RELATIONSHIP BETWEEN FORCES EXERTED ON THE BALL BY THE FINGERS AND BACKSPIN OF THE BALL DURING BASEBALL PITCHING

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The purpose of this study was to investigate how the fingers generate the force to rotate the ball, with high-speed 3D videography. Velocities of the ball and finger joints, angles of finger joints, backspin rate, and forces exerted on the ball were calculated for fourteen varsity baseball players. Subjects were divided into two groups, i.e. G1 with large backspin rate and G2 with less backspin rate. There were differences in the patterns of joint angles of the proximal and distal interphalangeal joints, the direction of forces and the position of fingers relative to the ball between G1 and G2. A typical subject from G1 developed the F_{NOR} (the force from the finger tip to the center of ball) downward to resist centrifugal force and F_{TAN} (perpendicular to F_{TAN}) forward to accelerate the ball, while a typical subject from G2 exerted these forces in the reversed manner to G1. It seemed that the difference in force application resulted from the difference in the position of the fingertips on the ball.

KEY WORDS: backspin, forces, fingers, pitching, baseball, motion analysis

INTRODUCTION: Throwing a baseball is one of the most dynamic skills in all sports (Barrentine et al., 1998). Although many studies on baseball pitching have been conducted, there is little investigation on the movement of the fingers (Stevenson, 1985; Takahashi et al., 1999; Takahashi et al., 2000). Fingers are considered to be important body segments in generating the backspin of the ball, which generates Magnus force that lifts up the ball. However, there is little investigation of the relationship between the backspin of the ball and the fingers movement during baseball pitching. The purpose of this study was to investigate how the fingers generate the force to rotate the ball, with high-speed 3D videography.

METHODS: Fourteen varsity baseball players (8 pitchers and 6 fielders) volunteered to participate in this study as subjects. Two trials of fastballs for each subject were selected for the analysis. The hand and fingers were videotaped with two high-speed VTR cameras (NAC, MEMRECAM Ci) operating at 1000Hz to obtain 3D coordinates of ten landmarks on the wrist (W), metacarpophalangeae joint (MP), proximal and distal interphalangeae joints (PIP and DIP), tip of the middle finger (EIP), and on the ball with a DLT technique (Figure 1). This study focused on a phase from the instant of the maximal velocity of the wrist (WV_{max}) to the ball release (REL), which was defined as the instant of 1ms before the ball completely released off the fingers. Kinematic parameters calculated were the velocities of the ball at release (V_1) and the instant when the ball passed over the front edge of the home plate (V_2), velocities of W, MP, PIP, DIP, EIP of the middle finger, and joint angles of the middle finger. The backspin rate of the ball was obtained by counting the number of flames that needed to rotate the ball completely after REL. Force exerted on the ball by the fingers was estimated from the acceleration of the ball (F_{RES}). Because the ball was held by various area of the fingers until about 50% time from WV_{max} to REL, it was difficult to estimate the point of force application. Since the ball moved to the EIP after 50% time, EIP was assumed as the point of force application in this study. F_{RES} after 50% time was resolved into two components, the first was the component of F_{RES} directing from the EIP to the center of the ball as F_{NOR}, and the second was the component perpendicular to F_{NOR} as F_{TAN}. The angle and force data were normalized with the time from WV_{max} to REL and averaged. The significance level for the statistical analysis was set at 5%.

RESULTS AND DISCUSSION: Table 1 shows correlation coefficients between V_1, V_2, the difference between V_1 and V_2 (V_{1-2}), backspin rate, and the maximal velocities of all the joints. Maximal velocities of all joints significantly correlated with the backspin rate. Table 2 shows the

comparison of kinematic parameters between groups with larger backspin rate and smaller backspin rate (G1 vs. G2). The backspin rate of G1 was significantly larger than that of G2. In addition, V_1, V_2, and WV_{max} of G1 were significantly larger than those of G2. However, there were no significant differences in maximal velocities of the EIP, DIP, PIP and MP joints between both groups. Figure 2 shows the patterns of the force components exerted on the ball were similar in both groups. F_{NOR} rapidly decreased from ca 75% time while F_{TAN} increased gradually from ca 60% time and reached to the peak ca 20% time before the release. The peak value of F_{TAN} ca 80% time of G1 was larger than that of G2. Since F_{TAN} could exert the moment of force to the ball, the difference of F_{TAN} may result in the significant differences of the backspin rate. Figure 3 shows the angles of DIP, PIP and MP joints for G1 and G2. The joint angles of the DIP and PIP showed different patterns between G1 and G2. At the instant of WVmax, DIP of G1 extended and PIP flexed more than those of G2. G1 gradually extended the joints of DIP and PIP to ca 90% time, and then flexed those joints toward REL. On the other hand, G2 began to flex the PIP joint from ca 70% time while DIP kept extending. In addition, maximal PIP angle of G1 was larger than that of G2, although maximal DIP angle of G1 was smaller than that of G2. Figure 4 shows the movements of the ball and the middle finger, and the force components of typical subjects from groups G1 and G2. In subj.A, F_{NOR} was developed downward and F_{TAN} was forward ca 50% time. On the other hand, in subj.B, F_{NOR} was directed forward and F_{TAN} was very small. These results indicate that subj.A exerted F_{NOR} to prevent the ball from moving toward EIP and exerted F_{TAN} to accelerate the ball forward from ca 50% time and to generate the moment of force to the ball after ca 90% time. Subj.B was likely to have used F_{NOR} to accelerate the ball forward rather than preventing the ball to move toward EIP. The difference in the direction of the forces may be caused by the difference in the position of the fingers relative to the ball. Observation of Figure 4 reveals that at WV_{max}, the EIP of subj.A positioned the upper part of the ball and gradually moved toward the lower part of the ball. The EIP of subj.B positioned in the central part of the ball and his hand tilted backward.
These results imply that at the instant of WV_{max}, the hand or fingers should not tilt backward too much and EIP should locate on the upper part of the ball, so that F_{TAN} can accelerate the ball and to generate rotation of the ball and F_{NOR} can play a role to prevent the ball from moving toward EIP.

CONCLUSION: The purpose of this study was to investigate how the fingers generate force to rotate the ball, with high-speed 3D videography. There were differences in the patterns of joint angles, the direction of forces and the position of fingers relative to the ball between a large backspin rate group and a less backspin rate group. It seemed that these differences resulted from the difference in the position of the fingertips on the ball.

Table 1 Correlation Coefficient Matrix between Kinematic Parameters

	V_1 (m/s)	V_2 (m/s)	$V_{1\text{-}2}$ (m/s)	Backspin rate (rps)	$EIPV_{max}$ (m/s)	$DIPV_{max}$ (m/s)	$PIPV_{max}$ (m/s)	MPV_{max} (m/s)	WV_{max} (m/s)
V_1	-	0.961 *	0.145	0.635 *	0.876 *	0.835 *	0.936 *	0.890 *	0.913 *
V_2		-	-0.135	0.707 *	0.850 *	0.808 *	0.924 *	0.881 *	0.937 *
$V_{1\text{-}2}$			-	-0.257	0.096	0.103	0.047	0.037	-0.081
Backspin rate				-	0.490 *	0.452 †	0.576 *	0.516 *	0.749 *
$EIPV_{max}$					-	0.954 *	0.880 *	0.854 *	0.758 *
$DIPV_{max}$						-	0.863 *	0.811 *	0.737 *
$PIPV_{max}$							-	0.918 *	0.824 *
MPV_{max}								-	0.764 *
WV_{max}									-

*: $p<0.01$ †: $p<0.05$

Table 2 Mean and SD of Kinematic Parameters shown in Table 1

		V_1 (m/s)	V_2 (m/s)	V_{1-2} (m/s)	Backspin rate (rps)	$EIPV_{max}$ (m/s)	$DIPV_{max}$ (m/s)	$PIPV_{max}$ (m/s)	MPV_{max} (m/s)	WV_{max} (m/s)
G1	Mean	33.45	31.54	1.91	32.36	35.99	33.63	28.67	25.79	19.96
	SD	3.60	3.29	0.29	2.62	8.72	8.65	3.65	2.59	1.37
		†	†	n.s.	*	n.s.	n.s.	n.s.	n.s.	*
G2	Mean	31.58	29.42	2.16	26.98	34.57	32.21	27.58	24.49	18.56
	SD	5.30	5.10	0.54	2.71	13.32	12.36	5.40	3.79	1.16

*: $p<0.01$ †: $p<0.05$

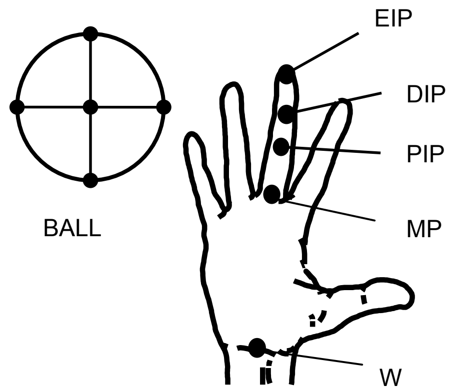
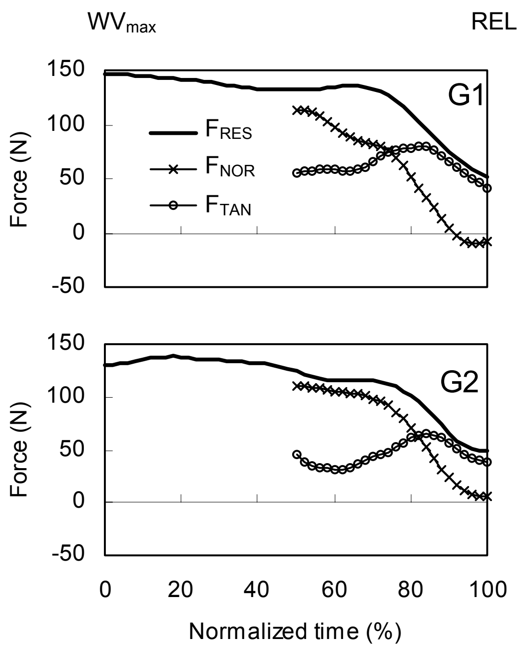


Figure 1 - Digitizing points on the hand and fingers.



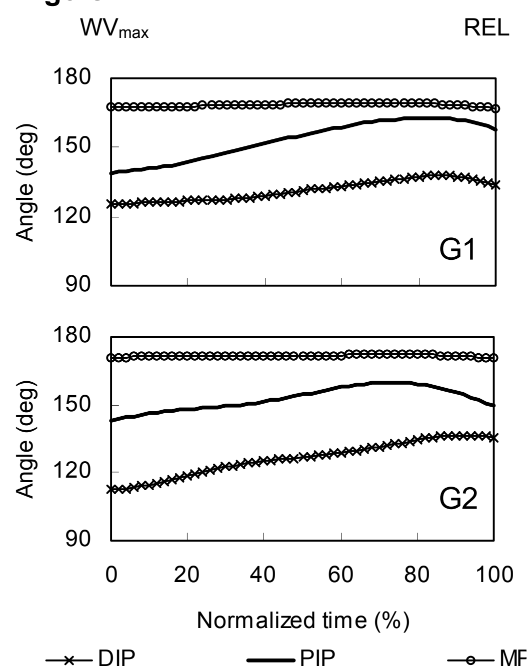


Figure 2 - The force patterns exerted on the ball by the EIP from WV_{max} to REL G1 and G2.

Figure 3 - The angle patterns of DIP, PIP and MP joints from WV_{max} to REL for G1 and G2.

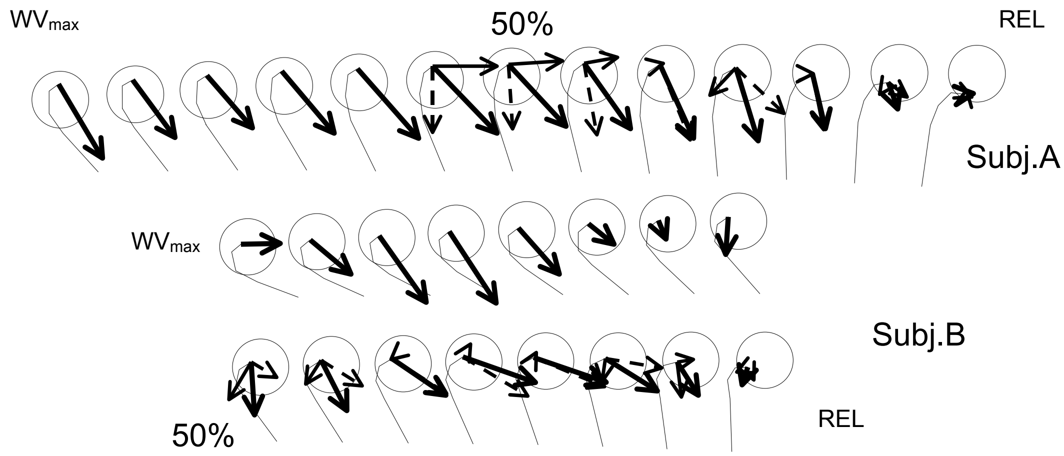


Figure 4 - The movements of the ball and the middle finger, and the force components for subject A and subject B. Thick arrows show the F_{RES}, dotted arrows show the F_{RES}, and thin arrows show the F_{TAN}.

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