Published in final edited form as:

Optom Vis Sci. 2017 August ; 94(8): 789–796. doi:10.1097/OPX.0000000000001100.

A Pilot Study of Horizontal Head and Eye Rotations in Baseball Batting

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Abstract

Purpose—The purpose of the study was to measure and compare horizontal head and eye tracking movements as baseball batters “took” pitches and swung at baseball pitches.

Methods—Two former college baseball players were tested in two conditions. A pitching machine was used to project tennis balls toward the subjects. In the first condition, subjects acted as if they were taking (i.e. NOT swinging) the pitches. In the second condition, subjects attempted to bat the pitched balls. Head movements were measured with an inertial sensor; eye movements were measured with a video eyetracker.

Results—For each condition, the relationship between the horizontal head and eye rotations was similar for the two subjects as were the overall head-, eye-, and gaze-tracking strategies. In the “take” condition, head movements in the direction of the ball were larger than eye movements for much of the pitch trajectory. Large eye movements only occurred late in the pitch trajectory. Gaze was directed near the ball until about 150ms before the ball arrived at the batter, at which time gaze was directed ahead of the ball to a location near that occupied when the ball crosses the plate. In the “swing” condition, head movements in the direction of the ball were larger than eye movements throughout the pitch trajectory. Gaze was directed near the ball until about 50ms-60ms prior to pitch arrival at the batter.

Discussion—Horizontal head rotations were larger than horizontal eye rotations in both the “take” and “swing” conditions. Gaze was directed ahead of the ball late in the pitch trajectory in the “take” condition, while gaze was directed near the ball throughout much of the pitch trajectory in the “swing” condition.

Keywords

head movements; eye movements; baseball; batting

Baseball batting is widely considered one of the most difficult tasks in sport. Professional batters have less than half a second to decide whether and where to swing the bat.¹ One of the most popular and enduring axioms in baseball is “keep your eye on the ball”. In spite of the common use of this phrase, there are little data demonstrating whether baseball batters can and do keep their eyes on the ball when swinging at pitches.

In hitting a baseball, batters must judge both when and where (vertically) the ball will arrive. In order to make these judgments, batters could use pre-pitch cues such as the pitcher's tendencies.² They could also make use of visual information after the pitch is released such as the direction of the seams on the ball.^{2,3} Information about the trajectory of the ball could also be derived from motion of the ball on the retina, or from signals associated with pursuit eye and pursuit head movements. Studies on tracking and catching fly balls suggest that trajectory information associated with pursuit movements predominates over information from retinal image motion.^{4,5,6,7,8,9}

Estimates of when the ball will arrive are likely not independent of estimates of where the ball will arrive. For example, the ball's vertical drop will be greater when the time to collision is longer. In this paper, we focused on horizontal movements during baseball batting. These movements are likely related to judgments of temporal and spatial properties of baseball pitches.

There are three published studies on eye and head movements over the course of an entire baseball pitch.^{10,11,12} In the first of these, Hubbard and Seng¹⁰ filmed Major League baseball players during batting practice. Hubbard and Seng concluded that during the *swing* both eye movements and head movements in the direction of the pitched ball were uncommon and eye movements stopped well before the ball reached the batter. It was also observed that the amplitude of head movements (in space) varied depending on whether the batter swung at the pitch or "took" (no swing or only a partial swing) the pitch. Larger head movements were more likely to be utilized when taking pitches than when swinging at pitches.

Bahill and LaRitz¹¹ performed a second study on eye and head movements in baseball. They obtained quantitative data on eye (in the orbit) and head (in space) movements associated with baseball pitches. Subjects, consisting of graduate students, collegiate baseball players, and one Major League Baseball player viewed a ball pulled toward them with a pulley system attached to a motor. The vertical motion of the ball was minimized and subjects were not allowed to swing a bat at the "pitches". The major findings in the study were as follows. First, the professional player used similar-sized eye and head movements to track the pitches while the other subjects made unequal eye and head movements. Second, while the professional player tracked the ball accurately (gaze error <2deg) until the ball was about 5.5 feet in front of the plate, the other subjects tracked the ball accurately only until about 9 feet in front of the plate. Third, one of the novice subjects did not attempt to track the ball continuously, but rather made a large predictive saccadic movement to a location in front of the ball. This saccade was perhaps made in an attempt to briefly foveate the ball as it crossed the plate.

In a third study, Fogt and Zimmerman¹² quantified the horizontal eye and head movements of inter-collegiate baseball players in tracking (but not swinging at) pitches. On average, subjects rotated the head to a greater extent than the eye(s) throughout much of the pitch and foveation was maintained through much of the pitch. If one were to attempt to predict the eye movement behavior of experienced baseball players based on these three studies, many potential conclusions could be reached. It might be that subjects "give up" smooth-pursuit

tracking with the eyes prior to the ball reaching the plate. Alternatively these subjects may try to track the ball with the eyes as long as possible. Finally, subjects may smoothly track the ball with the eyes for a period of time and then make a saccadic eye movement to the end of the pitch trajectory. Head-movement behavior is similarly difficult to predict. It may or may not be the case that baseball batters turn the head in the direction of the ball when swinging at pitches.

Given these possible outcomes, it is clear that more data are needed on eye and head movements when hitting a baseball.

The purpose of this study was to measure the horizontal rotational eye and head movements of batters when these batters swung at pitched balls, and to compare these data to those when the same batters were told to “take” pitches. In this case, “take” means that the subject knows prior to the pitch that he will not swing at the pitch. Deliberately taking the first pitch is sometimes employed by batters to gauge the speed of the pitcher's fastball.^{13,14}

Methods

The study was approved by The Ohio State University Biomedical Institutional Review Board. Written informed consent was obtained from each subject after the study was explained to subjects and prior to data collection.

Subjects

Data were collected on 2 adult male subjects. Both were under 30 years of age. The subjects had visual acuities of 20/20 in each eye while wearing contact lenses. Spectacles were not worn in the experiment.

Both subjects had played college baseball at the NAIA or NCAA Division III level. The subjects had both exhausted their eligibility at the college level but were still competing in baseball leagues.

Equipment

The study was carried out in an indoor batting cage. Subjects stood in a batter's box next to a “plate” at the end of the batting cage 56.3 feet from a pitching machine (described below). Both subjects batted right handed. The back (right) foot of the batter was aligned with the back of the plate. The subjects wore a tight fitting baseball helmet secured using a chin strap and equipped with a fitted cage to protect the face. The anterior-posterior distance of the subjects from the plate was 23.5 inches.

Pitching Machine

Tennis balls were “thrown” toward the subjects using a pneumatic pitching device (“Flamethrower”, Accelerated Baseball Technologies, Crystal Lake, IL).¹² The pitching machine was connected to a five-foot-long polyvinyl chloride tube from which the balls were ejected.

A laser and photodiode were vertically aligned across from one another at the end of the pitching machine tube to measure the time at which the ball left the tube. The tennis balls broke the plane of the laser when exiting the tube, leading to a drop in voltage from the photodiode which was recorded with an 11-bit analog-to-digital converter (USB-1208FS, Measurement Computing, Norton, MA).

In a separate experiment, a ballistic timing window (Model 57, Oehler Research, Inc, Austin, TX) was used to measure the average time required for the balls to travel a number of distances. The timing window was placed in 12 locations (6 feet to 56 feet from the end of the pitching machine tube), and between 47 and 50 pitches were “fired” through the timing window at each distance. The times required for each of the pitches to reach a particular location were then averaged. The standard deviation of these averages was 6ms or less at all distances, demonstrating the high temporal repeatability of the pitching machine.

A second-order polynomial was fit to the distance-versus-time data (Figure 1). The equation for the fitted curve could then be used to calculate the linear distance traveled by the ball and the horizontal angular change in ball location at any elapsed time after the pitch was released. The average linear velocity of the balls was determined to be 74.97mph.

Eyetracker

Eye position was recorded from the subject's left eye. The dominant eye was not ascertained. The influence of eye dominance on baseball batting is controversial, as some investigators have found that crossed eye-hand dominance may benefit batters while others have found no relationship between eye-hand dominance and batting success.¹⁵

Eye movements were monitored using infrared video-recording goggles (ISCAN Incorporated, Burlington, MA).¹² Measurements from an ISCAN eyetracker were found to be within 1 degree of measurements obtained simultaneously from a scleral search coil after accounting for a short delay (<50ms) in the ISCAN signal.¹² As the ISCAN measurements could be synchronized well with those from the search coil, the delay was assumed to be fixed.

The analog output from the ISCAN was recorded at 2000Hz using the same 11-bit analog-to-digital converter as that used for recording signals from the photodiode. Since the update rate of the ISCAN was 120Hz, the ISCAN output was oversampled.¹²

To determine the horizontal calibration factor of the ISCAN for each subject, the subjects were instructed to maintain the head in a constant position and to then fixate a small target attached to that portion of the batting cage to the right of and near the subject. They then fixated a small target just below the pitching machine. The horizontal angle between the two fixation targets was 51.1deg. The entire calibration was performed with both eyes open. The output of the ISCAN at each of the fixation positions was recorded to determine the horizontal calibration factor.¹² A vertical eyetracker calibration was also performed. Those data associated with vertical (eye and head) movements will not be discussed here, because they required a different analysis method and because horizontal movements are likely related to estimates of both when and where the pitch will arrive.

Headtracker

Head movement was monitored using two devices. Both headtrackers were attached to the top of the batting helmet. One headtracker was an inertial sensor (Model 3DM-GX1, LORD Microstrain Sensing Systems, Williston, VT).¹² The analog output of this device was recorded at 2000Hz through the same 11-bit analog-to-digital converter used to record from the photodiode at the end of the pitching machine tube and the eyetracker. The update rate of the Microstrain tracker was 100Hz, so the Microstrain output was also oversampled.¹²

Average measurements from the Microstrain tracker were previously found to be within 1 degree of measurements obtained from a scleral search coil after correcting for a delay in the headtracker.¹²

The other headtracker was a Flock of Birds magnetic tracker (Ascension Technology Corporation, Burlington, VT).. Those data from the Flock of Birds will not be discussed here as these data were redundant with those from the Microstrain.

Experimental Paradigm

The study was divided into 2 conditions. In the first condition, the subjects were told to behave as if they were “taking” pitches meaning that batters had no intention of swinging the bat. Fifty pitches were thrown to the subjects in this condition. The pitches were typically separated in time by approximately 3 to 5 seconds.

In the second condition, subjects were told to try and hit the balls. About forty pitches were thrown to subjects in this condition depending on when the pitching machine was stopped. In this condition, the average time between pitches was five to seven seconds. The additional time between pitches in the second condition was meant to allow the batter to reset his batting stance in preparation for the next pitch. Furthermore, a 30 second rest period was given after every 10 pitches.

In the first or “take” condition, the eyetracker was calibrated once prior to firing the 50 pitches. The eyetracker was calibrated twice (at the beginning of the test condition and mid-way through) in the “swing” condition to check for slippage of the equipment.

Analysis of Horizontal Eye and Horizontal Head Movements

Those horizontal data obtained from the ISCAN eyetracker and the Microstrain headtracker were analyzed in the following way. Those analog-to-digital (A-D) recordings from the headtracker were low-pass filtered at 10Hz. Then the A-D recordings from both the eyetracker and the headtracker were smoothed using a 41-point averaging (boxcar) filter. The approximate cut-off frequency of this latter filter was between 25 and 30Hz. We examined the temporal influence of this filter on those data from the eyetracker and headtracker by overlapping an unfiltered time series plot of eye and head position with a filtered time series plot for each subject. Overall, the filtered eye position plots showed a phase shift of 10ms or less compared to the unfiltered plots. For the head position plots, filtering had no discernible effect on the phase.

Next, the data were divided into separate columns based on the output of the laser/photodiode ball detection device at the end of the pitching machine tube. Each data column contained 2 seconds of eye- or head-tracking data associated with an individual pitch. These data columns were adjusted for short delays in the eyetracker and headtracker and then the beginning of the data columns were zeroed. Thus, the head movements, eye movements, and gaze locations described below were calculated from the initial location of the head and eyes when the ball exited the pitching machine tube, the assumption being that the batter's ocular gaze was initially aimed at the end of the tube. We tested this assumption previously on a group of Division 1 college baseball players and found it to be valid.¹² Next, these data were calibrated.¹² Finally, those eyetracker data associated with each pitch were plotted in order to look for blinks. For subject 1, eye- and head-tracking data were successfully captured for 41 pitches in the "take" condition and 38 pitches in the "swing" condition. Of these, 5 pitches in the "take" condition were discarded due to blinks, and 1 pitch in the "swing" condition was discarded due to excessive noise in the head-tracking data. For subject 2, eye- and head-tracking data were successfully captured for all 50 pitches in the "take" condition and for 40 pitches in the "swing" condition. Of these, in the "take" condition 11 pitches were discarded due to blinks and 1 pitch was discarded to a highly irregular (large and opposite to the ball) head movement. No pitches were excluded in the "swing" condition.

Batting Performance

In order to verify that the eye and head movement behaviors in the "swing" condition were associated with successful batting, one of the investigators graded batting performance. Subjects demonstrated similar success in batting the ball (percent of pitches for which good bat/ball contact was made was 71.7% (subject 1) and 70.0% (subject 2)).

Results

Horizontal Eye Movements, Horizontal Head Movements, and Horizontal Gaze Movements

The mean horizontal eye-movement amplitude, horizontal head-movement amplitude, and horizontal gaze (mean eye+ mean head) position was determined at regular intervals (every 50ms starting at 150ms) during the pitch trajectory. An elapsed time of 512ms was also included because this was the mean elapsed time at which the ball arrived at the plate. The results are shown in Figures 2 through 5.

Horizontal Head Movements

The mean horizontal head movements for the "take" condition are shown in Figures 2a and 3a. The mean horizontal head movements for the "swing" condition are shown in Figures 2b and 3b. The extent to which these head movements were the result of passive (following trunk movement) versus active (head and trunk potentially decoupled) movement was not addressed.

For subject 1 (Figure 2), in the "swing" condition there was greater head movement in the direction of the ball early in the pitch trajectory. However, at an elapsed time in the pitch trajectory of about 350ms, head movements in the direction of the ball were mostly discontinued, while head movements continued in the "take" condition.

For subject 2 (Figure 3), head movements in the direction of the ball occurred in both the swing and “take” conditions. These head movements were similar in the two conditions until an elapsed time in the pitch trajectory of about 450ms. At 450ms, head movements in the “swing” condition were mostly discontinued.

In summary, for each subject, head movements in the direction of the ball occurred in both the swing and “take” conditions, but only in the “take” condition did head movement continue throughout the trajectory of the pitch. These results are largely in agreement with those reported by Hubbard and Seng.¹⁰

Horizontal Eye Movements

As mentioned above, eye movements were calculated from the initial location of the eye when the ball exited the pitching machine tube. It is possible that our subjects, who were presumably in somewhat eccentric gaze (relative to the orbits) at the beginning of the pitch, could have manifested an (incomitant) heterotropia in this direction of gaze and then demonstrated ocular alignment (orthophoria) as the pitch approached and the batter's eyes moved closer to the primary position. We cannot determine whether such ocular deviations occurred from our monocular recordings. This leaves open the possibility that vergence eye movements may have occurred as the ball approached the batter. We believe this is unlikely, as the average eye movements encountered throughout most of the pitch were very small until late in the pitch trajectory (and on average the duration versus amplitude relationships of these late movements were more consistent with saccadic movements than with vergence movements¹⁶). However, it cannot be ruled out entirely that the small eye movements in the early and middle portions of the pitch trajectory were vergence movements rather than conjugate movements. It is also possible that gaze tracking was performed with only one eye (foveally) or parafoveally at times during the pitch trajectory if vergence eye movements did occur. The accuracy of binocular fixation in baseball batters and the type of eye movements encountered in these batters are topics for future study.

The mean horizontal eye movements for the “take” condition are shown in Figures 2a and 3a and the mean horizontal eye movements for the “swing” condition are shown in Figures 2b and 3b.

For subject 1 (Figure 2), in the “swing” condition the eye was moved opposite to the ball until an elapsed time in the pitch trajectory of 350ms. At 350ms, the eye movements were reversed such that these movements were now in the direction of the ball. In the “take” condition, subject 1 demonstrated a small eye movement opposite to the ball, followed by a larger amplitude movement in the direction of the ball (at an elapsed time of about 350ms). In both conditions, the early eye movement opposite to the ball is likely associated with the rotational vestibulo-ocular reflex. However, there is a possibility that this eye movement is associated with a change in vergence. The late eye movement is consistent with saccades.¹⁶

The eye movements for subject 2 (Figure 3) were similar to those of subject 1, although the change in eye movement direction occurred at an elapsed time of about 400ms in both the “swing” and “take” conditions.

In summary, significant eye movements in the direction of the ball only appeared late in the “take” condition for both subjects.

Horizontal Gaze Location

The mean horizontal gaze locations for the “take” condition and “swing” conditions are shown in Figures 4 and 5.

For both subjects, at an elapsed time of approximately 400ms the “swing” and “take” curves diverge. In the “take” condition, gaze was moved ahead of the ball such that gaze location was near the ball location when the ball reached the plate. On the other hand, in the “swing” condition gaze position fell well behind the ball at around 400ms and remained stable thereafter.

Overall, those data on head movements, eye movements, and gaze location in the “swing” condition are quite similar to those obtained by Bahill and LaRitz¹¹ on a Major League Baseball player even though this latter subject did not attempt to bat the approaching balls.

Discussion

Both subjects moved the head in the direction of the pitched ball in both the “take” and “swing” conditions. Of interest is the question of *why* these subjects moved the head in this manner, particularly in the “swing” condition.

Mann et al.¹⁷ examined head and eye movements in elite cricket batters and found that the head was rotated vertically with the ball while batting. These investigators suggested that the head may be moved with the ball because this maintains the ball in a constant direction compared to the head. This could then facilitate judgments about the location of the ball. A similar explanation has been applied in experiments on catching fly-balls.⁴ Horizontal head tracking would provide similar advantages to the vertical head tracking studied by Mann. In addition to Mann's suggestion, perhaps moving the head horizontally with the ball provides vestibular signals, proprioceptive information from the neck musculature, or motor efferent copy information sent to the neck musculature that may be used to estimate both when and where the ball will arrive at the plate.^{18,19}

There are some potential explanations as to why our batters utilized the head movement behaviors found in this study in spite of the relatively predictable pitch trajectories. First, there was some variance in the vertical and in particular the lateral (in a direction from the batter to the plate) locations of the ball. We assessed the range of vertical and lateral locations occupied by the ball along its trajectory. The results are shown in Table 1. While these spreads are quite small, they do demonstrate some mild variability. Ideally, batters should strike the ball at the center of percussion (eg. the “sweet spot”) of the bat.²¹ This “sweet spot” covers only about six inches along the length of the bat and about ½ inch in vertical height, so the vertical and lateral variability in ball location may have prompted the batters to turn the head with the ball to maximize swing accuracy.^{17,21}

On the other hand, perhaps rotating the head in the direction of the ball is simply a learned response, resulting from years of admonishment from coaches to avoid turning the head

away from the plate.²² Ocular gaze differed in the “take” and “swing” conditions. In the “take” condition, the subjects made large amplitude head and eye movements later in the pitch trajectory such that gaze was placed near the location of the ball when the ball crossed the plate. This behavior is likely beneficial under real-world conditions, as batters can perhaps use the visual information gained from viewing the ball near the time the ball crosses the plate to facilitate future swings.^{2,3,13} The fact that our subjects exhibited this behavior even with the predictable pitch trajectories used in this study is likely a testament to the level to which this behavior is perhaps learned and ingrained.

Different from the “take” condition, in the “swing” condition gaze was maintained quite close to the ball until an elapsed time of about 450ms (at which time the ball was about 5.5 feet from the batter). Perhaps maintaining gaze on the ball contributes to successful batting by enhancing target interception and time-to-collision estimates.^{5,6} That is, gaze tracking may enhance predictions of when and where the pitched ball will arrive and allows for longer periods of foveation of the features on the ball (eg. seam direction).^{5,6,7} This information might be beneficial until the arrival time of the ball at the batter is about 150ms (that is, until the ball is about 10-15 feet from the batter).²⁰ Why did the batters in this study track the ball at distances closer than 10-15 feet in spite of the fact that there may be no immediate advantage to doing so?

Perhaps these batters made a conscious effort to track the ball as long as possible, and this helps to ensure the accuracy of gaze tracking early in the pitch when much of the information about the pitch trajectory is apparently gathered.^{1,20,23} In addition, tracking the ball as long as possible might provide information that could be used in future at-bats, although the “take” data would suggest that these batters preferred to obtain data on pitch trajectory for use in later at-bats by placing gaze near the location where the ball crossed the plate. On the other hand, much like the head movement behaviors measured in this experiment, it could be that batters maintain gaze on the ball simply because they have been coached to “keep their eyes on the ball”.

Summary

Both batters in this study exhibited different head, eye, and gaze-tracking behaviors when taking pitches compared to when swinging at pitches. As a result of the head and eye movements late in the pitch trajectory in the “take” condition, gaze was directed ahead of the pitch to a location close to that occupied by the pitched ball as it reached the batter. On the other hand, in the “swing” condition gaze fell well behind the ball very late (about 100ms prior to pitch arrival at the batter) in the pitch trajectory.

The extent to which the predictability of the pitch trajectory influences head and eye movements and gaze tracking behavior is not known at this time. It is likely that for these two batters, the results obtained here are similar to those that would be obtained under game conditions where the pitch trajectories are less predictable if, as suggested by Bahill and LaRitz¹¹, placing gaze ahead of the ball in a predictive manner is the “optimal learning strategy”, and tracking the ball is the “optimal hitting strategy”. Future studies will be needed to determine whether the tracking strategies used by batters in this study are similar

to those of batters at higher levels, and whether less predictable pitch trajectories influence these tracking strategies.

Acknowledgments

The authors thank Erik Kuntzsch for his assistance. This work was supported in part by a grant from Optometric Educators, Incorporated to N. Fogt. A portion of this research was completed while T. Persson was a trainee under National Institutes of Health Award Number NIHT35EY007151. The content of this paper is solely the responsibility of the authors and does not necessarily reflect the official views of the National Institutes of Health. The methodology described in this paper is partially discussed in US Patent #US8553936B2 to The Ohio State University (Inventor: N. Fogt). A portion of this work was presented as a poster at the 2011 American Academy of Optometry Annual Meeting (Boston, MA).

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Figure 1.

Distance traveled (from the pitching machine) versus elapsed time for pitches in this experiment.

Figure 2.

Head and eye rotations for subject 1 in the take (**A**) and swing (**B**) conditions (error bars are ± 1 standard deviation).

Figure 3.

Head and eye rotations for subject 2 in the take (**A**) and swing (**B**) conditions (error bars are ± 1 standard deviation).

Figure 4.
Horizontal gaze locations in the take and “swing” conditions for subject 1.

Figure 5.
Horizontal gaze locations in the take and “swing” conditions for subject 2.

Table 1

Vertical and lateral spreads in ball location at various distances along the pitch trajectory.

Distance from pitching machine (feet)	Vertical spread (inches)	Lateral Spread (inches)
10	2.1	3.5
20	0.75	4
30	2.5	5
40	4	6
50	4.5	9
55	6	10