to quantify the linear and angular contributions to the ball velocity of the delivery motion among young male baseball infielders to obtain a better understanding of the motion from mechanical and developmental perspectives.

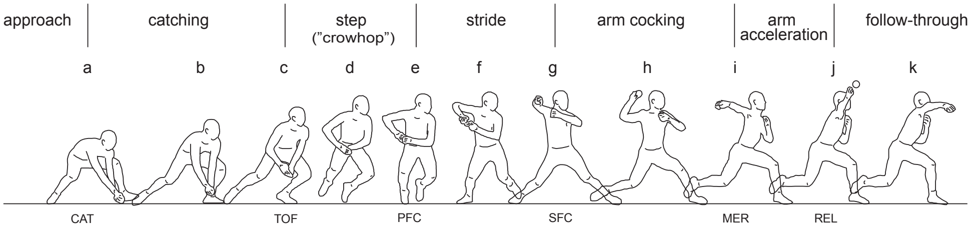

Figure 1: Definition of the seven phases in the delivery motion of a baseball infielder.

METHODS: Fifty-four skilled right-handed male baseball infielders, including 18 junior high school (age 13.2 ± 0.7 years: group J), 20 high school (15.8 ± 0.8 years: group H), and 16 collegiate (19.8 ± 0.8 years: group C), participated in this study. All of them were healthy and had no history of arm surgery or arm pain at present. Informed consent forms were signed by group C participants, and by the parents of the group J and H participants prior to the experiments. The mean standing height was significantly larger in groups H (1.72 ± 0.06 m)

and C (1.72 ± 0.04 m) than in group J (1.61 ± 0.06 m). The mean body mass was significantly larger in groups H (65.4 ± 7.4 kg) and C (68.8 ± 5.7 kg) than in group J (52.7 ± 8.4 kg).
Each infielder was requested to catch a ground ball rolled by a person in front of the shortstop fielding position, and then deliver the ball as quickly and accurately as possible with maximum effort toward a target (width: 1.4 m; height: 1.7 m) set up at first base, 35 m away. These deliveries were recorded using two high-speed 250 Hz genlocked video cameras (HSV-500C^3, NAC, Japan).
For each infielder, a single trial in which the ball hit the target was selected for subsequent analysis. Two-dimensional coordinates of 23 body landmarks and of the ball centre were manually digitized using a Video Motion Analysis System (Frame-DIAS, DKH, Japan). Three-dimensional (3D) coordinates of the body landmarks and of the ball centre were reconstructed using the direct linear transformation (DLT) method (Abdel-Aziz & Karara, 1971), and then smoothed using quintic spline functions (Woltring, 1986) with optimal cutoff frequencies (4-24 Hz) determined for each body landmark coordinate according to Wells & Winter (1980). The body segment parameters required for the calculation of the body CM motions were obtained from the standing height and mass of each infielder using de Leva's (1996) adjustments of the values reported by Zatsiorsky et al. (1990).
A one-way analysis of variance (ANOVA; unpaired) was performed using SPSS version 18 (SPSS Inc., Chicago, IL) to assess the differences in kinematic parameters between the three groups. A Bonferroni correction was also used to determine the differences between the three groups. The significance levels were set at $p < 0.05$ and $p < 0.01$ for each test.
The delivery motion was divided into seven phases based on six instants (catching the ground ball, CAT; takeoff the ground, TOF; pivot foot contact, PFC; stride foot contact, SFC; shoulder maximum external rotation, MER; and ball release, REL) as follows: approach (the start of the motion to a), catching (a-c), step (c-e), stride (e-g), arm cocking (g-i), arm acceleration (i-j), and follow-through (j to the end of the motion) (Figure 1).

RESULTS: Table 1 shows the release parameters. Ball velocity was significantly larger in groups H and C than in group J, and also significantly larger in group C than in group H. The angle of release was significantly larger for group J than for groups H and C. The height of release (as a percentage of standing height) was significantly larger for group J than for groups H and C.

Table 1
Release parameters.

	group J	group H	group C	significant differences
Ball velocity (m/s)	28.3 ± 1.7	31.8 ± 0.9	33.2 ± 1.5	J<H**, J<C**, H<C*
Horizontal velocity (m/s)	27.8 ± 1.9	31.5 ± 1.0	32.9 ± 1.6	J<H**, J<C**, H<C*
Vertical velocity (m/s)	5.0 ± 1.0	4.5 ± 0.6	4.1 ± 0.8	J>C**
Angle of release (deg.)	10 ± 3	8 ± 1	7 ± 1	J>H**, J>C**
Height of release (% BH)	90 ± 5	83 ± 7	84 ± 4	J>H**, J>C**

significant differences: * $p < 0.05$, ** $p < 0.01$

Table 2 shows the kinematic parameters of the system CM regarding the horizontal and vertical translations at each instant, and also the average values during the arm acceleration phase. Significant differences were found in 10 parameters between groups J and C, in three parameters between groups J and H, and in two parameters between groups H and C.
Horizontal velocity at SFC was significantly larger for group C than for group J. The horizontal angles at each instant and during the arm acceleration phase were significantly larger for group C than for group J, and also significantly larger for group C than for group H at SFC, and for group H than for group J at REL and during the arm acceleration phase. The heights of the system CM at SFC and REL were significantly larger for group J than for group

C, and larger for group H than for group C at SFC. During the arm acceleration phase, the D angle was significantly larger for groups H and C than for group J. Percentages of V_{HCON} and V_{ZCON} were significantly larger for group J than for group C, and larger for group C than for group J.

Table 2
Kinematic parameters[@].

	group J	group H	group C	significant differences
at PFC				
Horizontal velocity [V_H] (m/s)	2.8 ± 0.4	2.8 ± 0.3	2.9 ± 0.3	ns
Horizontal angle [H_a] (deg.) †1	− 8 ± 11	− 4 ± 6	1 ± 9	J<C**
Vertical velocity [V_v] (m/s)	− 0.3 ± 0.2	− 0.3 ± 0.2	− 0.3 ± 0.2	ns
Height of CM [H] (% BH)	47 ± 3	47 ± 3	45 ± 2	ns
at SFC				
Horizontal velocity (m/s)	3.1 ± 0.3	3.2 ± 0.2	3.3 ± 0.2	J<C*
Horizontal angle (deg.)	− 5 ± 8	− 2 ± 4	4 ± 6	J<C**, H<C*
Vertical velocity (m/s)	− 0.1 ± 0.2	− 0.2 ± 0.2	− 0.2 ± 0.2	ns
Height of CM (% BH)	45 ± 2	44 ± 2	42 ± 2	J>C**, H>C*
at REL				
Horizontal velocity (m/s)	1.7 ± 0.3	1.7 ± 0.2	1.7 ± 0.3	ns
Horizontal angle (deg.)	− 7 ± 9	1 ± 9	3 ± 6	J<H*, J<C**
Vertical velocity (m/s)	0.6 ± 0.2	0.6 ± 0.3	0.7 ± 0.1	ns
Height of CM (% BH)	47 ± 2	45 ± 3	44 ± 2	J>C*
Arm acceleration phase				
Horizontal velocity (m/s)†2	1.8 ± 0.3	1.9 ± 0.2	1.9 ± 0.2	ns
Horizontal angle (deg.) †2	− 8 ± 8	− 1 ± 9	2 ± 6	J<H*, J<C**
D angle [D_a] (deg.) †3	− 6 ± 9	2 ± 9	2 ± 7	J<H*, J<C*
V_{HCON} (m/s) †4	1.8 ± 0.3	1.8 ± 0.2	1.9 ± 0.2	ns
V_{HCON} (%)†4	6.4 ± 1.1	5.8 ± 0.8	5.7 ± 0.7	J>C*
Arm acceleration phase				
V_{ZCON} (m/s) †4	0.5 ± 0.3	0.5 ± 0.3	0.6 ± 0.2	ns
V_{ZCON} (%)†4	9.9 ± 6.0	10.8 ± 5.5	15.2 ± 4.7	J<C*

significant differences: * $p < 0.05$; ** $p < 0.01$; ns: not significant

[@]: The parameters were calculated based on the method reported by Dapena & Anderst (1997).

†1: A negative sign in the angle indicates that the deviation was toward the left in a view from overhead.

†2: The values indicate averages of the system CM during the arm acceleration phase.

†3: The values indicate the divergence angle between the horizontal direction of motion of the system CM during the arm acceleration phase and the horizontal direction of motion of the ball at release.

†4: These values indicated the effective velocities (m/s) and the contributions (%) of the horizontal and vertical velocities (V_{HCON} and V_{ZCON}, respectively) of the system CM to the horizontal and vertical velocities of the ball at release.

DISCUSSION: Although all infielders must throw the same distance (approximately 35 m), the ball velocity at REL was smaller in the group J infielders (Table 1). The only way that group J infielders can make the ball travel 35 m with a slower horizontal velocity is to allow it more time to travel before target contact. Thus, group J infielders had to increase the angle of ball release (to gain an increased vertical velocity of the ball at REL) relative to the other groups to increase flight time. Also, because the target height was constant across groups (1.7 m), it appears that the group J infielders also increased the absolute height of ball release (standing height x height of release as a percentage of standing height) to decrease the vertical range of motion (ROM) of the ball during flight; in turn, this allowed them to have a smaller angle of release than would have been required if the height of the ball at REL had also been about 90% of standing height in group J infielders. Thus, the changes in ball velocity, angle of release and height of release are all inter-related, and due primarily to the fixed target distance and height and to the smaller absolute ball velocity at REL in the youngest infielder group.

Overall, the system CM had 2.8 m/s of horizontal velocity at PFC. This value increased to 3.2 m/s at SFC. Pushing the pivot leg directly backward against the ground during the stride phase caused the increase of the horizontal velocity of the CM in the forward (i.e., throwing) direction. Thus, the group C and H infielders pushed strongly directly backward against the ground with the pivot leg while lowering the CM in comparison to the group J infielders. In turn, the horizontal velocity of the CM decreased from 3.2 m/s at SFC to 1.7 m/s at REL. This is due to a direct forward push against the ground with the stride leg. Thus, group C infielders strongly pushed directly forward on the ground with the stride leg while lowering the CM compared with the group J infielders.

The forward linear momentum of the thrower-plus-ball system contributes to the horizontal velocity of the ball, and the upward linear momentum of the system contributes to the vertical velocity of the ball (Dapena & Anderst, 1997). We calculated the average horizontal velocity and angle of the CM during the arm acceleration phase, and also the average vertical velocity of the CM in that phase. The average horizontal and vertical velocities of the CM were projected, respectively, on the horizontal and vertical velocities of the ball at REL. The percent increase in V_{HCON} was significantly larger for group J infielders than for group C infielders (Table 2). In contrast, the percent increase in V_{ZCON} was significantly larger for group C infielders than for group J infielders. These results suggest that group J infielders use an increased forward translation to increase the horizontal velocity of ball in spite of the fact that their CM travels in a more oblique direction (leftward: − 8 ± 8 deg.) in comparison with group H and C infielders. In the increase of vertical velocity of the ball, group C infielders use more upward translation than group J infielders.

The contribution of the horizontal velocity of the CM to the horizontal velocity of the ball was approximately 6% in the three groups. On the other hand, the contribution of the vertical velocity of the CM to the vertical velocity of the ball had a range of 10−15% in the three groups. These results indicate that 94% of the horizontal velocity of the ball comes from the rotation of the body, and 85−90% of the vertical velocity of the ball comes from the rotation of the body. Further studies should include an analysis of angular momentum.

CONCLUSION: The contributions of the translation and rotation of the body to the ball velocity in the delivery motion among the three levels of infielders were measured in this study. The forward and upward translation of the thrower made relatively small contributions to the velocity of the ball. Most of the velocity of the ball came from the rotation of the body. These results indicate the necessity for investigating the angular momentum of the body.

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