# Article • Vertical Head and Eye Movements During Baseball Batting

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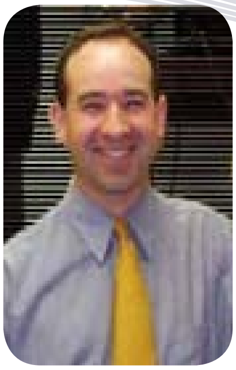

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## ABSTRACT

**Background:** The purpose of this paper is to describe a method used to measure vertical head and eye movements and gaze positions of baseball batters and to report the initial findings generated with this method.

**Method:** Two former collegiate baseball players participated. Subjects batted balls from a pitching machine.

**Results:** Responses were similar for the two subjects. The head demonstrated a small upward rotation, followed by a downward rotation. The eye was rotated opposite to the head throughout portions of the swing, while gaze was directed below the ball (more for one subject than the other) for much of the pitch trajectory.

**Discussion:** These data align with previous assertions that in baseball batting, players attempt to keep pitched balls in a constant egocentric direction.

**Keywords:** Baseball, eye movements, head movements, pursuit tracking

## Introduction

Baseball batting is a difficult task that requires very accurate spatial and temporal responses generated over a very short time period. For example, a 90mph fastball travels from a pitcher's hand to a batter in less than half a second.

Eye and head movements could have an impact on baseball batting. Studies have shown that pursuit eye tracking can be beneficial for perceptual estimates of when and where an approaching object will arrive[1-3] and for visuomotor responses associated with target interception.[4-6] Head movements could be beneficial in intercepting moving objects because turning the head in the direction of an approaching target maintains this target in a constant (egocentric) direction relative to the head.[7-8]

However, an unresolved question is whether a specific pattern of eye, head, and gaze tracking behavior is most beneficial for the interception of a moving target. It could be that individuals can vary in these tracking behaviors and still achieve the same level of performance.[9] In addition, eye and head pursuit of an approaching object that is to be intercepted could vary depending on the predictability of the point of interception.[10]

If a particular pattern of eye and head coordination and gaze tracking behavior can be shown to have the greatest positive influence on performance for most individuals in most conditions, then training players to emulate that pattern would be important.

Various approaches have been taken to establish whether there is a pattern of eye and head coordination that results in the best performance. One method is to compare the eye and head movement responses of expert and novice performers.[11-12] A reasonable assumption would then be that any differences in the groups impart advantages for the experts. However, it is possible that expert performers converge on a similar pattern of eye, head, and gaze tracking because of years of training, during which they may have been admonished to adopt this pattern.[13] To address this, it is necessary to establish not only what experts do, but why they do it.

Those data that have been published on the horizontal eye and head movements of baseball batters show that the head is moved in the direction of the ball throughout much of the pitch trajectory and that the eyes are moved very little until late in the pitch.[14-15] While these horizontal data suggest that batters are maintaining the pitched ball in a relatively constant egocentric direction, this hypothesis cannot be confirmed because there are no quantitative data on the vertical eye and head movements of baseball batters. If both vertical and horizontal movements are in the direction of the ball, then this suggests that the constant egocentric direction hypothesis could explain the head movement behavior. However, if only horizontal movements are in the direction of the ball, then this suggests that head movements may be more closely related to estimates of when the ball will arrive than where (vertically) it will arrive.

The purpose of this paper is to describe a method used to measure vertical head and eye movement data gathered from two baseball players for whom horizontal head movements were previously described.[14] Those data obtained with this method suggest that head movements are likely intended to ensure that the ball remains in a constant egocentric direction throughout the pitch.

## Methods

The protocol and consent document were approved by the Ohio State University Biomedical Sciences Institutional Review Board. Both participants signed a consent form prior to participation in the study. Some details of the methodology have been described previously.[14] The two right-handed male subjects, both less than 30 years of age, were former collegiate baseball players who played at the National Association of Intercollegiate Athletics or the National Collegiate Athletic Association Division III level.

In the first condition, the batters were told to act as if they were "taking" pitches "thrown" by a tennis ball pitching machine (Flamethrower, Accelerated Baseball Technologies, Crystal Lake, IL); they were then asked to swing at pitches. Since our interest here is in the tracking behaviors during the swing, the results from the "take" condition will not be discussed further. In the "swing" condition, the subjects were asked to bat tennis balls "thrown" by the pitching machine. The Flamethrower uses compressed air to launch the tennis balls over a very repeatable trajectory.[16-17] Batters assumed a batting stance about 56.3 feet from the pitching machine.

### Ball trajectory

The velocity of the ball was determined by firing pitches through a ballistic screen (Model 57, Oehler Research, Austin, TX) placed at various distances along the pitch trajectory and then comparing the time at which the ball exited the pitching machine (assessed with a photodiode) to the time the ball passed through the screen.[14] The average linear velocity of the ball was determined to be about 75mph. The vertical locations of the ball were determined by firing tennis balls (10 or 11 at each distance) against a sheet of plywood covered with a white piece of paper at 6 distances. The balls left a mark on the paper, allowing ball height to be measured. These height values were then converted to vertical angular locations (shown in Figures 1 and 2) relative to the batter (Appendix A).

### Eye movements

Eye movements were recorded (from the left eye) using an ISCAN video tracker (ISCAN, Burlington, MA). The eye tracker (spatial resolution 0.25deg, accuracy 0.25deg) consisted of goggles on which were mounted infrared cameras (120Hz) to track pupil location. To determine the vertical amplification or gain of the ISCAN, the subject turned his body to face the netting of the batting cage. With the head still, the subject fixated 2 small targets affixed to the batting cage and separated vertically by 26.6deg. ISCAN digital values were recorded at each of the fixation positions and were used to calculate the subject's vertical eye tracker gain.

### Head movements

Head movement was monitored with two devices. Both head trackers were attached to the top of the batting helmet worn by the subjects. One tracker was an inertial sensor (Model 3DM-GX1, LORD Microstrain, Williston, VT), which had an update rate of 100Hz. Only horizontal rotational values were recorded with this tracker. The second tracker was an electromagnetic device that measured the orientation of a receiver within a DC magnetic field (Flock of Birds, Ascension Technology Corporation, Shelburne, VT). The output of this tracker was in degrees of angular rotation. This second tracker was used to record the vertical head rotations.

Analog signals from the eye tracker, the Microstrain head tracker, and the photodiode at the exit of the pitching machine were recording in synchrony using an analog-to-digital (AtoD) converter (USB-1208FS, Measurement Computing, Norton, MA) at 2000Hz. In a separate computer, those data from the electromagnetic tracker were recorded through a serial port at approximately 56Hz. A customized computer program was used to record both those data from the electromagnetic tracker and a time stamp (2000Hz)

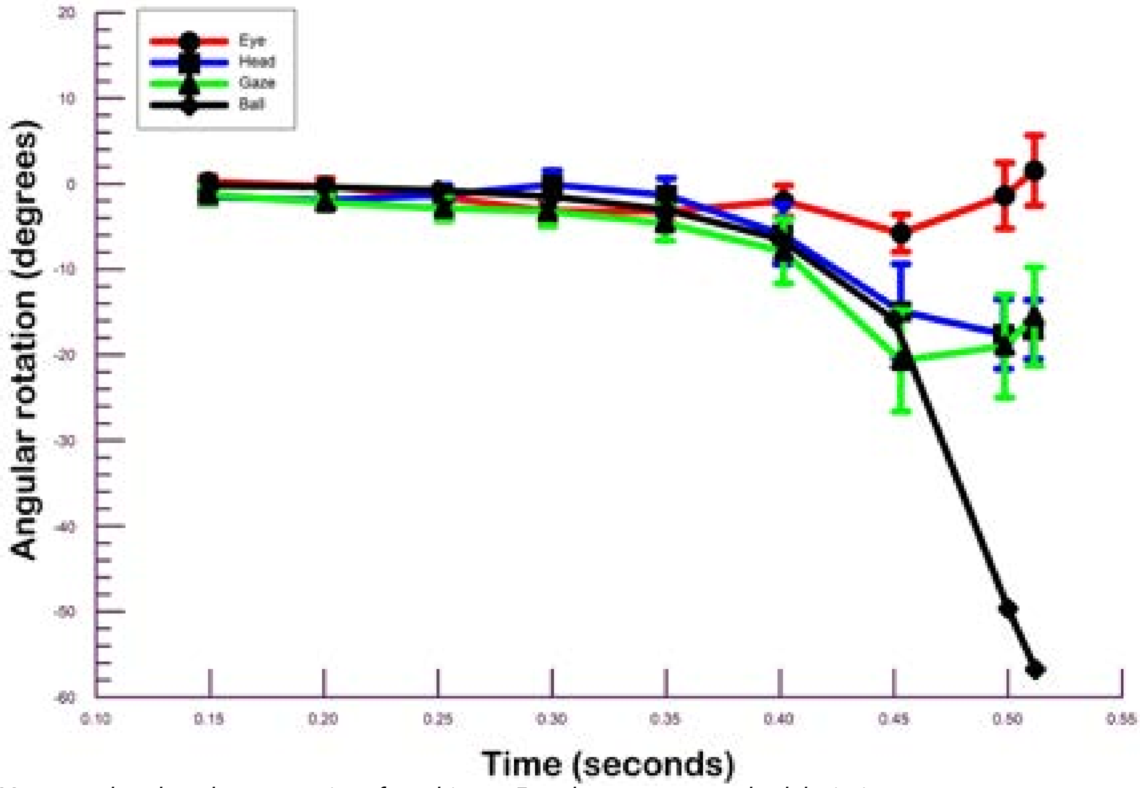

***Figure 1.*** *Mean eye, head, and gaze rotations for subject 1. Error bars are ±1 standard deviation.*

from an AtoD converter (CIO-DAS08, Measurement Computing) located in the same computer.

**Data analyses**

The head and eye positions at the beginning of each pitch were zeroed, so the rotations reported here are the changes from the beginning of the pitch to elapsed times of interest. The assumption is that gaze was directed at the location where the ball exited the pitching machine.

**Head tracking values**

A major goal in analyzing these data was temporally to synchronize those data from the Flock of Birds with those data from both the photodiode at the exit of the pitching machine and the eye tracker. To do this, those (horizontal) data from the Microstrain device were low-pass filtered (cut-off 10Hz). The filtered analog signals from the Microstrain and those from the photodiode were then passed through a computer program. First, this program applied a 40-point averaging filter to the already low-pass filtered Microstrain data. Next, the program identified those times when the tennis balls exited the pitching machine. Finally, the program calibrated the Microstrain data using a calibration factor measured previously[14] and divided these data up into individual files (two seconds) and associated with each pitch.

All of those horizontal data from the Flock of Birds were plotted, and on a separate graph, all of those data from the photodiode and the Microstrain were plotted. By comparing these plots, those data from the Flock of Birds could be manually parsed into individual pitches. Next, those data from each head tracker for each pitch were plotted together against their respective time stamps. The time stamp for the Microstrain was adjusted for a short (<10ms) lag. Once the Microstrain and Flock of Birds recordings were plotted against their respective time stamps for each pitch, then the Flock of Birds data were shifted in time to match those data from the Microstrain. Next, a determination was made as to whether the Microstrain data and the Flock of Birds data demonstrated a high degree of temporal and spatial coherence. Data were discarded in cases where coherence could not be established or where there appeared to be eye blinks. After this procedure, 23 pitches were analyzed for subject 1, and 13 pitches were analyzed for subject 2.

Finally, once the Microstrain and Flock of Birds horizontal tracking data were matched in time, the beginning of each Flock of Birds data file was zeroed. Then head rotational values were extracted from the Flock of Birds at various elapsed times (150ms, 200ms, 250ms, 300ms, 350ms, 400ms, 450ms, 500ms, and 512ms) in the pitch trajectory. Because of the relatively low update rate of the Flock of Birds tracker, it was not always possible to obtain data exactly at the elapsed time of interest. However, the mean times at which

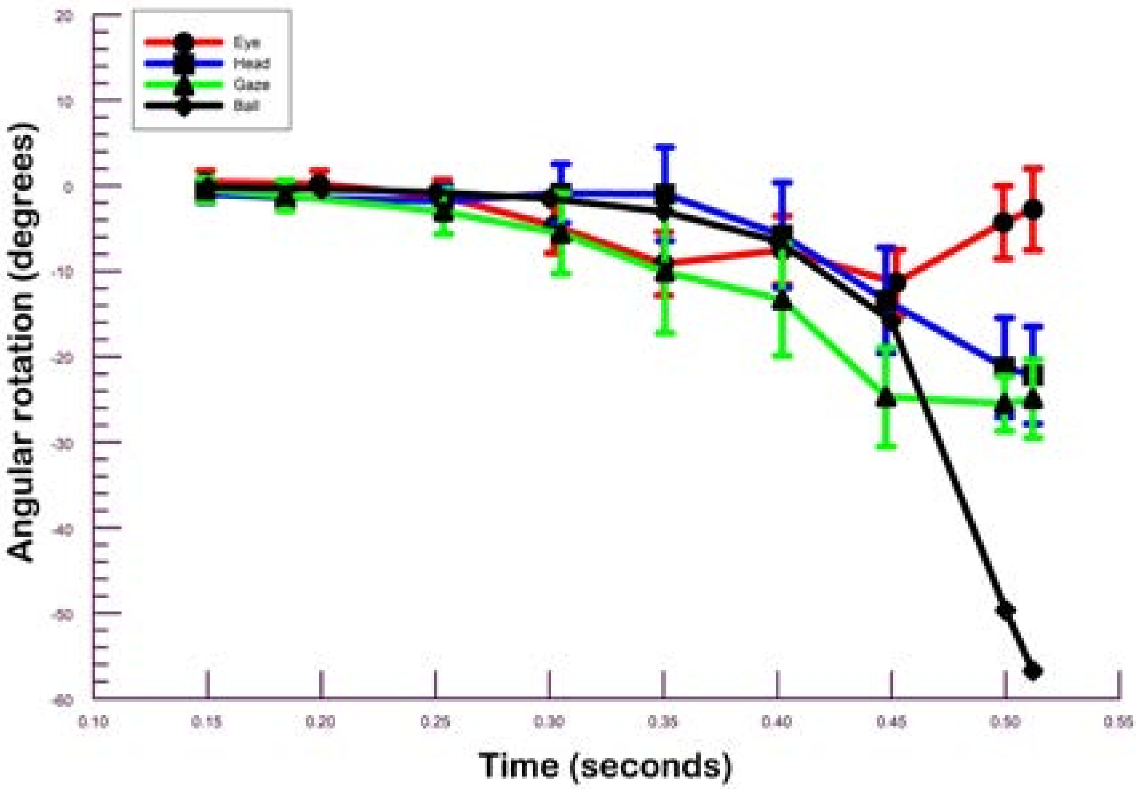


***Figure 2.*** *Mean eye, head, and gaze rotations for subject 2. Error bars are ±1 standard deviation.*

data were extracted were always within 3ms of the preferred times.

**Eye tracking values**

The vertical AtoD recordings from the eye tracker and those from the photodiode were passed through the same computer program that was used to analyze those data from the Microstrain device. The program calibrated the eye tracker data using the calibration factor measured in the experiment and then divided these data into individual data files two seconds in duration and associated with each pitch. Next, these data were shifted temporally to account for a measured delay (<50ms) in the eye tracker. Then the beginning of the data files was zeroed, and the vertical eye movement locations at the elapsed times of interest were extracted.

**Gaze values**

The vertical gaze values (eye position in space) allowed us to compare the fixation position of the eyes to the location of the ball at our elapsed times of interest during the pitch. The gaze values were calculated by adding the eye tracker rotational values to the head tracker rotational values at the elapsed times of interest.

## Results

The results for each subject are shown in Figures 1 and 2. In the following narrative, negative values indicate downward movements. All values are averages at a particular elapsed time. The results were largely similar for the two subjects.

Referring to Figures 1 and 2, during the swing, the head was moved upward slightly for a brief period for both subjects. Following this, the head was moved downward by -14.90deg (subject 1) and -13.39deg (subject 2) at an elapsed time of about 450ms and -17.04deg (subject 1) and -22.16deg (subject 2) at 512ms. For subject 1, the eye moved very little throughout the pitch trajectory, although there was a downward deflection (-5.77deg at about 450ms). For subject 2, the eye moved continuously downward until 450ms (-11.31deg). The origin of these eye movements is unclear, but since they are largely opposite in direction to the head rotation, they could partially be attributed to the vertical rotational vestibulo-ocular reflex.[18-19]

Gaze was below the ball for both subjects, although this gaze error was larger for subject 2. At about 450ms, gaze was directed below the ball by 4.80deg for subject 1 and 8.83deg for subject 2. Gaze errors increased substantially (gaze above the ball) after 450ms.

## Discussion

Overall, those data reported here for vertical head and eye movements and vertical gaze tracking were similar for the two subjects. For both subjects, the head demonstrated an upward deflection followed by a downward movement similar to the pitch trajectory. Initially, the eyes were moved downward, slightly for subject 1 and more significantly for subject 2. For much of the pitch trajectory, gaze was shifted continuously in the direction of the ball. Gaze was slightly below the ball for subject 1 and more significantly below the ball for subject 2.

The fact that the head tracking trajectory is similar to the trajectory of the ball after the upward deflection suggests that batters may indeed be attempting to maintain the pitched ball in a constant egocentric direction. Further, although gaze is below the ball for some of the pitch trajectory, gaze tracking continues until very late in the pitch trajectory. This suggests that continuous gaze tracking may provide benefits such as online correction of interceptive movements.[20-21]

The results reported here likely generalize to performance in games. One property of baseball pitches that could be hypothesized to influence the eye, head, and gaze tracking results is the predictability of the pitch trajectory. de la Malla et al.[10] demonstrated that observers only pursue a moving object that they are to intercept when the location of the interception point is difficult to predict. Thus, one might surmise that if the point of interception is known in batting, then the eyes and head would be shifted rapidly such that gaze is directed near the point of bat-ball contact. However, in the experiment described here, the interception location was very predictable, and yet gaze was continuously moved in the direction (albeit with a vertical phase lead) of the ball. This suggests that it is unlikely that batters would make a sudden shift to the location of expected bat-ball contact in games. It is possible, however, that the predictability of the pitch trajectory in this experiment may have been at least partially responsible for the gaze tracking lead.

A different argument against the generalizability of the results of this study is that while the subjects in the experiment knew in advance that they were to swing at all of the pitches, this is not the case in actual batting situations. Batters in games may be required to stop or “check” their swing before the bat crosses the plate. The stop signal leading a batter to interrupt an ongoing swing is thought to be largely independent of the motor pattern associated with the swing, so one might expect the typical motor program to be carried out at least until the discrepancy between the batter’s expected ball trajectory and the actual ball trajectory exceeds a certain threshold.[13]

**Acknowledgments**

This work was funded in part by a grant from Optometric Educators Incorporated. A portion of this research was completed while TWP was a trainee under NIHT35EY007151 from the National Institutes of Health. 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 work described here represents a portion of the material described in TWP’s Master of Science (Vision Science) thesis. Parts of this work were presented at the 2011 American Academy of Optometry annual meeting and the 2018 Association for Research in Vision and Ophthalmology annual meeting.

**Disclosure statement**

Author NF is listed as the inventor on a patent (#US8553936 B2) assigned to The Ohio State University. The technology described in the patent has not been licensed and NF has not received revenue related to the technology. Author TWP has no disclosures.

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## Appendix A

The following calculations were used to determine the vertical angle of the ball (β) in relation to the batter at elapsed times of interest. These values represent the change in vertical gaze angle required for the batter to fixate the pitched ball accurately. The variables are shown in Figures 3a and 3b and are defined in the figure caption.

$\tan \alpha = d/x$ (1)

$\sin \alpha = d/z$ (2)

$\tan \beta = w/z$ (3)

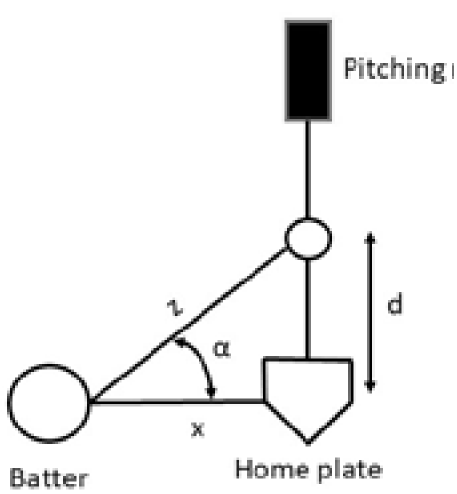


***Figure 3a.*** *View from the top as a pitched ball approaches the batter. d is the distance of the ball from the plate at the elapsed time of interest, and x is the distance of the batter from the plate.*

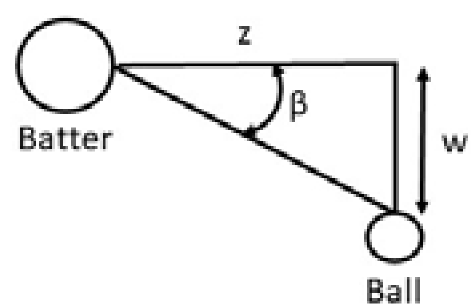


***Figure 3b.*** *View from the side as the pitched ball approaches the batter. w is the distance that the ball has dropped (from the initial height) at the elapsed time of interest. Angle β is the angle through which gaze must be rotated to maintain fixation on the ball at the elapsed time of interest.*