

Effects of Pelvic Rotation, Trunk Rotation, Ground Reaction Force on Bat Speed
in Collegiate Baseball Hitters

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Honor's Project Final Paper
May 1, 2020

INTRODUCTION

Most of the current existing research on baseball is focused on pitching mechanics because kinetic and kinematic factors like elbow valgus torque result in common injuries like ulnar collateral ligament sprains. However, there are many gaps in the research about baseball hitting. Most of what exists describes proper mechanics for a swing, but doesn't describe much about performance enhancement or injury prevention. This study was done to understand more about the effects of pelvic rotation, upper trunk rotation (X-factor) and ground reaction force on bat speed in baseball hitting. Based on the current research, trunk axial rotation, pelvic rotation and ground reaction force are hypothesized to predict bat speed on a multiple factor linear regression analysis.

Kinetic Chain

The kinetic chain is a mechanism of human movement that describes how the body propels force from lower limb joints and moves up through connecting the links, or joints, of the body until it reaches the maximum force of the desired output. This mechanism has been confirmed to be prevalent in overhand throwing movements because it requires the whole body to generate the most force in all three planes of motion, like baseball pitching, or any form of swing involved in tennis, or badminton.

Ground Reaction Force

The human body needs to be able to keep equilibrium with gravity in order to be able to function. Ground reaction forces are defined as the equal and opposite forces of the player's weight times the acceleration of gravity in the X and Y planes of motion¹¹. During the foot contact phase, past research has shown that force in the positive X and negative Y direction of the stride leg and shear force in the negative X and positive Y direction of the stance leg create the force couples that push the hips into rotation¹². However, Welch stops at this observation, so this study will be looking to

understand which specific factors of the ground reaction force directly correlate to bat speed of the baseball swing with pelvic and upper torso rotation.

Pelvic Rotation

Because the opposing ground reaction forces on each leg push the pelvis into rotation, the pelvis has an important effect on the beginning links of the kinetic chain. In McCulloch's study on the asymmetries in ranges of motion in stance and stride leg of baseball pitchers, researchers found that older, more experienced players had more external rotation of the stride hip as compared to stance hip⁶. This finding confirms the use of the hip joint in the kinetic chain in repetitive rotational movement patterns, like baseball pitching and swinging. However, this study is looking to quantify the velocity of pelvic rotation and understand how it correlates to the bat speed in the swing.

X Factor (Trunk Rotation)

The X factor is the difference in angle between the upper torso and pelvis, and has been examined as integral for the propulsion of power from the lower extremities to the upper extremities. In Szymanski's study comparing resistance and ballistic training programs on high school baseball players, the groups with the ballistic medicine ball training had statistically significant increases in bat speed¹². This can be attributed to the development of athletes' stretch shortening cycle and their ability to transfer energy up the kinetic chain by pushing their muscle's stretch limits before concentrically contracting due to muscle spindle reflexes. This study displays the athletes' ability to develop torso rotational strength and use it to ultimately amplify bat end speed. It also confirms the use of the upper torso in the kinetic chain. Further, the "X-factor," or upper torso rotation, has confirmed importance in baseball pitching, badminton, and tennis, but is not examined in baseball hitting. Because the similar repetitive rotational movement pattern is present in baseball hitting, this study looks to confirm the presence of the X factor in the kinetic chain of the baseball swing.

In Zhang's study, skilled badminton players generate higher angular velocities after completing the entire range of motion in their X factor rotation, whereas novice players make contact with the shuttlecock while they are still in the rotation of their upper trunk and don't reach as high velocities in their forehand smash, confirming importance of the X factor in the rotational movement pattern¹⁴. However, it is uncertain about what other factors could be increased to increase forehand smash velocity. Therefore, this study looks to identify what factors are statistically significant in increasing bat speed.

Blast Motion Sensor

One of the mechanisms that will be used to record angular and linear bat speed is the Blast Motion Sensor that is placed on the handle of the bat during a swing. A validation study was done to test the validity and accuracy of the motion sensor by comparing it to the 3D motion capture system along with 2 other hitting motion sensors. An R squared value, or coefficient of determination, was recorded at .9172, meaning the Blast Motion Sensor has high validity when compared to the golden standard of the 3D motion capture system. The Blast Motion Sensor will aid in capturing bat speed during this study as it is valid and accurate¹.

Swing Mechanics

The baseball swing is a high force movement pattern, so to understand the forces placed on the body, the swing is divided into several events that include lifting the front foot off the ground, front foot contact with the ground, and bat contact with the ball. This event phasing was used for the data collection of this study. The swing has also been divided into phases to understand what kinetic and kinematic factors occur in each phase⁷.

Stance Phase (Wind-Up or Cocking Phase)

As weight shifts to the stance (back) leg and the upper torso and pelvis rotates in the negative direction for the back swing, the stride (front) toe lifts off the ground. During this phase, the athlete begins the “cocking” or wind-up phase where a counter movement is created using the stretch shortening cycle. This is a protective mechanism meant to prevent overstretching, but is used to the athlete’s advantage because it initiates the forward rotation by reflexively contracting the muscle that is overstretched.

Stride Phase

Next is the stride phase that can be identified by the foot making contact with the ground. As with any ground contact, ground reaction forces respond and the kinetic chain is initiated. During this phase, the pelvis reaches peak loading of the counter movement.

Drive Phase

After the stride phase, the drive phase follows and the upper torso reaches peak loading of the counter movement while the hips reach peak unloading which is quantified as maximum velocity. This creates a separation between the upper and lower segments of the kinetic chain, which allows the pelvis to reach peak force before the following segment of the kinetic chain, so it can transfer the full potential of power possible up the kinetic chain. The separation creates an angle between the two segments called the X Factor allowing a way to quantify that separation¹⁴.

Ball Contact

Finally, at ball contact, the pelvis and shoulders continue to rotate about the axis of the trunk to create the maximum linear velocity of the bat to hit the ball¹³. With these phases, the ground reaction forces can be defined and its effects on other links in the kinetic chain can be quantified.

METHODS

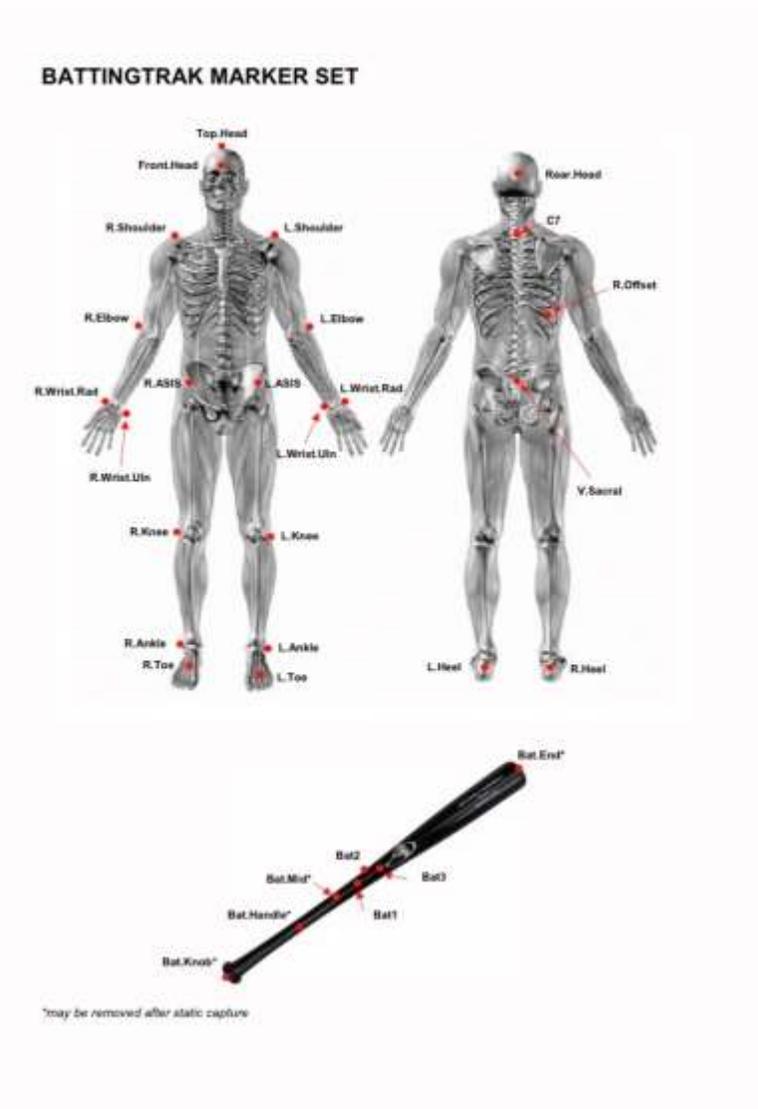
Subjects

10 collegiate baseball players from the Point Loma Nazarene University baseball team between the ages of 19 and 23 (5 left handed and 5 right handed) were measured in an 8 camera 3D motion capture system. All participants signed informed consent forms before participating in the study.

Set Up and Procedure

A baseball tee and net were set up in the indoor lab for the participants to swing in the capture volume on the force plates. The system was calibrated before each new session to ensure accurate results. All players were instructed to perform normal batting practice warm ups before swinging in the lab. 28 reflective markers were placed on bony landmarks around the joints of the participants to estimate 3D global locations of the joints, and 7 were on the bat. To ensure the markers would stay during the high intensity movements, Luko Tape and TufSkin were applied as needed.

During each recorded movement, the markers will be captured using a motion analysis system of 8 visible-red cameras (*Kestrel*, Motion Analysis Corp., Santa Rosa, CA)





with the *Cortex* motion capture software at a sampling rate of 240 fps. Ground reaction force (GRF) data will be collected using two force plates (Optima, AMTI, Watertown, MA) interfaced with the motion analysis system at a sampling rate of 1800 Hz. Kinematic and kinetic points will be extracted from the time-series data for subsequent statistical analysis².

Once ready for recording, the participants stepped on the force plates in anatomical position for the static capture. After a 3 second static capture of the

marker set with a pre-marked bat, participants were able to take practice swings until they were comfortable swinging the bat with the markers on and with tee placement. 8-10 swings were recorded with the motion capture system. In addition, the Blast Motion Sensor captured the swings for bat speed and were recorded to correspond with the numbered Cortex system recordings.

CONCLUSION

It was hypothesized the ground reaction force, pelvic velocity, and upper torso rotation would be significant indicators of bat speed. From the multiple factor linear regression analysis of bat speed, the results showed that 97% of the variance in bat speed can be explained by bat angular speed, X Factor, and stride length ($p = 0.01$), but there were no significant kinetic predictors of bat speed as hypothesized (i.e. ground reaction force). However, kinetic variables were found to influence specific kinematic variables (i.e. Ground reaction force correlated to X factor) further confirming

the presence of the kinetic chain, and displays indirect influence of the hypothesized variables. This study displays more insight on which variables influence each other in the baseball swing.

Bat Speed	Stance Length	X Factor	Bat Angular Speed
70.03m/s \pm 7.15	25.20 \pm 13.50	19.30356 \pm 13.1146	2505.39 \pm 200.25

X Factor

Further, this study explained more about the genesis of the X factor. It was correlated to Back Leg ground reaction force in the negative X direction, or increased amount of force in the negative X direction was correlated to an increase in upper torso rotation ($r = -.832, p = .003$).

Pelvic Velocity

The regression for pelvic velocity found that the anterior impulse on the back leg was a significant predictor of pelvis angular velocity ($r^2 = 0.477, p = .027$).

DISCUSSION

Bat Angular Speed

The equation that explains the relationship between linear velocity to angular velocity is:

$$\text{linear velocity} = \text{radius} \times \text{angular velocity}$$

The radius, in this case, is referring to the distance between the bat and the hitter in the arc that the hitter makes with the bat throughout the swing. It makes sense to draw the conclusion that the linear velocity of the bat would be correlated to the angular velocity because the difference between the two variables is distance that is being measured. Angular velocity looks at the rotational component and the linear velocity focuses on the forward movement.

Stride Length

Monti discusses that a longer stride delays hip rotation through the kinetic chain leading to a poor performance, and on average should be about 3.8 times the batter's hip width⁶. However, in this study, increased stride length in combination with an increased X factor and bat angular velocity predicted bat speed. The three biggest (in terms of height and muscle mass) participants in this study had the longest stride length and the fastest bat speed. It makes sense that the players who are tallest, therefore having longer levers, will have the longest stride length. Their strides sometimes were even too long to stay on the two force plates. These players were also the heaviest of the group, indicating that they have more muscle mass and generated the most amount of power (recorded by the BlastMotion Sensor), often resulting in the fastest bat speed. Further research would need to be done to confirm the correlation between stride length and bat speed because the small sample size of this study could explain why they were correlated here.

X Factor

X Factor was one of the factors that was originally hypothesized to be correlated with bat speed because it could help quantify the kinetic chain in other sport specific rotational movement patterns like pitching, tennis swing, and badminton forehand smash. Because the results did confirm its correlation to bat speed, these findings could validate the presence of the kinetic chain in the baseball swing. Further confirming these findings however, there was a correlation between X factor and stance leg ground reaction force in the negative X direction. This points to the use of the kinetic chain because the athlete presses their back leg into the ground behind them (negative direction) and the ground reaction force that responds initiates the chain by generating the initial amount of force that will transfer up the successive links of the body until reaching the upper torso and ultimately resulting in peak velocity of the swinging bat. These two factors are far away from

each other in proximity on the athlete (GFR begins at the toe and X factor ends at the upper trunk), so their correlation can only be explained by the kinetic chain's transfer of energy.

Pelvic Velocity

Although the pelvic velocity did not correlate directly to bat speed, the regression analysis of pelvic velocity found that anterior stance leg impulse was a predictor. The momentum equation states that

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

Impulse is a change in that momentum over time. As the hitter moves his back leg anteriorly, it has momentum because it has a constant mass and velocity. However, as it increases or decreases in velocity over a period of time it has impulse, so an increase in the impulse indicates an increase in velocity¹¹. Further, because it is a predictor of pelvic velocity, this is further confirming the use of the kinetic chain, even if it is not directly correlated to bat speed. The stance leg moves during the drive phase of the swing as weight shifts from the stance to the stride leg. This must occur just before the hips reach peak velocity in order for the impulse to be a predictor of the hip velocity, but they occur during the same phase. Further research could be done to examine the cause and effect of the lower extremity kinetic chain, like the muscle activation of specific muscle groups that create maximum velocity of the pelvis, or the angle of pelvic and its effect on the kinetic chain or bat speed.

In conclusion, not all of the hypothesized factors directly predict bat speed, but they all have a correlation to some piece of the kinetic chain in the movement pattern, and therefore, indirectly affect bat speed and the overall efficiency of the baseball's swing.

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