# Timing Adjustment of Baseball Batters Determined from Motion Analysis of Batting

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**Abstract**

It takes only 500 ms for a baseball to reach the batter after it leaves the hand of the pitcher. We at NTT Communication Science Laboratories set ourselves the task of figuring out how information is processed in the mind of skilled hitters, enabling them to respond and hit the baseball within this extraordinarily brief interval of time. Here, we explore the information processing time structure in the brain of a batter using motion analysis technology during actual pitcher-batter match-ups.

*Keywords: athlete, motion analysis, timing control*

## 1. Challenge of hitting a baseball

A baseball batting average of .300 in a season is quite respectable, considering that no player has ever reached an average of .400 in the entire history of professional baseball in Japan. A .300 average means that the batter safely gets a hit three times for every ten times at bat. One might initially assume that the pitcher has an obvious advantage, but actually this reveals a fascinating aspect of the game. The batting average can be attributed to the distance that separates the pitcher from the batter, traditionally established as 18.44 m. When the ball is thrown at a velocity of 140 km/h, it takes only about 500 ms for the ball to traverse this distance. The batter must determine within a split second precisely when and where the ball is going to cross the plate, then spatially and temporally synchronize his swing to connect with the ball.

What sort of processing and control goes on in the batter's mind and body to achieve this enormously difficult motor task has long been a subject of fascination, but the mechanism remains elusive. We explored this issue by conducting precise measurements of the batter's motions when he was squared off at the plate facing a pitcher. In this article, we share some of our findings and reveal the timing structure of batting when the batter is facing an actual pitcher [1].

## 2. Measurement of motion in pitcher-batter match-ups

In batting, there are two critical factors that the hitter must keep in mind: the *temporal factor*—how long it takes the ball to reach the plate after it leaves the hand of the pitcher—and the *spatial factor*—the trajectory of the ball as it approaches the plate. Let us first consider the temporal factor by measuring and analyzing the batter's movements when hitting two types of pitches: straight fastball pitches and off-speed changeup pitches*. A changeup is actually a slow pitch that is meant to deceive the batter into thinking it is a fastball and thus throw off the batter's timing.

The data gathered in this study were derived from two former professional baseball players—a pitcher and a batter—as subjects, both of whom were right handed. The trials were conducted by having the batter

* Motion was measured in this work using an inertial sensor motion capture suit (MVN Biomech Link manufactured by Xsens) at a sampling rate of 240 Hz. With the MVN Biomech Link suit, we were able to capture hitting and pitching action in the field and unrestrained swinging action of the subject without the use of a camera.

Table 1. Information on typical pitches and bat swings.

| Pitch type | Ball speed (km/h) | Time from pitcher's ball release to bat contact (ms) | Swing speed (km/h) | Outcome |
|---|---|---|---|---|
| Fastball | 123.9 | 496 | 114.4 | Strong hit |
| Changeup | 103.7 | 579 | 124.4 | Strong hit |
| Changeup | 109.9 | 533 | 106.0 | Miss |

swing and try to hit the balls thrown by the pitcher from the mound (at a regulation distance of 18.44 m from the plate) toward the catcher behind the plate. The order in which the two types of pitches (changeups or straight fastballs) were thrown was randomly determined by a computer, so there was no way for the batter to anticipate which type of pitch was coming next.

The pitcher threw the ball at velocities ranging from 125.1 km/h for straight fastballs (standard deviation 2.6 km/h) to 101.3 km/h for changeup pitches (standard deviation 4.5 km/h), so from pitcher's hand to hit, the ball was in the air for an average of 451 ms for straight fastballs (standard deviation 10 ms) and for 581 ms for changeup pitches (standard deviation 22 ms).

For the purposes of this discussion, we will consider three typical swings as illustrated in **Table 1**: a power swing that hits a straight fastball, a power swing that hits an off-speed changeup, and a swing that misses a changeup pitch.

## 3. Batting time structure

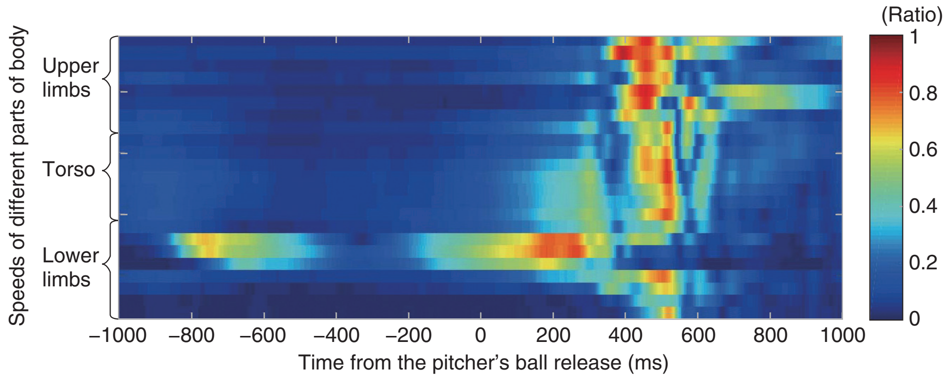
Let us first consider the batter's swing motion in addressing a straight fastball as the basic batting motion structure in baseball. A heatmap representing relative speeds of different parts of the batter's body is shown in **Fig. 1(a)**. This heatmap makes it easy to recognize the overall spatiotemporal structure. To make it easier to see what is going on, the findings are presented as a ratio of the data to the maximum speed of different parts of the batter's body to the time of the ball release, within the range of analysis (*i.e.*, 1000 ms before and after the pitcher releases the ball). The red portions in the figure represent faster movement.

In **Fig. 1(b)**, we can see time waveforms and characteristic event times for speeds of different parts of the batter's body: lower limbs, torso, and upper limbs. The batter estimates the timing as he raises his forward leg in synch with the pitcher's motion, then steps out with his forward leg as he shifts his center of gravity. About 350 ms after the ball has left the pitcher's hand, the batter plants his forward foot, stops the shift in the center of gravity, and increases the speed of his upper limbs (*i.e.*, his arms) while rotating his torso. One can see that a power hit involves a chainlike transmission of energy that begins in the legs and is transmitted to the torso, then to the player's arms, and finally to the bat in the form of bat head speed [2]. The characteristics of this movement, the so-called *kinetic chain*, are not confined to batting but are a fundamental sequential motion in many hitting and throwing sports. For example, they also exist in the swinging of a golf club, smashing the badminton birdie, and other maneuvers [3].

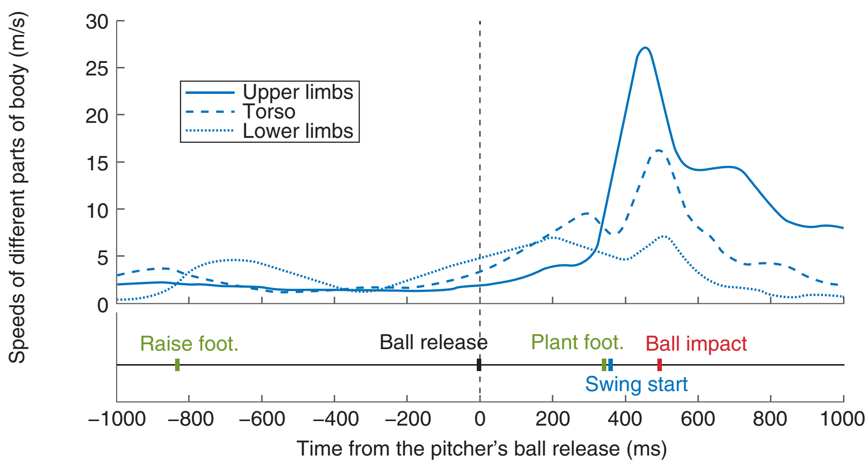
## 4. Changeups: when and how to respond?

Since there is no way for the hitter to know in advance if the next pitch will be a straight fastball or an off-speed changeup, he typically takes the stance of a player anticipating a fastball [4]. When the batter begins a swing motion expecting a fastball but then realizes the pitch is a changeup, he has to adjust his timing to fill the additional 90 ms before the ball reaches him, which thus requires a so-called pause (*tame*).

Once committed to a continuous swing, when and how is the batter able to adjust his movements? A comparison of the timing of successful swings for a changeup hit and a fastball hit is shown in **Fig. 2**. If one focuses on the velocity waveform of the batter's arms and the event timing, it is apparent that the batter delays the beginning of his swing when faced with a changeup, which means that the impact timing is also delayed. When the hitter's legs and torso turn, one can see that the waveforms are more or less the same regardless of pitch for approximately the first 300 ms after the ball is released from the pitcher's hand, but a change suddenly occurs as highlighted by the arrow in Fig. 2. The movement of the player's torso region (long dashed lines) abruptly slows when




(a) Heatmap




(b) Time waveforms

Fig. 1. Time structure of baseball batting.

dealing with a fastball but continues at the same speed when addressing a changeup pitch. Finally, in **Fig. 3**, we observe a downward motion in the movement of the batter's hips. In other words, the batter steps out with his forward foot while lowering his center of gravity; then when responding to the changeup pitch, he continues the downward shift, which allows him to adjust his foot placement timing and delay his swing.

In the case of a missed swing, the waveform is practically identical to the straight fastball hit; the batter stops shifting his torso downward, plants his leading foot, then goes into a swing with the same timing as when addressing a straight fastball. Thus committed, the batter is unable to adjust his timing to the slower changeup and misses the ball.

The data in Fig. 3 reveal that the batter begins to adjust his movement for a changeup pitch about 300 ms after the ball leaves the pitcher's hand. It takes another 150–200 ms for the batter to physically respond after visually confirming that the pitch is a changeup. Under the assumption that the batter obtains visual confirmation of a changeup and responds within 150 ms, the information needed to make a decision must be obtained within 150 ms after the ball leaves the pitcher's hand, which is equivalent to a travel distance of about 5 m in the air. Baseball coaches are fond of telling their players to keep their eyes on the ball until the bat makes contact with the ball, but with the limitations of human vision and reaction time, information about the latter half of the ball's trajectory is completely useless.

Although the findings presented here are based on a single former professional baseball player, we

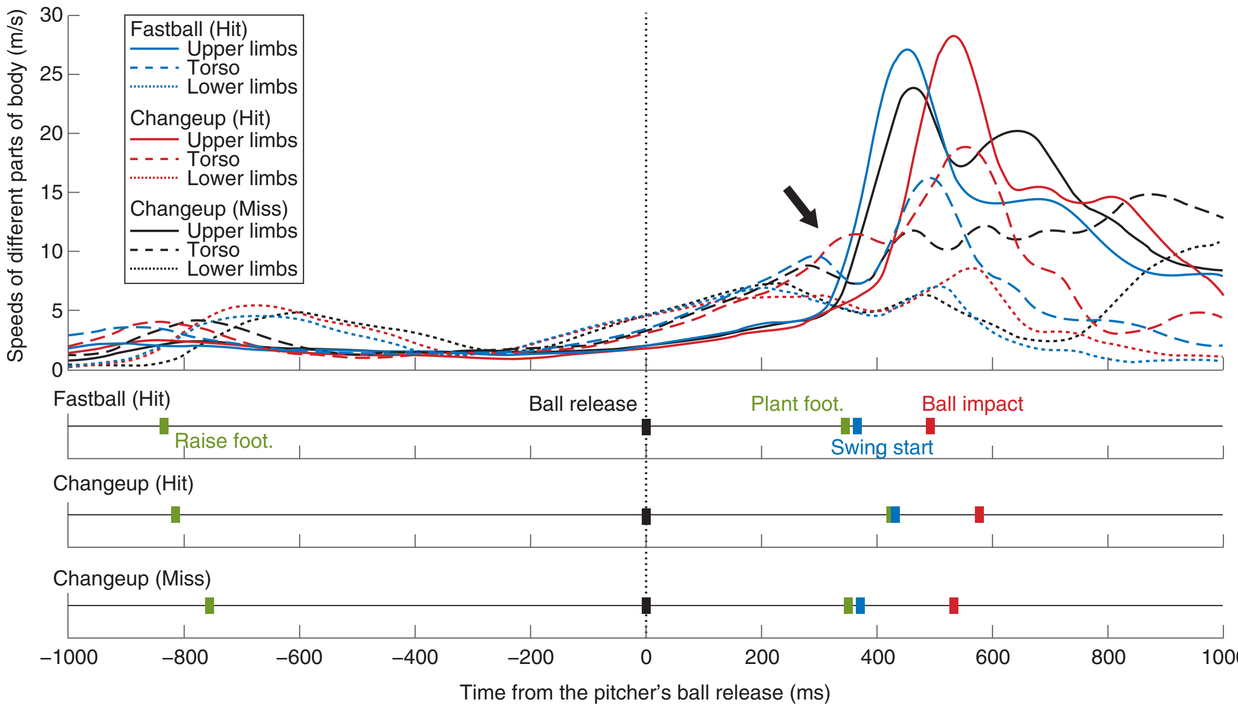



Fig. 2. Speeds of different parts of batter's body and characteristic event timing.

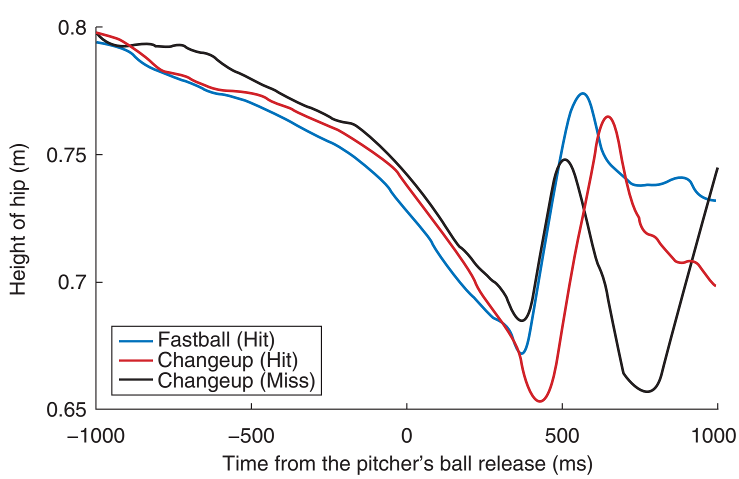



Fig. 3. Height of batter's hip and ball release timing.

obtained identical results for another former professional baseball player when measured under the same conditions. In other words, we observed the same shift in timing as the second player lowered his center of gravity about 300 ms after the ball left the pitcher's hand. Even more interestingly, we observed the same timing shift at 300 ms after the ball was released for a woman batter on a professional softball team. Our findings reveal that within a time frame of about 500 ms, figuring out how to obtain information enabling the hitter to make a decision (or from the pitcher's perspective, how to prevent the hitter from obtaining this information) within 150 ms after the ball leaves the pitcher's hand—after subtracting the time needed for the batter to adjust his stance based on visual confirmation of the pitch (about 150 ms) and the time needed for the batter to follow through with a swing (approximately 200 ms)—is critically important in determining whether the batter actually hits the ball or swings and misses.

## 5. Future development

This study focused on the critical time frame of a pitch lasting about 150 ms after the ball leaves the pitcher's hand. During this 150-ms window, the pitcher's pitching form and the trajectory of the ball are important pieces of information, but which is more important in helping the batter decide how to deal with the approaching pitch is not at all clear. To help answer this question, we are conducting a study using virtual reality (VR) technology as part of this project. VR gives us the ability to freely manipulate both the pitching form and the trajectory of the ball, so we can measure the batter's response in the same way as having the batter swing at pitches on a baseball field. With the addition of VR, we expect to corroborate the study's findings.

This study marks an important first step in identifying the mechanism involved in triggering motor tasks as whole-body movements within extraordinarily short reaction times of less than 500 ms as faced by batters on the baseball diamond. Gaining a clear understanding of how skilled hitters are able to move and maneuver when they are at the plate will provide valuable clues as to what to focus on in the future work in order to really comprehend this split-second reaction timing. To examine these elements in greater detail, we are employing VR, scrutinizing the motor tasks involved in maneuvering the arms, and conducting periodic measurements of brain activity. We are convinced that this approach will bring us a clearer understanding of the fundamental mechanism involved in batting.

We would also note that the analytical approach described here could be readily adapted to the onsite needs of capturing and assessing the performance of individual players. Even the limited task we set ourselves here of dealing with changeup pitches has produced some interesting results. We are now beginning to understand the different strategies players have for dealing with changeups, some of which are successful and others less successful, and feeding those insights back to the teams that we support and work with. Continuing to build on these efforts will enable us to directly aid and support the actual game on the field while at the same time contributing to further development of sports and brain science.

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### Trademark notes




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He received a Ph.D. in medicine from the Graduate School of Medicine, Osaka University, in 2014. He joined NTT Communication Science Laboratories in 2016. He has been engaged in research on human motor control and biomechanics in sports. He has recently been focusing on the relationship between sports performance skill and brain function in athletes. He is a member of the Society for Neuroscience, the Japan Society of Physical Education, Health and Sport Sciences, the Japanese Society of Biomechanics, and the Japan Society of Baseball Science.