High School and College Baseball Pitchers’ Response and Glove Movements to Line Drives

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The timing of glove movements used by baseball pitchers to catch fast approaching balls (i.e., line drives) was examined in two tests to determine the responses and temporal characteristics of glove movements in high school and college baseball pitchers. Balls were projected toward the head of participants at 34.8 m·s⁻¹ (78 mph) on average in an indoor test and at speeds approaching 58.1 m·s⁻¹ (130 mph) in a field test. Pitchers caught over 80% and 15% of the projected balls in the indoor and field tests, respectively. Analyses of glove responses indicated that all pitchers could track the line drives and produce coordinated glove movements, which were initiated 160 ms (± 47.8), on average, after the ball was launched. College pitchers made initial glove movements sooner than high school pitchers in the field test (p = 0.012). In contrast, average glove velocity for pitchers increased from 1.33 (± 0.61) to 3.45 (± 0.86) m·s⁻¹ across the tests, but did not differ between experience levels. Glove movement initiation and speed were unrelated, and pitchers utilized visual information throughout the ball’s flight to catch balls that approached at speeds exceeding the estimated speeds in competitive situations.

Key Words: reaction time, anticipation, vision, field study, sports

Impact injuries to baseball pitchers that result from a ball struck by a batter can be significant, especially when the ball hits the unprotected head of the player. While these injuries represent only a small percentage (3%) of all injuries to pitchers (Dick, 1999), such injuries can be fatal and represent a substantial problem in sports medicine (Nicholls, Elliott, & Miller, 2004). For pitchers at the college level, to avoid these injuries they must produce rapid glove and body movements in response to balls that can approach at speeds as high as 54 m·s⁻¹ (Nicholls, Elliott, Miller, & Koh, 2003). For Little League Baseball pitchers, it was found that the face was the most commonly injured body part and that incidents involving the pitcher being hit by a ball accounted for 49% of all pitcher related injuries (Mueller, Marshall, & Kirby, 2001). To reduce these types of injuries, reductions in ball exit velocities have been recommended to afford pitchers more time to generate a glove response (Owings, Lancianese, Lampe, & Grabiner, 2003).

Over the last several decades several studies have evaluated the response capability of players to respond to and catch fast approaching balls (e.g., Brandt, 1998; Cassidy & Burton, 1997; Owings et al., 2003; Williams & MacFarlane, 1975). In one analysis of the pitcher’s response time, Cassidy and Burton (1997) reviewed several laboratory and field studies and concluded that a pitcher needs approximately 400 ms to protect himself from a batted ball. In a study by Brandt (1998), participants responded to balls projected from an air cannon, and the relationship between the ball’s travel time and
the probability of success in deflecting the ball with the glove was determined. Based on these indoor tests, Brandt concluded that the minimum safe ball travel time for a pitcher to respond to a batted ball is approximately 380 ms. More recently, Owings et al. (2003) used a similar methodology to evaluate the timing limitations of young athletes ages 8 to 16 years to approaching balls, and found that the younger performers had longer response latencies than the older performers.

While previous projects provide an initial understanding of the response capabilities of pitchers and fielders, we find that these studies rely on the use of the “standard” reaction-time (RT) test methodology to evaluate a fielder’s response to a batted ball. As such, these studies may not generalize well to actual game and/or field situations, since RT is generally taken as the time from the onset of an unanticipated stimulus to the start of the response. In these studies, anticipation is controlled so that it does not influence RT. In fact, if the player can anticipate completely, RT can easily be reduced to zero, making the notion of “reacting” to the stimulus meaningless (Poulton, 1950; Whiting, 1991). In a fielding situation, the visual perception of the batted ball unfolds over time as the ball flies toward the player (Regan, 1997; Regan & Vincent, 1995), and certainly does not appear as a sudden stimulus as in laboratory experiments.

To further evaluate how pitchers respond (catch, deflect, or avoid) to balls projected rapidly toward them (i.e., line drives) after pitching a ball, we conducted two tests. The first part of the study was conducted indoors, with high school and college pitchers responding to balls projected at them with moderate velocities up to 40.2 m·s$^{-1}$. In order to better simulate a competitive-game situation, the second part of our study was conducted with more appropriate and realistic experimental conditions. This test evaluated performance in an outdoor baseball stadium; pitchers threw game-speed pitches at a strike zone behind home plate and then responded to balls returned back at them at much faster speeds, which ranged from 40.2 to 57.7 m·s$^{-1}$.

With these test conditions, we examined the pitcher’s general response capabilities as well as the timing of the glove’s first movement to catch the ball relative to the beginning of the ball’s flight, or the glove’s movement onset time (MOT), and the glove’s average velocity to address three questions: (a) Can pitchers coordinate glove movements in order to catch or deflect fast approaching balls? (b) Do pitchers initiate their movements early in the ball’s flight and move faster when their movements are successful? (c) Do college pitchers have more skilled capabilities (faster, more accurate movements) than high school pitchers?

### Methods

Eight right-handed high school (HS) and college (C) male baseball pitchers participated in the study. Two additional high school pitchers and one left-handed college pitcher served as replacements for individuals unable to attend the outdoor portion of the study. Age, height, and weight for participants varied by grade level, as shown in Table 1.

<table>
<thead>
<tr>
<th>Experience level</th>
<th>Age (yrs)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High school</td>
<td>16.9 (0.83)</td>
<td>1.8 (0.06)</td>
<td>77.7 (11.74)</td>
</tr>
<tr>
<td>College</td>
<td>20.7 (1.22)</td>
<td>1.8 (0.06)</td>
<td>91.7 (9.70)</td>
</tr>
<tr>
<td>All</td>
<td>18.9 (2.20)</td>
<td>1.8 (0.07)</td>
<td>85.1 (12.63)</td>
</tr>
</tbody>
</table>

All participants were members of their school’s baseball program, and each had more than 5 years of experience pitching and 12–16 years of competitive baseball experience. After the experimenter described the task and procedures, each participant (and guardian for the high school participants) provided his voluntary consent to perform in the experiment and to be videotaped. All participants were paid $25 for taking part in the study and all wore a Rawlings catcher’s helmet-mask, a padded chest protector, and a fielder’s glove. The Human Subject Research Committee at Exponent approved the test procedures.

The first set of pitching and catching movements was completed in an artificially illuminated indoor studio. Performers stood on a flat surface 18.4 m away from a 91.4 × 152.4 cm target, threw regulation (23 cm) baseballs to the target adjacent to a standard competition home plate, and responded to standard-size training balls projected by a pitching machine (Jugs Curveball Pitching Machine, Jugs...
Co., Tualatin, OR) positioned behind home plate. One participant elected to utilize an L-shaped protective screen placed 305 cm in front of the pitcher to block balls projected in the vicinity of his lower torso.

Six high-speed video cameras (240 fps, Falcon Analog System, Motion Analysis Corp., Santa Rosa, CA) were mounted onto support structures that hung from the ceiling above the pitching machine to record the 3-D ball trajectory as it approached the pitcher. Another six video cameras (240 fps, Falcon Analog System) were similarly positioned above the pitching area to capture the performer’s limbs, torso, and head kinematics. Calibration of the system was achieved from a small 4-point calibration device to define the X-Y-Z axes and a 500-mm wand to establish the camera linearization parameters. The system tracked marker motions to within 1 mm accuracy. After calibration, the pitcher’s kinematics were obtained from reflective markers placed on the various joint articulations, the protective face mask, helmet, upper-body pad, and fielder’s glove. A radar gun (R1000, Jugs Co.), which was placed behind the pitcher’s area, captured and displayed the speeds of balls pitched by and projected toward the pitcher. The radar gun was calibrated using a tuning fork and methods consistent with manufacturer instructions.

The second part of the test was conducted at the baseball stadium on the California State University, Long Beach campus. The pitching mound and home plate areas were consistent with, and unchanged from, conditions used for intercollegiate play.

An air cannon, developed by the Louisville Slugger Research and Development Division, served as the ball-return to project balls toward the pitcher’s head. Two plywood boards (61 x 81 cm), with a microswitch placed between them, served as the strike-zone target and activated the cannon when a pitched ball contacted the target. The end of the cannon (where projected balls exited) fit through a 25-cm (10-in.) circular hole in the center of the target. A protective screen (1.8 x 1.8 m) was placed on the vertical plane above the back edge of home plate and was covered with a black cloth to occlude the pitcher’s view of the air cannon and experimenter.

The time delay between the pitched ball’s contact with the target and air cannon’s projection of a ball toward the pitcher was approximately 8 ms. Four NTSC video cameras (TRV-900, Sony Corporation of America, New York) were used to document the pitcher’s movements. Two of the cameras were placed behind the pitcher’s mound to provide views of the radar gun’s digital output and the movement of the pitcher, and two cameras were placed in the area near the third base line to provide a side view of the pitcher’s actions as well as the pitcher and air cannon. A high-speed video camera (MotionXtra HG-LE, Redlake MASD, LLC, San Diego) was placed near the third base line and provided a view of the pitcher’s actions (windup, delivery, and catching response). The Redlake video was captured and stored at 250 frames per second directly into a computer, with 4-mm resolution of the glove and ball positions. The Jugs radar gun was placed behind the participants and measured the speeds of balls pitched and projected by the air cannon. Ball speeds recorded from the radar gun compared favorably with speeds digitized off the high-speed video ($r = 0.98$).

The procedures required each participant to provide his consent to participate and be videotaped, and complete a 15-min warm-up session. Next, each participant was instructed to pitch a ball to the target and then respond to a ball projected at him from the ball return apparatus (i.e., pitching machine or air cannon).

For the indoor test (Part 1), we were interested in whether pitching motion was a factor in how pitchers responded to approaching balls. As such, participants completed a set of 10 to 12 trials using a stretch pitching motion, and a second set of trials using a wind-up delivery. The participants used self-determined rates for the pitches thrown at the target. The experimenter attempted to trigger the projected ball as closely as possible to the contact of the pitched ball with the target during the indoor testing; however, this procedure resulted in a delay of approximately 0.5 s from the ball-target contact until the projected ball exited the pitching machine.

In the outdoor test, only pitches from the stretch position were performed, and pitchers were instructed to throw pitches at speeds consistent with game conditions. The pitching-catchling task was completed in sets of 12 pitches on average ($\pm 4$), as participants were allowed to throw more (or fewer) pitches at their discretion. Ball return speeds were increased after participants had completed a trial set.
The motion capture system (Motion Analysis Corp., EVaRT software) used in the indoor study recorded movement information about the pitcher and glove as well as the projected ball from the pitching machine. The components of glove velocity were calculated by differentiating the position data of the glove markers. These data were combined to obtain the glove velocity magnitude and direction. The glove velocity-time trace was used to determine when the glove started to move in the direction of the “ultimate” or “desired” position (i.e., position where the glove would catch the ball). Then, movement onsets were determined from the corresponding acceleration-time profile and indicated when the glove first accelerated toward its “desired” position. Specifically, movement onset was calculated using three criteria as established by Peper, Bottsma, Mestre, and Bakker (1994): one component of glove acceleration was directed to its “desired” position for at least 100 ms, the acceleration magnitude had to exceed 3.8 m·s$^{-2}$, and the acceleration magnitude could not dip below 0.9 m·s$^{-2}$.

The end of the glove movement was determined a priori as the time when the ball first entered the glove or reached the vertical plane of the glove. Glove velocity was then calculated as the average resultant velocity from the glove’s movement onset until the time when the ball reached the pitcher. In the outdoor portion of the study (Part 2), an NTSC video was used for qualitative analyses of the behavioral responses for all trials. The high-speed video-capture system was used to quantitatively analyze 36 movement responses of the pitchers. These high-speed (250 Hz) responses were analyzed using standard motion analysis techniques (i.e., frame by frame digitization).

Time-series analyses were completed to calculate ball flight characteristics (i.e., duration to pitcher) as well as pitching and catching characteristics (i.e., pitching stride, throwing motion endpoint, fielding ready position, movement onset of catching response, and catching movement time). The glove movement onset was defined as the glove-hand’s initial movement toward the approaching ball subsequent to the pitching motions and independent of changes in lower body and torso positions. The resultant average glove velocity was calculated as the change in distance from the glove’s first movement to the ball until the ball was caught or at the glove’s plane, and divided by the duration of the glove’s movement. Movement in both horizontal and vertical planes was analyzed to determine the resultant velocity.

Two nonparametric dependent variables included the overall performance of responses to approaching balls—categorized by the behavior generated (i.e., a defensive reflex or a coordinated catching movement)—and the overall success of movements attempting to catch the ball. Mann-Whitney U inferential tests were completed to determine statistical significance for the nonparametric measures. As well, we measured two temporal variables related to glove kinematics: (a) the timing of the glove’s movement initiation or MOT relative to when the ball was projected at the performer and (b) the movement speed of the glove used to intercept the approaching ball. As no differences were found between pitch types (wind-up vs. stretch) for any dependent variable ($p’s > 0.05$), data were collapsed across these conditions. Given the disparate experimental conditions (i.e., ball return methods, ball approach speeds, environmental surroundings), separate mixed-model ANOVAs were used to compare between-group (competitive level) and within-subject factors (catch vs. miss) for the indoor and field tests.

### Results

Both HS and C pitchers produced coordinated glove movements to catch (or deflect) balls that varied as a function of ball approach speed and trajectory. All participants threw pitches at a target, entered a crouched position, and then produced a coordinated reaching movement to catch the projected balls (Figure 1). Analysis of the glove displacement-time profiles revealed a relatively invariant pattern for each pitcher’s pitching motion, followed by a brief period of inactivity and then a pitcher-initiated glove movement to catch the ball. Because of variability in the trajectory of the returned ball and the ready position of the pitcher, glove movements

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\footnote{We chose MOT, instead of the RT, as the descriptive measure for movement initiation as pitchers could follow the pitched ball and anticipate when and if a ball would be projected at them. MOT was calculated as the duration of time from the instant the ball was projected toward the pitcher to the point when the pitcher initiated a response to catch the ball.}
to catch the ball varied in direction, magnitude, and speed (Figure 2). In all instances, regardless of the speed of the returned ball, pitchers made a reaching movement to catch the ball. These movements began with the glove at the torso level, generally in front of the chest, and moved to the location of the ball’s flight trajectory. Further, pitchers did not respond reflexively or defensively with movements to protect their head.

Further indications that pitchers could effectively respond to fast approaching balls were indicated by their ability to catch balls at speeds up to 46.4 m·s\(^{-1}\) for HS pitchers and 53.6 m·s\(^{-1}\) for C pitchers in the field test. The percentage of catches/deflections was relatively low (15%) in the field test, in which ball flight durations were on average 372 ms, and less than 320 ms in the fastest ball return trials. During the indoor test, pitchers caught a much higher percentage (83%) of the balls that approached them at more moderate speeds of 35.0 m·s\(^{-1}\) (± 0.1 m·s\(^{-1}\)) on average, with corresponding ball flight time durations of 481 ms (± 18 ms). No differences were found between HS and C pitchers, \(p = 0.386\).

Figure 1 — Schematic showing a participant (1) throwing a pitch, (2) entering a crouched “ready position,” (3) producing a coordinated reaching movement to catch the projected ball, and (4) catching the ball.
Glove timing and speeds were similar between successful (caught or deflected outcomes) and unsuccessful (missed) movements. In the indoor test, the average MOT was 171 ms (± 37 ms) for successful interceptive movements and did not differ significantly from the missed movements (152 ms, ± 54 ms), $p = 0.158$. The average glove velocity in indoor tests for successful trials was 1.11 m·s$^{-1}$ (± 0.33 m·s$^{-1}$), which was numerically slower than the average mistimed glove velocity (1.55 m·s$^{-1}$, ± 0.76 m·s$^{-1}$) but not statistically different, $p = 0.174$. In the field test, the average glove velocities (Figure 4, bottom) for both catches/deflections and misses averaged 3.45 m·s$^{-1}$ (± 0.83 m·s$^{-1}$) and were statistically similar, $p = 0.234$. A regression analysis showed rather weak relationships between MOT and glove velocity in both tests ($r < 0.16$), indicating that the start of the movement and speed of the movement were not coupled.

While glove velocities remained the same, C pitchers initiated sooner in the ball’s flight compared with HS pitchers. In the indoor test, the average glove velocity varied between HS and C participants, with values of 1.26 m·s$^{-1}$ (± 0.74 m·s$^{-1}$) and 1.40 m·s$^{-1}$ (± 0.48 m·s$^{-1}$), respectively (Figure 3, bottom). Although a trend was found for C pitchers to move faster than the HS pitchers, the difference was not statistically reliable, $p = 0.171$. Similarly, glove speeds for C pitchers (3.64 ± 1.02 m·s$^{-1}$) in the field test were slightly greater than for HS pitchers (3.18 ± 0.42 m·s$^{-1}$), but these differences were not significant, $p = 0.574$. As shown in Figure 3 (top), the glove MOT in the indoor test for catches/deflections produced by C performers was shorter on average (134 ± 42 ms) as compared to HS performers (189 ± 31 ms), and marginally significant, $p = 0.063$. In the field test, the average MOT (Figure 4, top) for the C pitchers (126 ± 35 ms) was statistically lower than for the HS pitchers (209 ± 31 ms), $p = 0.012$. 

Figure 2 — Exemplar glove displacement-time profiles for three pitching and catching trials (top) and corresponding acceleration-time profiles (bottom).
Discussion

One primary goal of this project was to provide insight about how skilled pitchers respond to fast approaching line drives hit toward them, and to extend earlier work on this general issue of fielding line drives. While our results include safety precautions not typical of actual game situations (e.g., pitchers wearing a catcher’s mask) that may alter pitcher behavior, the test conditions matched the pitcher behaviors (pitching and fielding), included ball approach speeds that would meet and exceed normal game conditions, and afforded an empirical method for evaluating pitcher response in realistic game-like situations.

The findings from both tests indicate that experienced players can track balls rapidly approaching them and produce coordinated glove movements in an attempt to catch them. Specifically, high school and college baseball players were capable of catching balls approaching in the range of 31.3–40.2 m·s⁻¹ (70–90 mph) with a very high rate of success. As ball approach speeds increased in the field test to values over 44.7 m·s⁻¹ (100 mph), pitchers in both high school and college tracked and avoided contact with the fast approaching balls, but successfully intercepted them at a lower percentage rate.

Analyses of the MOT indicate that pitchers began their movements after only a relatively short period of time that the ball had been in flight, sometimes under 100 ms. While the more experienced college pitchers began their glove movements sooner than the less experienced high school pitchers, the onset time did not become systematically shorter as ball speeds increased. Also, there were no significant differences in the timing of the glove’s

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**Figure 3** — Glove MOT (top) and glove velocity (bottom) for catches/deflections and misses for both high school and college performers in the indoor test.

**Figure 4** — Glove MOT (top) and glove velocity (bottom) for catches/deflections and misses for both high school and college performers in the outdoor test.
initiation and movement speed between successful and unsuccessful movements. Surprisingly, pitchers’ glove movements to missed balls were not initiated later or slower than successful movements, contrary to the notion that fast approaching balls are missed because pitchers cannot move their glove in time or quickly enough.

Taken together, the findings from these tests clearly show that pitchers began moving their glove early in the ball’s flight and adjusted the glove velocity in accordance with the ball’s speed (Peper et al., 1994), and were not responding to the ball with a preprogrammed or planned ballistic action void of corrective feedback processes.

The results presented here suggest that high school and college pitchers are capable of responding to and avoiding injury from a line drive approaching their head. Even with the balls projected at very fast speeds, high school and college performers were able to initiate a response to catch the ball very early in the ball’s flight. This of course did not always result in a successful catch. But these results suggest that, if the ball were projected directly at the pitcher’s head in a game, the pitcher would have enough time to bring the glove to the area of the head to deflect, or perhaps even catch, the ball at speeds beyond 44.7 m·s$^{-1}$ (100 mph), which is consistent with estimates of the highest batted-ball speeds from human performance testing and game situations (Brandt, 1998; Crisco, Greenwald, Blume, & Penna, 2002). Moreover, we would expect the capabilities of the pitchers to be even greater in actual game situations as cues about the bat-ball contact characteristics are observed.

At the same time, however, various conditions (e.g., fatigue, weather, noise, distractions of baserunners, stress) could potentially distract the pitcher from the fielding task. Nevertheless, the notion that a high school or college pitcher is a “sitting duck” and will at some point be struck (and possibly injured) by a batted ball is not supported by our findings. In fact, the results from the tests reported here indicate that the alert and attentive pitcher can initiate meaningful responses to batted balls of the highest likely speeds during a game situation, and has the ability to avoid being injured by contact with the ball.

References


