Eye and Head Movements in Novice Baseball Players versus Intercollegiate Baseball Players

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

By

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Graduate Program in Vision Science

The Ohio State University

2017

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Abstract

**Purpose.** Record head and eye movements and analyze horizontal gaze tracking of novice subjects (no intercollegiate or professional baseball experience) as they viewed pitched balls. Compare these novice data to a group of Division 1 intercollegiate baseball players.

**Methods.** Novice subjects with no prior intercollegiate or professional baseball experience viewed tennis balls projected from a pneumatic pitching machine in a simulated batting set up, but were not allowed to swing. Subjects were asked to call out numbers and the color of these numbers (red or black) printed on the balls. Eye movements were monitored with a video eye tracker, while the head was monitored with an inertial sensor. The eye and head movement data were synchronized with ball position using an analog recording device. Data were analyzed for 14 subjects. These data were then compared to data recorded in a similar manner for Division 1 intercollegiate baseball players.

**Results.** Eye rotation, head rotation, and gaze errors (signed and unsigned) were calculated at various elapsed times. Overall, novice subjects tracked the ball with the head throughout the pitch trajectory, while the eye remained stable until very late in the pitch flight. Despite significant differences between subjects for the mean amplitudes of head and eye movements, a common tracking strategy emerged (partial rotational...
vestibulo-ocular reflex suppression) for all subjects. Anticipatory saccades were not visually detected for any subject based upon the mean amplitudes of gaze errors. When the novice subjects were compared to the intercollegiate subject data, significant differences emerged in the mean amplitudes of head and eye movements, along with gaze error differences especially very late in the pitch trajectory. Overall however, the novice subjects performed relatively similar to the intercollegiate subjects.

**Conclusions.** On average, novice subjects tracked the pitched ball primarily with the head throughout most of the trajectory and maintained gaze relatively close to the ball until late in the pitch. Overall, the novice subjects performed fairly similar to the intercollegiate group, however significant differences do exist, primarily in the head movement amplitudes late in the pitch trajectory. However, when the novice subjects were examined by experience level significant differences emerge especially for those who have never played organized baseball. These subjects showed larger than average head movements, along with larger eye movements in a direction opposite of their head movements
Dedication

This document is dedicated to my mother, Pamela K. Kuntzsch.
Acknowledgments

I would like to thank Dr. Zimmerman and Dr. Fogt for all of the time and effort spent investing in this study and my future. Working with these two dedicated clinicians, researchers, and educators has pushed me to strive to become a better clinician, researcher, and lifelong learner.

I would also like to thank parents, Stephen and Pamela Kuntzsch, along with my sister Mayleigh Kuntzsch. Their support has always been the driving force behind all of my endeavors and without them I would not be where I am today.
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Publications

Koeppen AH, Kuntzsch EC, Bjork ST, Ramirez RL, Mazurkiewicz JE, Feustel PJ.
Friedreich Ataxia: Metal Dysmetabolism in Dorsal Root Ganglia. Acta Neuropathol

Koeppen AH, Ramirez RL, Bjork ST, Mazurkiewicz JE, Kuntzsch EC. Friedreich’s
Ataxia: Iron and Zinc Redistribution in Dorsal Root Ganglia. Journal of Neuropathology

Fields of Study

Major Field: Vision Science

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Chapter 1: Introduction

1.1: Pitch Dynamics

Baseball legend and Hall of Famer, Ted Williams has said, “the hardest thing to do in a sport is to hit a baseball.”\(^1\) The physical dimensions of hitting a baseball help to further describe the difficulty of the task. The pitcher’s mound in 60 feet, 6 inches away from home plate. Flanking home plate, 6 inches from either side are two batter’s boxes, 4 foot by 6 foot rectangles where the batter is allowed to stand depending on their batting preference (right or left handed).\(^2\) Assuming the pitcher releases the ball 5 feet in front of the apex of the mound, a pitch averaging 90 miles per hour will reach home plate in under half a second.\(^3\) After taking into account the average duration of a major league baseball player’s swing of about 194 milliseconds\(^4\), the batter has only 200-250 milliseconds to decide whether and when to swing the bat.

Yale Professor and baseball researcher, Robert Adair has called hitting a baseball a superhuman feat that is, “clearly impossible”, yet baseball players across the globe are successful in making contact between a 2.25 inch diameter baseball bat and 3 inch diameter baseball traveling at 90 miles per hour. Physical attributes along with contextual cue assessment (pitcher’s tendencies, game situation, current pitch count, previous encounters with the pitcher and history of pitches thrown) are likely to influence batting success.\(^3,5,6\) Ocular attributes such as visual acuity may also lead to batting
success. Visual cues before, during, and after the pitch may provide useful information for the batter. The combination of physical, mental, visual/perceptual attributes are combined, analyzed, and utilized to help predict when and where a pitched ball will arrive at the plate for a better chance at successful hitting.

1.2: Gaze Tracking in Baseball/Previous Studies

There is a strong emphasis in baseball coaching for the player to “keep their eyes on the ball” when batting. Many individuals and companies have attempted to develop training methods to improve a batter’s ability to track a pitch throughout its flight to the plate. Some methods use a pitching machine to “pitch” balls with multiple colored dots or multiple numbers in which the batter must try to discern. Professional baseball players have been reported to have used these methods and some even claim the ability to call out the colors or numbers on the pitched balls consistently while training.

It is still unclear in regards to the aforementioned type of vision training and in baseball hitting in general to what extent can the batter actually track and maintain foveal fixation on the pitch. Additionally, it is not fully known whether maintaining foveation of a pitch longer throughout its trajectory actually provides hitting performance benefit. Hubbard and Seng in 1954, and Bahill and LaRitz in 1984 conducted two notable ocular gaze tracking studies looking to answer these questions. Here, the term gaze is used to describe the location of the eyes relative to space (i.e. relative to the outside world), where gaze is calculated by adding the rotation of the eye in the orbit with the rotation of the head.
Hubbard and Seng video-taped 29 professional baseball players during batting practice to monitor head and eye movements. Their results indicated that professional batters use smooth pursuit eye movements to track an incoming pitch, with their heads essentially fixated. The researchers found that ocular gaze tracking for their group of professional batters stopped when the ball was eight to 15 feet from the plate.

Hubbard and Seng also noted that there were distinct differences between when a batter was swinging at a pitch versus when the batter was allowing the pitch to pass without a swing (the “take” condition). Of 556 pitches observed when the player swung the bat, Hubbard and Seng only noted two incidences of head movements accompanied by a swing. Under the “take” condition however, the batters more commonly utilized head movements, exhibiting a notable head movement in 392 of the 648 pitches that were “taken” by the batter.⁹

Bahill and LaRitz studied attempted to quantitatively study head and eye movements by batters during a baseball pitch using a white plastic ball suspended on fishing line, attached to a motorized pulley system to simulate a pitched ball. The motorized pulley system was capable of moving the ball at speeds of 65 to 100 miles per hour. Due to technical constraints, batters were not allowed to swing at the simulated pitches, and the vertical movement of the “pitches” was minimized. To record eye and head movements of the batters, a limbal infrared eye tracker and head mounted light emitting diode (LED) video monitoring system were utilized. The subjects included graduate students, collegiate players from the Carnegie-Mellon University baseball team, and one Major League Baseball (MLB) player. Despite 50 hours of experimentation time
noted by Bahill and LaRitz, complete head and eye data was collected for only six full pitches and 15 partial pitches, demonstrating the difficulty of obtaining usable data in this area of research.10

Bahill and LaRitz found that their MLB player had the ability to accurately track the ball (less than two degrees of error) to a position of 5.5 feet from the plate. Bahill and LaRitz stated that the MLB player’s eye pursuit velocity reached up to 120 degrees per second, quite faster than the normal terminal pursuit velocity of 75-90 degrees per second noted in other literature.11,12 These data presented by Bahill and LaRitz suggest that due to the MLB player’s higher velocity of eye pursuit movements, he was more effectively able to track the ball to a closer position to the plate compared to the other subjects in the study.

Bahill and LaRitz noted that the MLB player was capable of effectively cancelling the rotational vestibulo-ocular reflex (RVOR), thus allowing him to move his head in the direction of the pitch without loss of fixation. The RVOR normally functions to stabilize the retinal image during head and body motion by causing the eyes to move in a direction opposite to the head. For example, rotating the head to the right would trigger the RVOR to stimulate a conjugate eye movement to the left.13 Thus, as one can imagine in a batting scenario without successful cancellation of the RVOR, a right-handed batter would rotate his/her head to the right to follow the pitch, stimulating the RVOR, resulting in a conjugate eye movement to the left. However as stated above, Bahill and LaRitz found that their MLB player had the ability to cancel the RVOR allowing him to concurrently move his head and eyes in the same direction simultaneously. Summat
the MLB player’s eye pursuit velocity of 120 degrees per second with his concurrent head rotation of 30 degrees per second resulted in a gaze velocity of 150 degrees per second. The advantage in the ability to utilize both head and eye movements is obvious, as it results in substantially higher tracking velocities than either the head or eye alone.

1.3: Expert vs. Novice Athlete Visual Attributes/Performance

An emerging area of sports research is determining the differences between novice and expert athletes, and to what extent do these possible differences contribute to successful or unsuccessful athletic performance. If such differences exist, the next question to be asked is if these differences are mental, physical, or perceptual in nature. If a significant disparity does exist in any of these facets, could it then be possible to train the novices to reduce the discrepancies between themselves and expert athletes?

A number of studies have compared visual attributes of expert athletes to those with less experience. Laby et al. conducted a study looking at the visual function of 378 professional baseball players including visual acuity, stereoacuity, and contrast sensitivity. Their findings demonstrated that the professional baseball players had significantly better mean visual acuity, distance stereoacuity, and contrast sensitivity when compared to the general population and also when compared to minor league baseball players. Approximately 81% of the professional baseball players tested by Laby et al. had a visual acuity of 20/15 or better (-0.125 logMAR) while also demonstrating superior distance random dot stereoacuity and contrast sensitivity, especially at higher spatial frequencies.14 Hoffman et al. also compared contrast sensitivity between collegiate
baseball players and non-athlete graduate students using Arden grating plates, and revealed a statistically significant difference between the two groups. A study by Rouse et al. compared the dynamic visual acuity (the ability to resolve an object/detail of a target that is moving relative to the observer) of 17 college baseball players to those of 25 non-athlete graduate students using projected angular motion of a “Landolt C” with varying target velocities from 10 degrees per second up to 110 degrees per second with an exposure time of 400 milliseconds. These researchers found a statistically significant difference in the dynamic visual acuity between the college baseball players and non-athlete graduate students. Based upon these studies, it seems plausible that many visual attributes of expert athletes may be superior to novice athletes or to those of the general population.

While many studies have shown that expert athletes may exhibit specific superior visual attributes compared to novices, Bahill and LaRitz have performed one of the only studies directly comparing ocular gaze tracking in relation to baseball hitting between these two groups.

Bahill and LaRitz found that the MLB player was able to accurately track a pitch within 5.5 feet from the plate (less than two degrees of error), while other less-experienced subjects were only able to accurately track up until nine feet from the plate. The researchers found that this difference in tracking efficiency could be due to a number of reasons including the fact that the MLB player higher velocity smooth pursuit eye movements and a better ability to cancel the RVOR as stated previously.
Bahill and LaRitz found varying strategies of head and eye movements between the non-professional subjects and the MLB player. The MLB player demonstrated consistent and approximately equal amplitudes of head and eye movements while tracking, while other subjects exhibited unequal and/or disproportional movements of the head and eyes. While the MLB player was able to successfully and accurately track a pitch within 5.5 feet of the plate, the authors found that some of the less experienced subjects did not attempt to continuously track the pitch throughout the trajectory. One subject in particular minimized head movements while tracking, possibly in an attempt to minimize RVOR intrusion, tracked the pitch with smooth pursuit eye movements throughout the first half of its trajectory, and then made a large saccadic eye movement away from the ball toward the plate, subsequently placing the eyes ahead of the ball. The authors hypothesized that this anticipatory saccade was made in an attempt to catch a glimpse of the ball as it crossed the plate. Bahill and LaRitz\textsuperscript{10} and Gray\textsuperscript{3} both offer similar explanations for this behavior in that the anticipatory saccade made in an attempt to fixate the ball as it crosses the plate may be beneficial in predicting the location of future/subsequent pitches. The authors suggest that the batter uses the information gleaned from the anticipatory saccade to determine the ball’s actual trajectory facilitating predictions about the location of future pitches as they cross the plate.

Similar anticipatory gaze movements that move the eyes to the interception point with the ball have been recorded previously in cricket. Land and McLeod recorded the eye movements of three batsmen (a professional player, an experienced minor counties player, and a novice) using a head mounted eye camera as they viewed balls propelled
from a bowling machine. Despite vastly different skill levels among the subjects, the same general tracking strategy emerged. These researchers found that these players followed the ball with pursuit eye movements for the first 100-150 milliseconds of the trajectory, at which point a saccade was made to the predicted ball bounce location. The batsmen would then, allow their foveas to “lay in wait” for the bounce and would then again track the ball with smooth pursuit eye movements. However, it should be noted that comparisons between baseball and cricket gaze tracking should be done so with caution, as the trajectory of a pitched ball in baseball is significantly different than a ball released from a cricket bowler (the ball bounces prior to the batsmen making contact with the bat in cricket, unlike in baseball where there usually is no bounce prior to contact). Due to these differences in ball flight trajectory between the two sports, gaze tracking behaviors may not directly translate.

1.4: Baseball Gaze Tracking: Motor versus Perceptual Elements

Gaze tracking in baseball encompasses both motor and perceptual elements. The motor elements simply incorporate how a batter moves the head and eyes to accomplish the tracking task throughout the pitch trajectory. A batter may utilize various types of eye movements during a baseball pitch including saccades, pursuits, RVOR movements, and/or vergence eye movements. These eye movements and their properties will next briefly be described.

Saccades are fast moving, ballistic, conjugate eye movements that help to redirect the fovea toward objects of interest. The ballistic nature of saccades refers to the fact that
once initiated, these eye movements must complete their movements; thus once a saccade has begun, it cannot be adjusted “on the fly”. Saccades can reach velocities of up to 700 degrees per second.\textsuperscript{18} The latency of saccadic eye movements is reported to be about 200 milliseconds.\textsuperscript{19} As stated above, saccades may be utilized during pitch gaze tracking to move the eyes to a predicted final position of the pitch, thereby allowing the batter to compare their prediction of a pitch’s location to the actual final location of the ball.

Pursuit eye movements are slower, gaze-shifting, conjugate eye movements that help to maintain the fovea on a moving target of interest. Pursuits have been reported to reach terminal velocities of up to 90 degrees per second.\textsuperscript{11} The latency of pursuit eye movements has been reported to be about 100-120 milliseconds.\textsuperscript{19} Pursuit eye movements are believed to play a major role in baseball pitch tracking, and may be an area where expert and less experienced batters differ, with those more experienced players exhibiting higher pursuit velocities as shown by Bahill and LaRitz.\textsuperscript{10}

Rotational vestibulo-ocular (RVOR) eye movements are conjugate eye movements that function to stabilize the retinal image during head/body movements. Signals from the semi-circular canals in the inner ear measure rotational head movements and provide information to the oculomotor nuclei to elicit eye movements to counteract the head movement.\textsuperscript{18} The reported 10-16 millisecond latency of the RVOR is very short, allowing for nearly real-time eye movement adjustments to movements of the head/body.\textsuperscript{20} The RVOR may be another area in which expert and novice batters differ during pitch tracking. A better ability to cancel the RVOR may allow a batter to better
track a pitch, in that the head and eyes can be moved in conjunction as shown by Bahill and LaRitz.\textsuperscript{10}

Vergence eye movements are disjunctive eye movements that help to adjust the angle between the eyes to targets of different distances. The latency of the vergence system has been reported between 120 to 160 milliseconds.\textsuperscript{19} It is believed that the vergence system does not play a role in baseball gaze tracking due to the fact vergence movements are not stimulated until the ball is very close to the batter, at which point, the latency of the vergence system is too slow to elicit a timely response as the ball passes the batter. This is due to the high relative angular velocity of the ball at that time and distance.\textsuperscript{10}

Comparing the location of a batter’s gaze to the actual location of a pitched ball during its flight can be used to determine the accuracy and efficiency of the player’s tracking ability. The perceptual aspects of gaze tracking include the sensory input that may influence a player’s success in tracking and hitting alike.

When one attempts to hit a baseball, the act of hitting can be reduced to simple judgments of \textit{where} and \textit{when}. The \textit{when} portion of these judgments is referred to as the time to collision (TTC) and it is vital for the batter to accurately estimate the TTC to be successful. Here, the TTC refers to the time at which the ball crosses the plate and/or the time at which the bat makes contact with the ball depending on scenario, “take” or swing, respectively. The TTC for an approaching pitch can be estimated by using information based on the expansion of the ball’s retinal image size as it advances toward batter and the change in retinal disparity.\textsuperscript{3,21,22}
Kato and Fukuda studied the visual search strategies of expert and novice batters during the pitcher’s motion (the “pitcher’s motion” are the movements made by the pitcher in preparation of the pitch just prior to release of the ball). Their study included nine expert university baseball players along with nine novice, non-athlete university students. Eye movements of all subjects were recorded while viewing a video of a pitcher throwing a series of 10 types of pitches. Kato and Fukuda found that the novice players moved their eyes faster (fixated points for a shorter period of time) and over a larger area of fixation points compared to the expert players who exhibited a more stable visual search pattern with a smaller area of fixation points, consistently near the pitcher’s arm, elbow, or anticipated release point. These investigators suggested that based on these data and pattern of fixation, more experienced players use information before the pitch based upon the pitcher’s arm and hand location during ball release to predict the pitch’s trajectory, velocity, and final location.

Once the ball has been released and is in flight, it may be advantageous for the batter to continuously track the pitch for as long as possible as it may improve TTC predictions compared to fixating the point where the ball ultimately may arrive. Enhanced TTC prediction secondary to continuous tracking has been demonstrated.

Bennett et al. conducted a study examining the role of ocular pursuits in regards to the accuracy of TTC estimations. The researchers tested 22 subjects, randomly distributed to two experimental groups based upon viewing condition (fixation vs. pursuit). The subjects viewed a computer screen with a proprietary program that would
displays a black spherical object (object of regard) and a vertically oriented line, which represented the terminal endpoint for the TTC. The program was set to move the object of regard horizontally across the screen at varying velocities until it reached the vertically oriented line. Subjects were instructed to estimate the TTC as accurately as possible by pressing the spacebar when the object of regard reached the vertically oriented line. Those subjects in the fixation group were instructed to only look at the vertically oriented line (subjects eyes were monitored via real time video to ensure adherence to the instructions), while those subjects in the pursuit group were instructed to follow the object of regard as it moved across the screen. Bennett et al. found that the fixation group exhibited a significant constant misperception of TTC at each of their tested object velocities. For the fixation group only, there was a significant effect of object velocity on TTC estimation error, showing relative overestimations for slow velocity objects of regard and relative underestimations for faster velocity targets.

1.5: Summary of Gaze Tracking In Baseball

In summary, there have been very few quantitative published studies in the field of head and eye tracking in regards to baseball hitting, and even fewer directly comparing a novice group of batters against a more experience group of expert players. Due the scarcity of data on gaze tracking in baseball hitting, it is difficult to speculate on any concrete differences between expert and novice players in tracking strategy or efficiency. To this date, Bahill and LaRitz have been one of the few researchers who have done so, but in limited fashion, only recording and analyzing six full pitches along with 15 partial
pitches. And although Bahill and LaRitz demonstrated differences in pitch tracking ability and strategy between their MLB player and less experienced batters, the small number of pitches analyzed led us to reexamine this issue.

While differences between expert and novice players are likely to exist, which of these differences/strategies are likely to confer an advantage in pitch gaze tracking? Alternatively, if experts and novice players seem to utilize similar strategies, why might this occur? Is there a head and eye movement strategy must be utilized inherently due to the physical dynamics of pitch tracking?

1.6: Aims of the Study

The focus of our study was to measure head and eye movements used by novice athletes in tracking pitched balls in a “take” pitch scenario. The “take” pitch scenario is defined as a condition in which the subject knows before the pitch is thrown that he will not swing at the pitch. These novice data were then used to compare to previously published data recorded in a similar fashion by Fogt and Zimmerman for intercollegiate baseball players. We sought to determine whether head and eye tracking strategies differed between novice and intercollegiate baseball players and whether or not these differences may confer an advantage in ocular gaze tracking.
Chapter 2: Methods

2.1: Subject Enrollment and Eligibility

This study was approved by The Ohio State University Biomedical Institutional Review Board. All subjects signed an informed consent form as well as a HIPAA form prior to participation in the experiment. Data were collected from 20 novice baseball players. For the purposes of this study a novice player was defined as one who has never played any intercollegiate or professional organized baseball. Baseball experience for this group ranged from none to high school varsity level. All subjects were under 30 years of age. Monocular visual acuity was tested with a Bailey-Lovie chart. Upon completion of the study, subjects received a gift card.

2.2: Pitching Machine

Tennis balls were projected from a pneumatic pitching machine, called The Flamethrower (Flamethrower®, Accelerated Baseball Technologies; Barrington, IL) (Figure 1). This specific pitching machine uses a rubber bladder that compresses air that is in turn used to launch tennis balls repeatedly and accurately (Figure 1).
A light emitting diode (LED) flashlight and photodiode were vertically aligned across from each other and mounted at the end of the tube closest to the subject. This LED flashlight and photodiode apparatus allowed the accurate measurement of the exact time at which the ball left the tube. As the tennis balls were projected from the end of the PVC tube, the ball would break the plane of the LED flashlight and photodiode apparatus, causing a measurable drop in voltage output from the photodiode, allowing for the exact moment the pitch was projected to be determined. The output from the photodiode was routed through an inverting amplifier and used for further evaluation, explained in upcoming sections.
2.3: Ball Location

In order to make accurate gaze calculations, it was necessary to know the position of the ball at various points of the trajectory. To calculate the position of the ball throughout these various points, it was necessary to determine the time required for the ball to traverse a particular linear distance.

A ballistic timing window (Oehler, Model 57 Ballistic Screen; Austin, Texas) was used to measure the mean time required for the balls to travel various particular distances. The ballistic timing window was moved to nine various locations, ranging from five feet to 42 feet, 8 inches, which represented the full distance from the end of the PVC tube on the pitching machine to the front of the home plate for our experimental set up. The 42 feet, 8 inch distance was chosen simply due to size constraints of our specific laboratory set up. This distance represented the longest distance at which our equipment could be set up. At each specified distance, 104 total pitches were projected through the timing window. The distances at which recordings were made and the resultant mean elapsed times for the pitches to traverse these distances are shown in Table 1.
<table>
<thead>
<tr>
<th>Test Distance, feet</th>
<th>Number of Trials</th>
<th>Measured Time (SD), ms</th>
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</table>

Table 1. Time (in milliseconds) required for a tennis ball to traverse specified distances and corresponding mean linear velocities for each distance.

The mean elapsed times for the pitches to traverse the various distances are plotted in Figure 2. A linear regression was fit to these data. This linear regression was used to calculate the linear distance traveled by the ball at an elapsed time point of interest as the ball was projected from the pitching machine. The linear velocity of the balls was calculated to be 113.9 feet per second (77.7 miles per hour) as the ball reached the plate.
Figure 2. Elapsed time versus distance traveled by tennis ball.

Eye movement amplitude, head movement amplitude, and gaze positions were determined at regular intervals throughout the pitch trajectory. The elapsed times of the trajectory selected were: 150 ms, 200 ms, 250 ms, 298 ms, 333 ms, 375 ms. The last value was chosen because it was the last elapsed time as the ball crossed the plate. The linear distance traveled by the ball was then calculated based upon these selected elapsed times (Table 2).

These data recorded from the timing window were then used to determine the gaze angle required for the subjects to foveate the ball in the horizontal meridian. The linear distances the ball had traveled were converted to the necessary gaze angle required by the batters using the calculations shown in Appendix A. The required gaze angles for
the various time points of interest (based on the subject’s set 28 inch distance from the plate) are shown in Table 2 and Figure 3.

<table>
<thead>
<tr>
<th>Elapsed Time, ms</th>
<th>Linear Distance Traveled by Tennis Ball (feet)</th>
<th>Linear Distance from Batter (feet)</th>
<th>Change in Visual Angle from Start (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>17.8</td>
<td>24.9</td>
<td>1.9</td>
</tr>
<tr>
<td>200</td>
<td>23.5</td>
<td>19.2</td>
<td>3.2</td>
</tr>
<tr>
<td>250</td>
<td>29.2</td>
<td>13.5</td>
<td>5.6</td>
</tr>
<tr>
<td>298</td>
<td>34.7</td>
<td>8.0</td>
<td>11.1</td>
</tr>
<tr>
<td>333</td>
<td>38.6</td>
<td>4.0</td>
<td>23.5</td>
</tr>
<tr>
<td>375</td>
<td>42.7</td>
<td>0</td>
<td>87.4</td>
</tr>
</tbody>
</table>

Table 2. Change in visual angle between pitched ball and the subject at elapsed times of interest.

Figure 3. Horizontal target gaze angle (assuming a 28 inch distance to the middle of the plate) vs. elapsed time.
2.4: Eye and Head Monitoring

2.4a: Monitoring Eye Movements

All subjects were right-handed and thus stood in the right-handed batter’s box at a distance of 28 inches from the plate. Eye movements were recorded using a video eye tracker from ISCAN Incorporated (Burlington, MA). The ISCAN cameras were affixed to a tight fitting goggle. The ISCAN system utilizes 120 Hz refresh rate infrared cameras and beam-splitters to monitor pupil position, with the ability to detect both vertical and horizontal eye movements. Only horizontal values were recorded in this study. Binocular eye movement recordings were made, but only data from the lead eye closest to the pitching machine (left eye) were analyzed.

The spatial resolution of the ISCAN system has been determined to be at least 15 minutes of arc. In a previous separate experiment by Fogt and Zimmerman, the mean difference between angular values from the ISCAN was determined to be within one degree of measurements made with a search coil.²⁵

The output of the ISCAN system was recorded in digital format and for analysis purposes, was converted to analog using a digital-to-analog converter. These analog signals were then output to an 11-bit analog-to-digital converter (ADC) (USB-1208FS; Measurement Computing, Norton, MA).

The horizontal amplification or gain of the ISCAN was determined by using a five point calibration (49.7 degrees apart total), including the end of the PVC pitching machine tube and four small fixation targets affixed to a wall that spanned the length of the pitch trajectory. For calibration, each subject was instructed to look at each of the
five calibration points while maintaining a fixed head position. The ISCAN digital values were then recorded at each corresponding calibration as well at the end of the PVC pitching machine tube fixation point. These data were then plotted against the calculated change in visual angle between each calibration point. The gain for each subject was determined to be the slope of the linear regression of these plots.

2.4b: Monitoring Head Movements

A head-tracking device (MicroStrain 3DM-GX1) (LORD Corporation, Williston, VT) was tightly fastened to the top of a visor-less baseball batting helmet. This specific head-tracking device has the capability for horizontal (yaw), vertical (pitch), and tilt (roll) movement measurements, but for the purposes of this study, only horizontal movements were measured.

In previous work, Fogt and Zimmerman assessed this MicroStrain device for potential artifacts related to cross talk due to head tilt. No horizontal artifacts were noted. Fogt and Zimmerman also compared this specific MicroStrain against a search coil and found that on average the MicroStrain was within 1 degree of the search coil, with a standard deviation of less than one degree.

Lastly, Fogt and Zimmerman determined that slippage of the batting helmet was unlikely to significantly influence data recorded from the MicroStrain during the experimental procedure.
The MicroStrain recorded data in analog format and were output into the same 11-bit ADC as the ISCAN and photodiode at the end of the PVC pitching machine tube. This allowed for the MicroStrain, ISCAN, and photodiode to record in synchrony.

The MicroStrain refresh rate was 100 Hz, whereas the MicroStrain analog data after being routed through the ADC were recorded at 2000 Hz. Due to this oversampling, the data from the MicroStrain was smoothed with an averaging filter (explained in later sections).

The gain of the MicroStrain remains constant between subjects; therefore a single calibration factor for the horizontal amplification or gain was determined for all subjects using the MicroStrain when mounted on a protractor. Fogt and Zimmerman compared these horizontal rotational data to those data obtained simultaneously from a search coil and determined that the Microstrain device was within $0.10 \pm 0.86$ degrees.$^{25}$

2.5: Experimental Design

After the informed consent process and visual acuity measurement, each subject was briefly asked about their prior organized baseball experience (estimated years of baseball experience and highest level of baseball played). Then each subject put on the ISCAN goggles and visor-less batting helmet with the MicroStrain device affixed. The subjects were asked to hold a baseball bat throughout the experiment to more closely emulate a true batting stance, but the subjects were told not to swing the bat. The measured distance between each subject’s forehead and the center of home plate was 28 inches.
Next, the five-point ISCAN calibration measurements were made. Each subject was then shown two example tennis balls (Figure 4). One tennis ball had a number written in six locations in black, the other had numbers written in the same manner but in red. The numbers were approximately 18 mm tall and 2 mm wide. Subjects were asked to call out the color (black or red) and the number (0-8) on the balls as they were pitched from the pitching machine. Subjects were told to guess if they were unsure.

![Figure 4. Example of tennis balls used as targets, with numbers ranging from 0-8 in red or black, written in permanent marker on six locations of each ball.](image)

Responses to color/number naming were not recorded as Fogt and Zimmerman previously found that this task in a highly similar experimental set up with a group of intercollegiate baseball players did not produce responses higher than random chance.25 Instructions for subjects to attempt to name the color and number written on the balls
were kept identical in this experiment to keep the task and possible behavior consistent between the novice subjects and the intercollegiate baseball player subjects in Fogt and Zimmerman’s previous study.

Fifty-two pitches were presented to each subject in two back-to-back runs. Each pitch was separated by three to five seconds.

2.6: Data Analyses

Data could be analyzed for 14 of the 20 subjects. All of those data from the other six subjects could not be analyzed due to improper recording from one or more of the devices used in the experimental setup. For each of the 14 useable subjects, a single run (52 pitches) was analyzed. The second set of pitches was used for the analysis in most cases. For two subjects the first set of pitches had to be used.

It should also be noted that an assumption was made that all subjects were looking at or near the PVC pitching machine tube when each pitch was released. Specific instructions on where to look before the start of each pitch were not given. The absolute position of the head (relative to the body) was not measured before each pitch. At the beginning of each pitch, the head and eye position was zeroed, so the reported head rotation is the change in rotation from the beginning of the pitch to the elapsed times of interest.
2.6a: Objective Assessment of Eye Movement Amplitude, Head Movement Amplitude, and Gaze Error

The raw data from the eye and head trackers were analyzed using a custom computer program. This custom program served a variety of functions. The custom program first applied a 40-point averaging filter to the raw head and eye data and was also able to apply the respective calibration (gain) values. The program was also able to identify those times at which a pitch exited the pitching machine by looking for a drop in voltage from the LED flashlight/photodiode apparatus on the PVC pitching machine tube. The program was then set to divide these data into individual files spanning two seconds of data after a pitch was released (dividing each run into individual pitches). Lastly, the program was able to compensate for temporal delays between recording devices to ensure synchrony of these data.

At this point, the beginning of the data files were zeroed under the assumption that all subjects were looking at or near the PVC pitching machine tube at the start of each pitch mentioned above. The angular changes in eye and head positions from the beginning of the pitch to six elapsed times after the pitch was released were calculated. These elapsed times of interest included 150, 200, 250, 298 (approximately eight feet short of the plate), 333 (approximately four feet short of the plate), and 375 milliseconds (full distance to the plate). The elapsed time of 298 milliseconds was chosen because at this time the ball is about eight feet from the batter, the same distance at which Hubbard and Seng found that professional players stop tracking the ball. The elapsed time of 333 milliseconds was chosen for a similar reason. At the 333 millisecond time, the ball is at a
similar distance to that at which an MLB player (5.5 feet) could no longer accurately track a pitch in a previous study by Bahill and LaRitz.\textsuperscript{10}

Before final analyses of the gaze and eye movement data, each individual pitch trace for every subject was inspected for indication of a blink. The ISCAN data for those pitches where a blink was suspected were graphed to ensure a blink was present. Pitches that exhibited blinks were discarded before analysis. There were a large number of instances in which blinks occurred at the last elapsed time point of interest (375 milliseconds). In that instance, the last time point of interest was discarded only, with the rest of the data kept for analysis.

The gaze angle was calculated by adding the angular changes in eye and head rotation from the beginning of the pitch to each of the elapsed times of interest. The gaze error was calculated by taking the difference between angular change in ball position and the angular change in gaze position. Signed gaze error and unsigned gaze position was calculated. The signed gaze error reveals if there was a lag or lead of gaze position, whereas the unsigned gaze errors gives insight into overall accuracy of gaze tracking.

2.6b: Comparison to Previously Recorded Intercollegiate Data

The head, eye, and gaze data from our novice subjects was compared to the data published and recorded in a similar fashion by Fogt and Zimmerman for Division 1 intercollegiate baseball players.\textsuperscript{25} Permission was obtained to reanalyze these data (the primary change being that fewer data points were included in calculating the summary statistics) and to compare them statistically to the novice data. In order to most directly
compare our novice data to those data from the intercollegiate baseball players recorded by Fogt and Zimmerman, slightly different elapsed times of interest were calculated to match the gaze angles recorded and analyzed by Fogt and Zimmerman. The elapsed times of interest used in our novice data to compare to Fogt and Zimmerman’s intercollegiate data were 124, 172, 222, 278, 317, and 375 milliseconds. These times were chosen because they corresponded with the gaze angles analyzed previously by Fogt and Zimmerman. The corresponding gaze angles for the aforementioned elapsed times of interest were 1.4, 2.4, 4.1, 8.2, 16, and 87.97 degrees, respectively. The discrepancy in the elapsed times of interest stems from a shorter overall pitching distance (Flamethrower to the batter) in this study compared to Fogt and Zimmerman’s.

It should be noted that for the experts the second set of 49 pitches was used for the analysis, except for two individuals in which the first set of 49 pitches was used. This was done because the second set of pitches were not recorded appropriately.
3.1: Subject Data

3.1a: Visual Acuity Data

Mean logMAR visual acuity for the 14 subjects analyzed was 0.08 (20/25+ Snellen equivalent, SD 0.10) RE and 0.06 (20/25+2 Snellen equivalent, SD 0.13) LE. No subjects had a visual acuity worse than 0.32 logMAR in either eye (only one subject was 0.32 logMAR). The visual acuity data for each subject is shown in Table 3.

3.1b: Age and Baseball Experience Data

The average age of participants was 24.9 years old, with a range from 18-30 years.

Of the 14 subjects analyzed, three had no organized baseball experience, five played at the Little League level, two played at the Junior Varsity level, and four had experience at the high school Varsity level. None had any experience at the intercollegiate or professional level.

Three subjects reported no organized baseball experience, two subjects reported 0-2 years of experience, one subject reported 3-5 years of experience, three subjects reported 6-8 years of experience, and five subjects reported 9+ years of experience.

The level and years of baseball experience for each subject can be seen in Table 3.
Table 3. Subjects' reported baseball experience, age, and logMAR visual acuity.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Highest Level of Baseball Experience</th>
<th>Years of Baseball Experience</th>
<th>Right Eye LogMAR Visual Acuity</th>
<th>Left Eye LogMAR Visual Acuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Varsity</td>
<td>9+</td>
<td>-0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>Junior Varsity</td>
<td>6–8</td>
<td>0.00</td>
<td>-0.10</td>
</tr>
<tr>
<td>3</td>
<td>Little League</td>
<td>0–2</td>
<td>0.00</td>
<td>-0.10</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>None</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td>None</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>6</td>
<td>Little League</td>
<td>3–5</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>7</td>
<td>Varsity</td>
<td>9+</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>8</td>
<td>Junior Varsity</td>
<td>9+</td>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>9</td>
<td>Varsity</td>
<td>9+</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>10</td>
<td>Varsity</td>
<td>9+</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>11</td>
<td>Little League</td>
<td>6–8</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>12</td>
<td>Little League</td>
<td>0–2</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>13</td>
<td>None</td>
<td>None</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>14</td>
<td>Little League</td>
<td>6–8</td>
<td>0.10</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

3.2: Novice Data

3.2a: Combined Head Movement, Eye Movement, and Gaze Data

The collective mean data from all analyzed subjects showed that the head tracked the target for much of the pitch trajectory. Figure 5 shows the mean head, mean eye, and mean gaze positions of all the novice subjects throughout the trajectory of the pitches. These data also showed that mean eye movement amplitude remained nearly constant until very late in the pitch trajectory, initially showing a small leftward movement, in the opposite direction of the flight of the ball (likely associated with the RVOR), followed by a larger rightward movement in the direction of the ball later in the trajectory.

Lastly, the mean gaze was directed near the target throughout much of the pitch.
Figure 5. Mean eye rotation, mean head rotation, and mean gaze position vs. time for all novice subjects. Error bars denote ± one SD.

3.2b: Novice Head Movement Behavior

A one-way analysis of variance (ANOVA) was calculated at each of the elapsed times of interest in regards to head movements. At each of the elapsed times, significant differences were demonstrated between head movements of the subjects (p < 0.001 for all elapsed times).
3.2c: Novice Eye Movement Behavior

A one-way ANOVA was calculated at each of the elapsed times of interest in regard to eye movements. At each of the elapsed times, significant differences were demonstrated between eye movements of the subjects (p < 0.001 for all elapsed times).

3.2d: Relationship between Head and Eye Tracking Values for Individual Subjects

Table 4 shows the mean head movement, mean eye movement, and mean signed gaze errors for each subject at each elapsed time of interest in the pitch trajectory. Looking at these data, if the RVOR is invoked during the head-eye tracking throughout the pitch trajectory, a negative relationship between the amplitudes of head and eye movement is to be expected. Initial inspection of these data suggests that this negative relationship seems to exist, but there are some cases where the mean eye movement amplitude was equal to or greater than the mean head movement amplitude for some subjects at the elapsed time of 333 milliseconds. These cases, are not consistent with typical RVOR-related eye movement.
Table 4. Mean head movement (degrees), mean eye movement (degrees), and mean signed gaze error (SGE) (degrees) for individual subjects at each elapsed time of interest throughout the pitch trajectory. The column “n” represents the number of pitches analyzed for each subject. The standard deviation of these means is included in parentheses in all cases.
The difference between head movement amplitude and eye movement amplitude was plotted against head movement amplitude. With the data plotted in this manner, if the RVOR was fully invoked (no RVOR suppression), then the slope of this line would be 2.0; if the RVOR was completely suppressed, then the slope of the line would be 1.0. These plots can be seen in Figure 6. The linear regression for each elapsed time of interest can be seen in Table 6.

<table>
<thead>
<tr>
<th>Elapsed Time, ms</th>
<th>Head Rotation – Eye Rotation Linear Regression Equation</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>y = -1.30 + 1.66 (head rotation)</td>
<td>0.93</td>
</tr>
<tr>
<td>200</td>
<td>y = -2.65 + 1.62 (head rotation)</td>
<td>0.91</td>
</tr>
<tr>
<td>250</td>
<td>y = -4.11 + 1.53 (head rotation)</td>
<td>0.87</td>
</tr>
<tr>
<td>298</td>
<td>y = -4.65 + 1.23 (head rotation)</td>
<td>0.65</td>
</tr>
<tr>
<td>333</td>
<td>y = -6.83 + 1.02 (head rotation)</td>
<td>0.44</td>
</tr>
<tr>
<td>375</td>
<td>y = -10.93 + 0.82 (head rotation)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table 5. Linear regression plots of (head rotation - eye rotation) versus (head rotation) for various elapsed times in the pitch trajectory.
Figure 6. (A–F) Regression plots of (head rotation - eye rotation) versus (head rotation) for various elapsed times in the pitch trajectory. The dashed lines show the 95% confidence intervals for the regression fits. (A) elapsed time = 150 milliseconds; (B) elapsed time = 200 milliseconds; (C) elapsed time = 250 milliseconds; (D) elapsed time = 298 milliseconds; (E) elapsed time = 333 milliseconds; (F) elapsed time = 375 milliseconds.
3.3: Novice versus Intercollegiate Subject Data

As mentioned previously, to directly compare our novice data to the intercollegiate baseball player data collected by Fogt and Zimmerman, specific target angles were determined and matched between the two groups. Table 6 below displays the matching target angles along with corresponding times of interest in regards to our data and Fogt and Zimmerman’s original data.\(^{25}\)

<table>
<thead>
<tr>
<th>Elapsed Time (ms) – Novice Data</th>
<th>Matching Target Angle (degrees)</th>
<th>Elapsed Time (ms) – Fogt and Zimmerman, Intercollegiate Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>1.4</td>
<td>150</td>
</tr>
<tr>
<td>172</td>
<td>2.4</td>
<td>200</td>
</tr>
<tr>
<td>222</td>
<td>4.1</td>
<td>250</td>
</tr>
<tr>
<td>278</td>
<td>8.2</td>
<td>300</td>
</tr>
<tr>
<td>317</td>
<td>16.0</td>
<td>341</td>
</tr>
<tr>
<td>375</td>
<td>87.37/87.97</td>
<td>381</td>
</tr>
</tbody>
</table>

Table 6. Matching target angles for our novice data and Fogt and Zimmerman's intercollegiate player data and their corresponding elapsed times.

3.3a: Statistical Comparison of Mean Novice versus Mean Intercollegiate Subject Data

The collective mean head, mean eye, and mean signed gaze error for all 14 novices is shown in Table 7. Likewise, from Fogt and Zimmerman’s data, the collective mean head, eye, and signed gaze error for all 15 intercollegiate subjects is shown in Table 8.
Table 7. Collective mean of all novice subject head positions, eye positions, and signed gaze errors for gaze angles matching the intercollegiate subject data. The standard deviation of these means is included in parentheses in all cases. Values marked with an asterisk represent significant differences compared to the collegiate collective mean data.

<table>
<thead>
<tr>
<th>Target Angle (degrees)</th>
<th>Elapsed Time (ms)</th>
<th>Novice Mean Head Rotation (degrees)</th>
<th>Novice Mean Eye Rotation (degrees)</th>
<th>Novice Mean Signed Gaze Error (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>124</td>
<td>1.5 (1.0)</td>
<td>-0.2 (0.9)</td>
<td>-0.1 (0.4)</td>
</tr>
<tr>
<td>2.4</td>
<td>172</td>
<td>2.6 (1.6)</td>
<td>0.2 (1.4)</td>
<td>0.4 (0.8)</td>
</tr>
<tr>
<td>4.1</td>
<td>222</td>
<td>4.6 (2.5)</td>
<td>0.6 (2.1)</td>
<td>1.1 (1.4)</td>
</tr>
<tr>
<td>8.2</td>
<td>278</td>
<td>9.2* (4.4)</td>
<td>1.0 (3.5)</td>
<td>2.1 (3.3)</td>
</tr>
<tr>
<td>16.0</td>
<td>317</td>
<td>14.7* (6.4)</td>
<td>4.1 (7.0)</td>
<td>2.7* (8.5)</td>
</tr>
<tr>
<td>87.37</td>
<td>375</td>
<td>26.0* (11.0)</td>
<td>15.6* (12.7)</td>
<td>-45.8* (17.4)</td>
</tr>
</tbody>
</table>

A two sample t-test was used to compare the mean head, mean eye, and mean signed gaze errors of our novice subjects to that of the Division 1 intercollegiate baseball...
players studied in Fogt and Zimmerman’s previous study. Table 9 shows the t-test comparing the mean head rotation, mean eye rotation, and mean signed gaze errors between the two groups for each of the matched target angles of interest throughout the pitch trajectory. Significant differences between the novice and intercollegiate subjects were apparent late in the pitch trajectory for mean head position, mean eye rotation, and mean signed gaze error with the novice subjects exhibiting larger head and eye movements, but smaller gaze errors.

<table>
<thead>
<tr>
<th>Target Angle (degrees)</th>
<th>Mean Head p-value</th>
<th>Mean Eye p-value</th>
<th>Mean Signed Gaze Error p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>0.157</td>
<td>0.117</td>
<td>0.585</td>
</tr>
<tr>
<td>2.4</td>
<td>0.198</td>
<td>0.210</td>
<td>0.715</td>
</tr>
<tr>
<td>4.1</td>
<td>0.212</td>
<td>0.392</td>
<td>0.868</td>
</tr>
<tr>
<td>8.2</td>
<td>0.040*</td>
<td>0.472</td>
<td>0.273</td>
</tr>
<tr>
<td>16</td>
<td>0.022*</td>
<td>0.714</td>
<td>0.004*</td>
</tr>
<tr>
<td>87.97</td>
<td>0.003*</td>
<td>0.042*</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

Table 9. Two-sample t-test comparing novice and intercollegiate baseball player mean head, mean eye, and mean signed gaze errors values at matching target angles of interest. Significant p-values are marked with an asterisk.

3.3b: Statistical Comparison of Variance between Collective Mean Novice and Intercollegiate Data

Levene’s test of equal variance was used to determine if variance between the novice and intercollegiate subjects differed. Levene’s test was applied to the mean head, mean eye, and mean signed gaze error values between the two groups. Table 10 shows results of Levene’s test at each of the matched target angles of interest throughout the pitch trajectory. The only significant difference in variance between the novice and
intercollegiate groups was noted at the 375-millisecond elapsed time for the mean eye position only

<table>
<thead>
<tr>
<th>Target Angle (degrees)</th>
<th>Mean Head p-value</th>
<th>Mean Eye p-value</th>
<th>Mean Signed Gaze Error p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>0.399</td>
<td>0.438</td>
<td>0.996</td>
</tr>
<tr>
<td>2.4</td>
<td>0.505</td>
<td>0.515</td>
<td>0.921</td>
</tr>
<tr>
<td>4.1</td>
<td>0.395</td>
<td>0.600</td>
<td>0.444</td>
</tr>
<tr>
<td>8.2</td>
<td>0.131</td>
<td>0.461</td>
<td>0.806</td>
</tr>
<tr>
<td>16.0</td>
<td>0.119</td>
<td>0.066</td>
<td>0.771</td>
</tr>
<tr>
<td>87.97</td>
<td>0.159</td>
<td>0.040*</td>
<td>0.273</td>
</tr>
</tbody>
</table>

Table 10. Levene’s test of equal variance comparing novice and intercollegiate baseball player mean head, mean eye, and mean signed gaze errors values at matching target angles of interest. Significant p-values are marked with an asterisk.

3.3c: Statistical Comparison of Various Novice Experience Levels versus Intercollegiate Data

To further look into possible differences between the novice and intercollegiate groups, the novice data was again split into various groups based upon experience level. The novice subjects were divided into three different groups based upon their highest level of baseball experience. For these analyses, the three novice groups included, “High School” (which included those who reported “Varsity” or “Junior Varsity” as their highest level of baseball experience), “Little League”, and those who reported “None”. Since the groups were not evenly distributed, the Kruskal-Wallis test was used to compare three novices groups and the intercollegiate subject data using a one-way ANOVA to evaluate the mean head movements, mean eye movements, and mean signed gaze errors at all matching gaze angles listed in Table 11.
The mean head, eye, and signed gaze errors are shown for each group in Tables 11, 12, and 13 respectively.

### Table 11. Mean head movements of the “High School”, “Little League”, “None”, and “Intercollegiate” groups. The standard deviation of these means is included in parentheses in all cases. Target angles marked with an asterisk represent angles at which significant.

<table>
<thead>
<tr>
<th>Group</th>
<th>1.4</th>
<th>2.4</th>
<th>4.1</th>
<th>8.2</th>
<th>16.0*</th>
<th>87.97*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School</td>
<td>1.0 (0.8)</td>
<td>1.9 (1.4)</td>
<td>3.7 (2.4)</td>
<td>8.3 (4.4)</td>
<td>13.7 (6.3)</td>
<td>25.2 (10.4)</td>
</tr>
<tr>
<td>Little League</td>
<td>1.4 (0.7)</td>
<td>2.4 (1.4)</td>
<td>4.2 (2.5)</td>
<td>7.9 (4.2)</td>
<td>11.8 (5.7)</td>
<td>19.9 (8.6)</td>
</tr>
<tr>
<td>None</td>
<td>2.7 (0.8)</td>
<td>4.3 (1.3)</td>
<td>7.1 (1.7)</td>
<td>13.6 (2.1)</td>
<td>21.4 (2.7)</td>
<td>37.5 (8.1)</td>
</tr>
<tr>
<td>Intercollegiate</td>
<td>1.0 (0.7)</td>
<td>1.9 (1.3)</td>
<td>3.5 (2.1)</td>
<td>6.2 (3.2)</td>
<td>9.5 (4.7)</td>
<td>14.1 (7.5)</td>
</tr>
</tbody>
</table>

### Table 12. Mean eye movements of the “High School”, “Little League”, “None”, and “Intercollegiate” groups. The standard deviation of these means is included in parentheses in all cases. Target angles marked with an asterisk represent angles at which significant.

<table>
<thead>
<tr>
<th>Group</th>
<th>1.4*</th>
<th>2.4*</th>
<th>4.1*</th>
<th>8.2*</th>
<th>16.0*</th>
<th>87.97*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School</td>
<td>0.4 (0.5)</td>
<td>1.2 (0.8)</td>
<td>1.9 (1.6)</td>
<td>3.0 (2.7)</td>
<td>8.1 (7.2)</td>
<td>23.5 (14.9)</td>
</tr>
<tr>
<td>Little League</td>
<td>-0.1 (0.3)</td>
<td>0.2 (0.7)</td>
<td>0.8 (1.4)</td>
<td>1.6 (2.3)</td>
<td>4.3 (3.3)</td>
<td>13.4 (3.9)</td>
</tr>
<tr>
<td>None</td>
<td>-1.6 (0.9)</td>
<td>-1.8 (1.0)</td>
<td>-2.2 (0.7)</td>
<td>-3.9 (0.8)</td>
<td>-4.4 (2.6)</td>
<td>3.4 (7.0)</td>
</tr>
<tr>
<td>Intercollegiate</td>
<td>0.3 (0.6)</td>
<td>0.8 (1.1)</td>
<td>1.3 (1.8)</td>
<td>1.9 (2.7)</td>
<td>3.3 (3.2)</td>
<td>7.5 (5.2)</td>
</tr>
</tbody>
</table>
Table 13. Mean signed gaze errors of the “High School”, “Little League”, “None”, and “Intercollegiate” groups. The standard deviation of these means is included in parentheses in all cases. Target angles marked with an asterisk represent angles at which significant.

<table>
<thead>
<tr>
<th>Group</th>
<th>1.4</th>
<th>2.4</th>
<th>4.1</th>
<th>8.2</th>
<th>16.0*</th>
<th>87.97*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School</td>
<td>0.1 (0.4)</td>
<td>0.7 (0.7)</td>
<td>1.5 (1.2)</td>
<td>3.1 (3.8)</td>
<td>5.8 (11.3)</td>
<td>-38.6 (22.1)</td>
</tr>
<tr>
<td>Little League</td>
<td>-0.2 (0.4)</td>
<td>0.3 (0.9)</td>
<td>1.0 (1.7)</td>
<td>1.3 (3.4)</td>
<td>0.1 (5.8)</td>
<td>-54.0 (10.0)</td>
</tr>
<tr>
<td>None</td>
<td>-0.3 (0.7)</td>
<td>0.1 (0.9)</td>
<td>0.7 (1.4)</td>
<td>1.6 (2.8)</td>
<td>1.0 (5.1)</td>
<td>-46.5 (15.0)</td>
</tr>
<tr>
<td>Intercollegiate</td>
<td>0.0 (0.5)</td>
<td>0.5 (0.8)</td>
<td>1.2 (1.8)</td>
<td>0.8 (2.7)</td>
<td>-6.1 (5.7)</td>
<td>-66.4 (10.1)</td>
</tr>
</tbody>
</table>

Upon the Kruskal-Wallis one-way ANOVA between the four groups (“High School”, “Little League”, “None”, and “Intercollegiate”), significant differences are shown especially late in the trajectory for head movements between groups. In terms of head movement throughout the pitch, the “None” group exhibits the largest rightward head movement.

The ANOVA also revealed significant differences at all target angles for the mean eye movements, with the “None” experience group exhibiting a leftward (negative) eye movement in the opposite direction of the flight of the ball, whereas all other groups are able to generate an eye movement toward the direction of the flight of the pitch earlier in the its flight.

When the signed gaze error between the four groups is analyzed, the groups perform fairly similar until very late in the pitch trajectory, only exhibiting significant
differences at the last two target gaze angles, at which point the intercollegiate group exhibited the largest signed gaze errors.

3.3d: Baseball Experience Based Head Movement, Eye Movement, and Gaze Data

To determine if there were differences between the novice subjects based upon baseball experience, the subjects were divided based upon their level of baseball experience. Subjects were divided into one of four groups, “Varsity”, “Junior Varsity”, “Little League”, or “None”, corresponding to their reported highest level of organized baseball played. The mean head movement, mean eye movement, and mean gaze error was then calculated for each group and plotted throughout the pitch trajectory in Figures 7, 8, and 9 respectively.
Figure 7. Mean head position relative to the ball, separated by experience level. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.
Figure 8. Mean eye position relative to the ball, separated by experience level. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.
Figure 9. Mean gaze position relative to the ball, separated by experience level. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.
Chapter 4: Discussion

4.1: Variability between Novice Subjects

4.1a: Novice Baseball Experience Level and Tracking Strategy

Based upon Figures 7-9, an interesting trend emerged. Those subjects who reported “None” as their highest level of baseball experience showed the largest mean head movements of the four different experience groups, while also exhibiting the smallest mean eye movements (and also the largest negative eye movements away from the ball), suggesting poor RVOR cancellation throughout the pitch trajectory. These results are consistent with the results between the novices and MLB player reported by Bahill and LaRitz.\textsuperscript{10} It is difficult to pinpoint the exact reason why the novice subjects were less successful in cancelling the RVOR. It could simply be due to the fact that, intrinsically, these subjects knew that with eye movements alone they would not be able to successfully track the pitch, therefore large compensatory head movements were required for them to complete the task. And thus due to the large head movements, the RVOR was more heavily stimulated. Conversely it is also completely within the realm of possibility, that the more experienced players simply just have a greater ability to cancel the RVOR compared to novice batters. It has been shown in patients with vestibular dysfunction that the VOR gain can be modulated with visual adaptation protocols.\textsuperscript{27,28} It is possible that the more experienced players have viewed enough pitches in their
baseball careers that they have successfully “visually adapted” their RVOR gains to something more advantageous to baseball hitting.

The subjects in the “None” experience group also tended to move their head in excess compared to the other groups, with their head positions even leading the ball throughout most of the trajectory. The mean eye movements for the “None” experience group showed a slight negative (leftward) movement (opposite direction of the head rotation) throughout most of the trajectory, only showing a relative positive (rightward) movement toward the ball at the end of the pitch trajectory. The resultant gaze position allowed for the “None” experience group’s mean gaze to be conjugate to the ball throughout most of the pitch trajectory. Based upon Hubbard and Seng’s early observational studies, it seems as if when players are swinging at a pitch head movements are minimized, so it is reasonable to imagine that these novice subjects may struggle to adapt the same strategy when actually attempting to hit the ball. In terms of our experimental design, the large head movement strategy was beneficial in terms of our synthetic task of color/number naming, whether or not this type of strategy would relate to actual on-field performance remains to be seen.

The “Varsity”, “Junior Varsity”, and “Little League” experience groups all tended to show relatively similar tracking with the head, with head movements at or slightly behind the position of the ball throughout the trajectory. The mean eye movements for these groups remained fairly constant throughout the trajectory until very late in the pitch flight. Additionally, the mean gaze for the “Junior Varsity” and “Little League” groups was directed near the ball throughout most of the pitch. The “Varsity” experience group
showed a mean gaze that was ahead of the target for most of the pitch’s flight, but this may have been due to one subject in the “Varsity” group having unusually large head and eye movements up to 2-3 times larger than the others in the group. This may have skewed these results. Figures 10, 11, and 12 show the mean head, mean eye, and mean gaze positions respectively for these groups with the “Varsity” subject with unusually large head and eye movements excluded from analysis. When this “Varsity” subject is removed, the gaze tracking for the “Varsity” group matches those in the “Little League” and “Junior Varsity” experience groups.

It is intriguing that the “Varsity”, “Junior Varsity”, and “Little League” groups all behave remarkably similar, while the “None” group exhibits the differences mentioned above. It is unlikely that the differences noted between the groups was simply due to random chance in that those subjects in the “None” group simply had a poorer innate ability to cancel the RVOR. With that being said, it seems that with even very limited experience/a brief familiarity with the task at hand, subjects can perform rather well and with similar overall strategies.

These results may also have implications in regards to sports vision training and/or sport specific practice in general. This could indicate that perhaps sports vision training may not confer a specific relatable advantage beyond a certain point in athletic performance/level, seeing as those subjects with a relatively limited amount of experience can still perform similar to those with much greater amounts of experience at least for our set up. In other words, it is possible that sports vision training may help the lowest level
players catch up to the rest of the pack, but may not necessarily propel those players already within the normal ranges to the elite level.
Figure 10. Mean head position relative to the ball, separated by experience level after dropping one “Varsity” level subject. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.
Figure 11. Mean eye position relative to the ball, separated by experience level after dropping one “Varsity” level subject. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.
Figure 12. Mean gaze position relative to the ball, separated by experience level after dropping one “Varsity” level subject. The number of subjects in each group is listed in the legend in the parentheses. Error bars denote ± one SD.

4.1b: Head and Eye Movement Relationship

The one-way ANOVA on head and eye movement amplitudes respectively demonstrated significant differences between our individual novice subjects. Despite these differences detected on the ANOVA calculations, the strong correlation discovered between the difference of head movement amplitude and eye movement amplitude versus the head movement amplitude (Figure 6) suggests that subjects utilized a common strategy when tracking the pitches. This strategy consisted of partial RVOR suppression
in conjunction with an eye movement superimposed in the direction of the ball. This finding was also identified in Fogt and Zimmerman\textsuperscript{25} and may suggest that there may be an inherent reason for this consistent strategy to emerge. Could this similar strategy be linked back to the fact that in the batter stance, while looking at the pitching machine, the batter begins in somewhat extreme lateral gaze? Would a different strategy emerge if batters began the pitch in primary gaze rather than in a lateral gaze? Further studies on the function of the RVOR in lateral gazes and how it relates to baseball hitting are needed to elucidate this topic.

4.1c: Gaze Tracking Errors and Head and Eye Movement Amplitudes

Looking at the individual mean data (Table 4), the gaze errors were relatively close to the ball (within +/- 5 degrees) for a majority of the novice subjects up to the elapsed time of 298 milliseconds, but were again not as accurate as the two degree precision of the MLB player in the study by Bahill and LaRitz.\textsuperscript{10} The MLB player showed faster than average pursuit velocities, which may have enabled him to precisely track the pitch. With such a small MLB player sample size, it is difficult to determine whether or not this specific MLB player simply had an innate higher ability for pursuits, which led him to excel to the elite baseball level or whether or not this aspect was something that he had learned/trained. Upon visual inspection of the individual mean eye data, anticipatory saccades were not readily apparent.

One-way ANOVA testing on signed and unsigned gaze errors revealed significant differences between novice subjects. Regression analyses also showed that signed and
unsigned gaze errors and head movement amplitudes are not correlated (Table 5). Regression analyses showed that there might be some correlation between larger eye movements and unsigned/signed gaze errors very late in the pitch trajectory (Table 7), but at the very last time point of interest, all but one of the subject’s gaze errors were greater than 30 degrees (Table 4). Larger eye movements may position the gaze closer to the ball at the last time point, but overall the gaze is still very far away from the actual position of the ball and likely is of little value visually. Although, the information very late in the pitch trajectory is unlikely to have much value in terms of hitting a pitch when undertaking in a ballistic swing, just attempting to follow the ball late in the pitch trajectory may be of value in terms of getting into the habit of tracking the pitch earlier in the pitch flight, which definitely is valuable in terms of hitting. It may also be advantageous to track the ball all the way to the plate as this information could be used to gain spatial information as to where future pitches may cross the plate.

4.2: Novice Gaze Tracking Strategy

When comparing the overall means of the mean head, mean eye, and mean gaze position data from our group of novice subjects (Figure 5), to that reported of the MLB player in the study by Bahill and LaRitz, the data appears to be fairly similar.\textsuperscript{10} For both the MLB player and our novice group of subjects, the head is moved rightward, in the direction of the ball throughout the trajectory; meanwhile the eye position remains relatively stable. It is not until later in the pitch flight, that a larger eye movement is made in the direction of the ball. However, Bahill and LaRitz noted that the MLB player
was able to accurately track the pitch within 2 degrees up to 5.5 feet from the plate, whereas our novice subjects were unable to maintain that small degree of gaze error between the eight foot and four foot distances from the plate (298 millisecond and 333 millisecond elapsed times, respectively).

The differences in ability to track to a closer distance may confer a specific advantage to the MLB compared to our novice group who could only accurately track between eight feet and four feet. Most likely the novice group would not be able to initiate and execute a swing and quickly as an MLB player. So, with this in mind, the novice players are seemingly doubly disadvantaged as they cannot track a pitch to glean as much as information as compared the MLB player and they also have to initiate a swing earlier, lessening the overall available time for information to be gathered from the pitch as swinging is widely considered ballistic.

No anticipatory saccades were visually detected for any of our subjects, which is somewhat in agreement with a study by Mann et al. on elite and sub-elite cricket batsmen. Mann et al. monitored head and eye movements of two elite cricket batsmen and compared to those of two sub-elite club level players. These authors showed that the elite batsmen were more likely to exhibit predictive saccadic eye movements compared to their sub-elite counterparts when tracking in cricket. The subjects in study were certainly sub-elite, which could explain the distinct lack of predictive saccades. And as mentioned previously, comparisons between cricket and baseball must be done with caution as the ball bounces before contact in cricket, unlike in baseball where the ball typically does not bounce before the batter hits the ball.
The results shown in Figure 8 show a strong linear relationship between the difference in head and eye movement amplitudes and the head movement amplitude until 333 milliseconds and 375 milliseconds. At these later times in the pitch trajectory, and even sometimes appearing in the 298 millisecond time of interest, large negative ordinate values appeared, representing large eye movements.

Overall, the novice subjects seem to track the pitch early in the trajectory using a partially suppressed RVOR movement. As seen in Table 5, the slope of the regression lines at elapsed times between 150 to 250 milliseconds remained similar, but less than 2.0, indicating the partially suppressed RVOR. Whereas later in the pitch flight, the subjects seemed to utilize an eye movement in the direction of the pitched ball overlaid atop the initial RVOR movement, which is evidenced by the increasing y-intercept seen in Table 5 as the elapsed time increases. This overlaid movement could be a pursuit or saccade.

4.3: Novice versus Intercollegiate Subject Strategy

4.3a: Comparing Collective Means of the Novice vs. Intercollegiate Groups

For the purposes of this discussion, the elapsed times corresponding to the matched target angles will be referenced according to the novice elapsed times, but it should be understood that these times correspond to the proper elapsed time recorded by Fogt and Zimmerman (see Table 6).

Between the elapsed times of 278 to 375 milliseconds, the mean head positions differed significantly, with the novice subjects showing larger head movements toward
the ball (Tables 7, 8). Thus, it seems the novice group must rely on larger head movements to accurately track the pitch or have less effective RVOR suppression necessitating the use of a large head movement. The mean eye positions were only significantly different at the last measured elapsed time of 375 milliseconds, again with the novice group showing a larger rightward eye movement toward the ball (Tables 7, 8).

Lastly, looking at signed gaze error, the novice and intercollegiate subjects performed rather similarly throughout much of the ball’s flight. Only at the elapsed times from 317 to 375 milliseconds, were significant differences in signed gaze error noted. At the 317-millisecond mark, the novices were slightly ahead of the target, while the intercollegiate players were slightly behind the target. Looking at the 375-millisecond elapsed time, both the novice and intercollegiate groups were far behind the target, with the intercollegiate group actually exhibiting a significantly larger lag behind the target when compared to the novices. These differences could be explained due to a difference in mental construct of the task. The novices were simply following the instructions to attempt to call out the color and number of the pitch being projected, so they may have been extremely motivated to follow the pitch late into the trajectory. Whereas the intercollegiate subjects may have inadvertently treated the pitches more like actual in game scenarios. Due to their prior experience the intercollegiate players may have realized that they do not readily obtain any useful information that late in the pitch flight, therefore they did not as fervidly attempt to track the ball that late.
4.3b: Comparing Novice Experience Levels versus Intercollegiate Subjects

After breaking down the novice group into separate groups (“High School”, “Little League”, and “None”) and comparing those groups to the intercollegiate subjects interesting trends emerge (Tables 11-13). Significant differences in the mean eye movements between groups were observed at all target angles. Again, the “None” experience group showed negative eye movements, away from the ball’s direction of flight throughout most of the trajectory.

Here again, those players with no experience have a high degree of difficulty cancelling the RVOR. Future training regimens may wish to focus on task the maximize learning how to cancel/minimize the RVOR.

4.4: Summary of Variability Analyses

Despite differences in between the novice head and eye movement strategies, all novice subjects were similar in that most subjects maintained a close gaze to the trajectory of the ball throughout much of the pitch flight, exhibiting no evidence of anticipatory saccades. At this time, it is unclear whether this lack of anticipatory saccades is true or secondary to the methods used in this experiment. It could be possible that these anticipatory saccades could be more evident with a less predictable target as Gray has mentioned that use of saccades as the “optimal learning strategy”. If the location/velocity of our targets were to be varied, it is possible saccades would become more apparent. Gray suggests that batters may use these saccades to compare their prediction of spatial and temporal location to the actual final spatial and temporal
location that the saccade affords them to see as the ball passes. Due to the predictable nature of the pitches projected from our pneumatic pitching machine, the anticipatory saccadic movements may have been masked.

Overall, subjects were similar in that they also seemed to display closer head movement coupling to that of the ball trajectory, compared to that of the eye movement. This head coupling behavior is consistent with some literature that argues that many visual-motor tasks are controlled egocentrically.\textsuperscript{29,30} The thought here is that players may use their eyes to guide head movements to a position that keeps the ball in a consistent position relative to the head. If successful in keeping the ball in a single consistent egocentric location, batters may be better able to perceive the location of the ball.

4.5: Limitations

One of the major limitations to our study is that all subjects were asked to track the pitch under the “take” pitch scenario only. No head and eye tracking data was recorded when the subjects were allowed to actively swing the bat at the pitch. Hubbard and Seng first noted that players might exhibit varying tracking strategies under the two different conditions, “take” versus “swing”.\textsuperscript{9} Tyler Persson, in his 2013 Master of Science thesis at The Ohio State University also demonstrated that subjects utilize different head and/or eye movement strategies when asked to take a pitch versus when swinging at a pitch.\textsuperscript{31}

It may also be difficult to realistically simulate the actual tracking behavior when the subject’s know that they will not be swinging at the pitch. A player may exhibit
different strategies when they themselves must make the go/no-go decision as to “take” or swing at the pitch.

Another limitation was the fact that the pitching machine threw pitches at a relatively low velocity compared to that of a Major League pitch. At higher pitch velocities it is possible that a larger difference between novice and intercollegiate subjects may exist. Compounding this issue, our pitching machine was able to consistently throw pitches under predictable circumstances in terms of both spatial and temporal frequency, which may have influenced the overall accuracy of gaze tracking.

4.6: Additional Studies

Ideally, head and eye movement behaviors for baseball batters would be monitored in a true in-game scenario. In reality it would be difficult for this to be done. For future gaze tracking studies, players should be allowed to swing at pitches as this would aid in determining if the behaviors found in this study may be applicable to actual on-field performance. Studies looking into less predictable targets (pitches with varied speeds and locations) would also help determine the presence and/or role of predictive saccades in hitting.

In light of our data from the novice subjects who had never played baseball, it would be interesting to possibly incorporate some sort of head movement restriction (i.e. a neck brace) while these subjects practiced batting in a future study. In theory, the neck brace would hopefully limit head movement and therefore allow the novice to more closely mimic the behavior of the more experienced players. With limited head
movements, would the novice players more quickly learn to cancel the RVOR? At the very least, there would be less chance for large head movements and thus less RVOR intrusion.

Lastly, the question still remains as to whether or not maintaining foveation on a pitch through its trajectory provides any actual hitting performance benefits, a future occlusion study would be pertinent. Through the use of shutter glasses it would be compelling to occlude a batter’s view of certain portions of a pitch’s trajectory. For example, the batter would be allowed to see the first 80% of the flight, while the latter 20% is occluded; could the batter still hit the ball? Adair postulated that the lights could be turned out halfway through a pitch and an experienced batter would show no difference in performance as if the entire pitch had been seen.6 With this type of experimental setup, Adair’s claim could be put to the test; the exact portions of the trajectory that are critical for hitting could be isolated.

4.7: Conclusions

The major aims of our study was to record head and eye movements of novice subjects while viewing a baseball pitch and to compare these data to more experienced intercollegiate subjects to examine the possible inherent differences and/or similarities in gaze tracking. The results from this study indicate that while differences may exist between subjects in head and eye movements when tracking a pitch, some underlying strategies may be common (partial RVOR related movements). And for the given task in our study, the novices and intercollegiate subjects performed remarkably similarly in
terms of gaze errors differences, albeit sometimes with varying head and eye movement strategies.

Comparing the novice subjects to the intercollegiate subjects, significant differences in the head movement were apparent toward the end of the pitch trajectory with the intercollegiate subjects exhibiting smaller overall head movements. Conversely, those subjects who had never played baseball before demonstrated the largest mean head movements. Why might the intercollegiate subjects favor smaller head movements? At this time it is unknown and cannot be concluded whether or not these differences could be related to actual on-field hitting performance. But it does seem that the novice players, especially those with no baseball experience must more heavily rely on larger head movements to maintain their gaze at a location close to the ball.

Surprisingly, the novice subjects actually showed smaller signed gaze errors for our last two elapsed time points of interest when compared to the intercollegiate group, which seems counterintuitive in relation to speculated hitting success – though their gaze position was still substantially away from the ball.

In conclusion, we found that differences do exist in gaze tracking strategies between some novice and intercollegiate subjects, but with some underlying similarities. Future studies looking at the gaze tracking strategies of elite players (hopefully MLB players) could reveal the importance of accurate tracking and the relationship to successful hitting. And likewise, studies in attempts to train novice players could reveal aspects that may lead to better training methods and thereby better performance.
References


13. Barnes GR. Visual-vestibular interaction in the control of head and eye movement: The role of visual feedback and predictive mechanisms.


Appendix A: Horizontal Target Gaze Angle Calculation

In Figure 13 below, $\alpha$ represents the horizontal gaze angle of the ball, $X$ is the distance from home plate to the pitching machine (42.67 feet), $R$ is the distance the ball has traveled over that specified elapsed time of interest, and $Y$ is the distance from the subject to the plate (measured anterior to posterior, 28 inches).

The horizontal target gaze angle relative to the batter at our elapsed times of interest were calculated using the following calculations.

$$P = X - R$$

$$\tan \gamma = P/Y$$

$$\alpha = 90 - (\gamma + \beta)$$

The values calculated represent the change in horizontal gaze angle required for the batter to precisely fixate the ball at each elapsed point in time.
Figure 13. Diagram for horizontal gaze angle calculations.