CORRELATIONS BETWEEN TRUNK AND BAT KINEMATICS FOR BASEBALL PLAYERS CALCULATED USING BOTH INDIVIDUAL AND GROUP STATISTICS

Peter J Sinclair, Matthew Hollings, Jonathan Freeston

Discipline of Exercise and Sport Science, the University of Sydney, Sydney, Australia

This study aimed to investigate kinematic parameters associated with high batting velocity by using both group and individual analysis methods. Twenty seven junior baseball players each performed 35 strikes off a tee at speeds of 60, 80 and 100% of maximum; with pelvis, upper-trunk and bat kinematics measured by 3D motion analysis. The maximum values of all kinematic variables were positively associated with bat speed when assessed with both group and individual methods. For variables measured at impact, however, there were very different individual associations; with some participants showing strong positive correlations and others having similarly strong negative correlations with bat speed. These findings indicate that different players use different techniques to achieve high bat speeds.

KEY WORDS: baseball, batting, technique, correlation, individual

INTRODUCTION: Batting is one of the key offensive skills required in baseball and one of the most difficult skills in sport, with high performing players achieving successful hits in only 30% of attempts (Welch et al. 1995). Batted ball speed is an important variable which increases the batter's chance of reaching base safely and promoting run-scoring chances. It is influenced by a number of factors including bat speed, contact quality, bat weight and bat material (Crisco et al. 2002). High bat speed is the most important factor for achieving high batted ball velocities (Szymanski et al. 2009), and this is achieved through a coordinated sequence of body movements (Welch et al. 1995). Prior research, however, has not always been consistent in identifying kinematic features of fast bat swings. For example, Inkster et al. (2011) reported a higher angular velocity of the pelvis for faster swinging batters, while Dowling and Fleisig (2016) reported the opposite result.
Correlation analysis is often used to identify particular kinematic characteristics that allow athletes to perform at a high level. Because of differences in technique between individuals, however, it is possible that individual athletes can display trends opposite to those exhibited by group analysis (Salter et al., 2007). One reason for this is the fact that modelling of group performance can result in the identification of a "mythical" participant that does not represent any given individual (Dufek et al., 1995). The purpose of the present study, therefore, is to apply both individual and group analyses to a cohort of youth baseball players to identify characteristics associated with faster bat swings.

METHODS: Twenty seven baseball players (age±SD 15.9±1.8 yrs; height±SD 1.80±0.05m; mass±SD 74.8±8.9kg) were recruited from the NSW state under 16 team (n=15), the NSW state under 18 team (n=10) and NSW state senior team (n=2). Participants each performed 35 swings off a tee into a net. Initially, five swings were performed at maximum velocity with the bat-tip speed recorded for each trial. Average speed of these maximum trials was then calculated to determine target speeds for a further 10 swings each, randomised in blocks at 60%, 80% and 100% of maximum speed. Trials for the 60 and 80% target speeds were re-done if the resulting bat-tip speed was more than 10% higher or lower than target.
Ten 15 mm retro-reflective markers were attached to the skin to determine 3D motion of the upper-trunk, pelvis and feet. Markers were placed on the manubrium; vertebrae C7, T3, and S1; left and right ASIS; and the calcaneus and 3rd metatarsal of both feet. A standard baseball was wrapped in reflective tape to serve as its own marker, while two markers were placed proximally on the bat and one distal to determine its kinematics. 3D motion data (200 Hz) was captured using a 16-camera Cortex Motion Analysis System (Version 6.2, Motion Analysis Corporation Ltd., USA).

Kinematics of the bat and ball near impact were determined from un-filtered marker coordinates to avoid issues arising from the sudden change in velocity at impact (Dowling and Fleisig, 2016). The frame after ball contact was determined from the first frame where the ball marker moved 2 mm from the initial position and ball speed determined from the average of five frames after this point. Angular velocity of the bat and linear velocity of the bat-tip were determined via a quadratic function fitted to velocity measurements five frames before impact. Kinematics of the trunk and feet were determined from displacement data that was filtered at 19 Hz (Dowling and Fleisig, 2016). Angular displacement and velocity of the upper-trunk, pelvis and bat were calculated in the transverse plane using the C7 and manubrium markers for the upper-trunk, mid-point of the ASIS markers and S1 for the pelvis, and mid-point of the bat proximal markers and the distal marker for the bat. After rotating pelvis angle by 90° to make it consistent with upper-trunk angle, the angle of separation in the transverse plane was calculated as the difference between upper-trunk and pelvic angles. A positive separation angle indicates that the pelvis has rotated in advance of the upper-trunk. Stride Length was calculated from the distance between the mid-points of markers on each foot.

Correlations between various kinematic variables (Table 1) and bat speed were initially calculated for all data points (n=945). The same correlations were then calculated individually for the 35 trials performed by each participant. With n=945, very trivial correlations can be found to be statistically different from zero. The sizes of correlations were therefore reported according to Hopkins (2016) as “large” ($0.5 \le r < 0.7$), “very large” ($0.7 \le r < 0.9$) or “almost perfect” ($r \ge 0.9$). Correlations below 0.5 were ignored for the present paper so as to highlight only those making large associations that explained more than 25% of the variance in a relationship.

RESULTS: Mean values for all subjects are shown in Table 1. There was a significant increase in all variables with strike intensity ($p < 0.001$).

Table 1
Mean and Standard Deviations of kinematic measures for all subjects at each strike intensity

		60%	80%	100%
Variables measured at impact	Bat-tip linear velocity (m.s^{-1})	21.5 ± 2.0	28.3 ± 2.5	34.7 ± 2.5
	Ball speed (m.s^{-1})	21.0 ± 2.5	27.5 ± 2.9	33.0 ± 3.5
	Bat angular velocity (°.s^{-1})	1667 ± 161	2239 ± 200	2763 ± 220
	Bat handle linear velocity (m.s^{-1})	2.14 ± 0.99	2.67 ± 1.25	5.11 ± 2.03
	Pelvis linear velocity (m.s^{-1})	0.22 ± 0.16	0.29 ± 0.18	0.35 ± 0.20
	Pelvis angular velocity (°.s^{-1})	124 ± 62	134 ± 81	224 ± 118
	Upper-trunk angular velocity (°.s^{-1})	197 ± 76	252 ± 90	362 ± 110
	Separation angular velocity (°.s^{-1})	72 ± 51	117 ± 65	139 ± 112
	Stride length (m)	0.31 ± 0.05	0.34 ± 0.05	0.37 ± 0.05
Variables measured at maximum value	Pelvis angular velocity (°.s^{-1})	381 ± 65	512 ± 74	651 ± 61
	Upper-trunk angular velocity (°.s^{-1})	681 ± 149	960 ± 195	1228 ± 214
	Separation angular velocity (°.s^{-1})	328 ± 124	472 ± 172	621 ± 206
	Maximum Angle of Separation (°)	33.6 ± 9.2	38.5 ± 8.2	48.6 ± 9.5

Table 2 shows the correlations between the velocities of the bat-tip at impact with all other variables. Across all participants, there were almost perfect correlations present for ball speed and bat angular velocity; very large correlations for maximum angular velocity of the pelvis and upper-trunk segments; and large correlations for linear velocity of the bat handle at impact, angular velocity of the upper-trunk at impact, maximum angle of separation and maximum angular velocity of the separation angle.

Average correlations for individual subjects were larger for all variables than they were for the overall correlations for all participants calculated together; however, there were individual participants that produced substantial negative correlations for some variables measured at the point of impact. These large negative correlations were for linear velocity of the pelvis (2 participants), angular velocity of the pelvis (2 participants) and separation angular velocity (1 participant).

Table 2
Correlations between linear velocity of bat-tip and other kinematic measures.

		Correlations for All Subjects	Correlations for Individual Subjects		
			Minimum	Mean	Maximum
Variables measured at impact	Ball speed	0.92***	0.77**	0.93***	0.98***
	Bat angular velocity	0.96***	0.98***	0.99***	1.00***
	Bat handle linear velocity	0.65*	-0.32	0.70**	0.91***
	Pelvis linear velocity	0.22	-0.81**	0.44	0.95***
	Pelvis angular velocity	0.43	-0.84**	0.53*	0.91***
	Upper-trunk angular velocity	0.53*	0.55*	0.84**	0.96***
	Separation velocity	0.20	-0.67*	0.46	0.94***
	Stride length	0.45	0.14	0.79**	0.95***
Variables measured at maximum value	Pelvis angular velocity	0.85**	0.92***	0.97***	0.99***
	Upper-trunk angular velocity	0.78**	0.93***	0.97***	0.98***
	Separation velocity	0.59*	0.81**	0.91***	0.96***
	Maximum Angle of Separation	0.60*	0.42	0.87**	0.96***

DISCUSSION: This study examines how youth baseball players achieve increases in bat velocity across three different speed conditions. An almost perfect correlation between bat-tip velocity and bat angular velocity was expectedly observed. The correlation was lower for ball exit velocity (r=0.89) because of variability in the quality of bat-ball contact. This suggests that, if a coach is interested in developing bat swing speed, then a direct measure of bat speed is required; rather than relying on the measurement of ball velocity with a radar gun.

Overall, every variable assessed increased significantly with increasing bat speed. Maximum angular velocities of the pelvis and upper-trunk increased at higher swing speeds; with every participant demonstrating an almost perfect correlation between maximum angular velocities of the pelvis and upper-trunk and bat-tip velocity. While this finding is consistent with previous work among sub-elite Australian baseball players showing higher pelvis angular rotation velocities for more proficient players (Inkster, 2011), it contrasts with work by Dowling and Fleisig (2016) which reported higher pelvis rotation velocities for youth players (11.8 years, $743°.s^{-1}$) compared to high school (15.9 years, $686°.s^{-1}$) and professional players (20.8 years, $665°.s^{-1}$). From the findings of Dowling and Fleisig (2016), we had expected slower pelvis angular rotation velocities during swings performed at faster speeds. This contradiction in results between studies would be an interesting topic for future investigation.

The maximum velocities of rotation were all more highly correlated with bat speed than were those measured at the point of impact. While a positive rotation velocity of the pelvis at impact can reduce the joint velocities required in the trunk and upper limbs, there is a proximal to distal sequence of rotations throughout the kinetic chain (Escamilla et al., 2009; Welch et al., 1995). This process is likely to be similar to that during throwing and kicking actions, where higher velocities of the distal segments result in a kinematic induced deceleration of the more proximal segments (Putnam, 1993).

While the average of the individual correlations between bat speed and angular velocity of the pelvis was only 0.54, 20 out of 27 subjects produced a correlation stronger considered “strong”, with 16 out of 27 being “very strong”. The reason for this apparent contradiction is that two of the subjects produced strong negative correlations. Therefore, although most participants showed a strong relationship, the direction of this relationship was opposite for some participants (eg. Figure 1). Most participants were therefore displaying consistent trends with increasing ball speed, but using different strategies to achieve higher speeds.

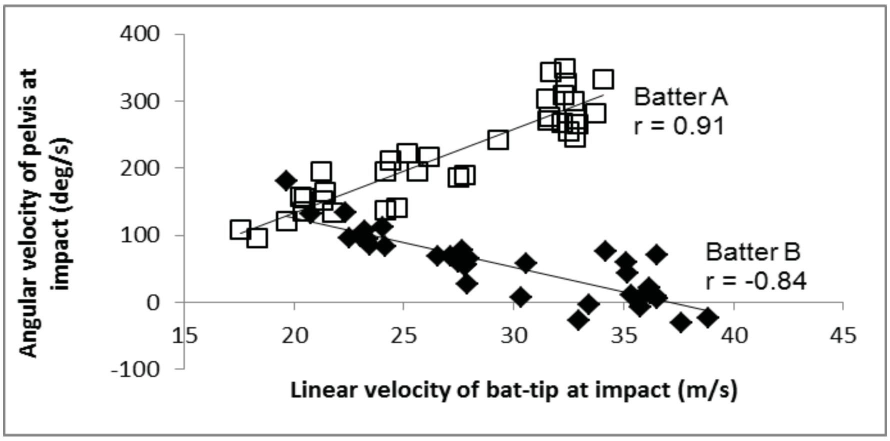

Figure 1. Correlation between bat-tip speed and angular velocity of the pelvis at impact for two exemplar participants

While there were different patterns of correlations exhibited by different participants, there was no apparent difference between levels of performance. Splitting the cohort into the 10 fastest and 10 slowest batters revealed no measurable difference in correlations between groups. When subjects like Batter B in Figure 1 exhibit opposite patterns of change to the majority of players, further investigation is warranted to understand what they do differently to achieve high bat speeds.

CONCLUSION: This study sought to determine the kinematic variables that contribute to increases in bat velocity across three different speeds among a group of youth baseball players. In contrast to some previous work, higher bat speeds were associated with increases in maximum angular rotation velocity of the pelvis and upper trunk as well as pelvis/upper trunk separation. Individual analysis revealed significant differences in correlations between key variables and bat-tip speed, indicating individual variability in techniques used to achieve bat-tip speed increases. This individual variability warrants further research to understand whether there are implications for performance and/or injury.

REFERENCES:

Crisco, J.J., Greenwald, R.M., Blume, J.D., Penna, L.H. (2002). Batting performance of wood and metal baseball bats. *Medicine and Science in Sports and Exercise,* 34, 1675-1684.

Dowling, B., Fleisig, G.S. (2016). Kinematic comparison of baseball batting off of a tee among various competition levels. *Sports Biomechanics*, 15, 255-269.

Dufek, J.S., Bates, B.T.,Stergiou, N., James, C.R. (1995). Interactive effects between group and single-subject response patterns. *Human Movement Science*, 14, 301-323.

Escamilla, R.F., Fleisig, G.S., DeRenne, C., et al. (2009). A Comparison of Age Level on Baseball Hitting Kinematics. *Journal of Applied Biomechanics*, 25, 210-218.

Hopkins, W.G. (2016). *A New View of Statistics*, http://newstatsi.org. Accessed 30 January 2017.

Inkster, B., Murphy, A., Bower, R., Watsford, M. (2011). Differences in the Kinematics of the Baseball Swing between Hitters of Varying Skill. *Medicine and Science in Sports and Exercise*, 43, 1050-1054.

Putnam, C.A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations *Journal of Biomechanics*. 26(Suppl 1), 125-35.

Salter, C.W., Sinclair, P.J., Portus, M.R. (2007). The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches. *Journal of Sports Sciences*, 25, 1279 – 1285.

Szymanski, D.J., DeRenne, C., Spaniol, F.J. (2009). Contributing factors for increased bat swing velocity. *The Journal of Strength & Conditioning Research,* 23, 1338-1352.

Welch, C.M., Banks, S.A., Cook, F.F., Draovitch, P. (1995). Hitting a baseball - a biomechanical description. *Journal of Orthopaedic & Sports Physical Therapy*, 22, 193-201.