Tracking a Baseball During a Color Naming Task

A Thesis

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By

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Abstract

Baseball players of all ages work on improving their skills during practice. Some more recent training methods have worked on vision training to improve hitting skills. One particular method involves using a pitching machine to throw tennis balls at a high velocity. The goal of this training is to be able to call out colored numbers written on the tennis balls as they are pitched, as this relates to pitch recognition during game play. There has been no scientific research done on this system to see whether or not players are able to improve their tracking ability. This study seeks to investigate the tracking accuracy of subjects using the color naming task.

Subjects were tested using a pitching machine called the Flamethrower. Tennis balls with numbers written in either black or red ink were fed at random into the Flamethrower for each pitch. Balls were pitched from a distance of 60.75 feet from home plate. The average velocity was 79.76 MPH for each pitch. Eye movements were recorded using the ISCAN infrared tracking device, while head movement were recorded using the mini-Bird 800, which was mounted to the ISCAN goggles. Raw data from these devices were converted to digital format, compared, and analyzed with a computer program written in Visual Basic 6.0.

Thirty subjects were assigned at random into one of three groups. The subjects tasks in these three groups were color (and number) naming of a pitched ball, tracking the ball as well as one can, and coordinating the eye and head as one would when batting. Subjects wore the ISCAN goggles to record data during each pitch. Data was recorded on total of 2950 pitches between the three groups.
The primary outcome measure was mean gaze error away from the location of the ball, which was measured at 6 feet in front of the plate. Mean gaze error for groups 1, 2, and 3 were -4.81 degrees (StDev 4.30), -2.20 degrees (StDev 6.08), and -3.03 degrees (StDev 5.82) respectively. A one-way analysis of variance with Tukey's post-hoc testing showed a significant difference between each group (P<0.001).

The tracking accuracy of subjects in the color naming group was not as accurate as subjects tracking the ball alone. The results of this study suggest that color naming may not play a significant role in improving tracking ability. It cannot be ruled out, however, that color naming may work on another aspect of training baseball batters such as attention or kinetic visual acuity. Further work needs to be done to determine the relationship of attention and kinetic acuity, if any, to hitting a baseball, and whether or not these would benefit from color naming training.
Dedication

This thesis is dedicated to my wonderful, patient, and supportive wife, Elizabeth.
Acknowledgments

I would like to thank Dr. Nick Fogt for allowing me to participate in previous baseball and eye movement studies and encouraging me to pursue this project. I would also like to thank him for being an outstanding advisor and for his support throughout this project.

Special thanks go to Dr. Aaron Zimmerman for the work he put into his previous baseball study and for all of his assistance and advice, which helped make this study possible.

Additional thanks to Mike, the custodian, for tolerating us all of those late nights while we worked on the third floor of Fry Hall.

I would also like to thank Elizabeth Young for her help with data collection.
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Field of study

Major Field: Vision Science
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CHAPTER 1: INTRODUCTION

1.1 Practice Makes Perfect

In 2003 USA Today ranked “hitting a baseball” as the hardest thing to do in sports. Major League pitchers can throw the ball upwards of 90 MPH. At these speeds, the ball will reach home plate in less than 0.4 seconds from the time it is released. That leaves the batter less than 0.2 seconds for the brain to process the information and make the decision to swing. Baseball players require tremendous hand-eye coordination, physical ability, and concentration. That is why even the most successful baseball players average a hit every three out of ten tries.

Part of being a good hitter in baseball is natural ability. It has been shown that Major League Baseball players from different generations such as Babe Ruth or Albert Pujols have better visual acuity, shorter saccadic latency, and faster overall reaction time than the average human being. The other part of being a good hitter is practice. Repetition helps the greatest players improve their performance. Even the great hitters in Major League Baseball practice hitting every day.

In the last 10 years, some new baseball training methods have included vision training. Utilization of colored and numbered balls for baseball training is referred to on a number of websites, online publications and in several newspapers. The specific details of the training method vary considerably. Some of these variations include calling out the colors and numbers on the ball, attempting to bat only balls of a particular color, or viewing the balls at very high speeds. Some of these methods are used by youth, high school, college, and Major League Baseball players, with the expectation that this will improve hitting performance by improving a batter’s ability to
see or follow the ball.\cite{4,14,17}. The focus of this thesis will be on the color naming methodology and its impact on tracking.

### 1.2 Tracking the Ball

The following are general comments about tracking objects. As the pitcher releases the ball, the angle of the ball in relation to the batter is roughly 2 degrees. As that pitch crosses the plate it reaches an angle of 90 degrees to the batter. If a ball is pitched at a speed greater than 90 MPH the angular velocity reaches a speed of about 75 degrees/second at a point 10 feet in front of the plate. However, the most significant change in angular velocity occurs after the ball crosses this point. Between 8 feet and 4 feet in front of the plate the batter must already be swinging in order to contact the ball, but during these 4 feet the ball will travel at approximately 450 degrees/second.\cite{4}

In order to track a baseball, one might use smooth pursuit eye movements. Smooth pursuit eye movements are driven by retinal image motion. Retinal image motion initiates a pursuit to follow the object.\cite{5} The time it takes for the brain to perceive a moving object and initiate a pursuit eye movement to match the target velocity is around 100ms for faster moving objects such as a baseball pitch.\cite{7} A Pursuit is initiated when angular velocity reaches about 1 degree/second, and they have been shown to be accurate for objects traveling at speeds of 90-100 degrees/second.\cite{6} Therefore when the pitched ball reaches the point about 8 feet in front of the plate, the angular velocity becomes too great for the batter to accurately track the ball with pursuit eye movements alone. Table 1 and Figures 3 and 4 show the velocities and angular positions associated with the pitching machine used in the experiment described in this thesis.
Once the pursuit system falters, to continue tracking the ball it is necessary to interject higher velocity movements within the pursuit eye movements. These eye movements are called catch-up saccades. Saccades are known to reach velocities over 500 degrees/second. A continuously visible retinal image cannot be maintained during saccades. This is primarily because saccades result in retinal image motions that cannot support vision. The blurred image of the world during a saccade is suppressed by the brain in a process called saccadic omission.

Eye movements are not the only elements involved in tracking a ball. When a batter tracks a pitch he may use a combination of head and eye movements. When measuring a batter’s tracking ability, the combination of head and eye movements are analyzed to produce the batter’s position of gaze.

Head movement may be beneficial in tracking a pitched ball, as the angular velocity of the head will be added to the angular velocity of the eye. Therefore, gaze (eye + head) pursuit tracking velocity can be substantially higher than ocular pursuit velocity alone. On the other hand, head movement has the potential to detract from a batter’s ability to track the ball due to the rotational vestibulo-ocular reflex (VOR). This is because the VOR causes the eyes to move in a direction opposite to the head in order to stabilize the retinal image during body motion. The latency of the VOR is very short, on the order of about 15ms. If a batter tracks a pitch using head movements, the batter will need to suppress the VOR.

### Table 1. Change in angular velocity as the ball approaches the plate.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Change in angle</th>
<th>Angular Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 feet short</td>
<td>434 ms</td>
<td>5.371</td>
<td>74.03 deg/sec</td>
</tr>
<tr>
<td>8 feet short</td>
<td>451 ms</td>
<td>6.956</td>
<td>114.4 deg/sec</td>
</tr>
<tr>
<td>6 feet short</td>
<td>468 ms</td>
<td>9.564</td>
<td>199.03 deg/sec</td>
</tr>
<tr>
<td>4 feet short</td>
<td>485 ms</td>
<td>14.625</td>
<td>424.32 deg/sec</td>
</tr>
<tr>
<td>0 feet short</td>
<td>519 ms</td>
<td>87.6</td>
<td>5919.8 deg/sec</td>
</tr>
</tbody>
</table>
1.3 Studies on Eye Movements in Baseball

There have only been a handful of studies looking at what the eyes and head do while tracking a baseball pitch.

Hubbard and Seng monitored head and eye movements of a number of professional baseball players during batting practice. They used a video-camera mounted 15 to 20 feet from the batter for this task. While not particularly quantitative, they found that the batters used pursuit eye movements to track the ball. Generally, very little head movement was used for tracking. They stated that ocular tracking movements stopped when the ball was 8 to 15 feet from the plate. They speculated that pursuit movements stopped either because these ocular pursuit movements were ineffective in tracking at distances closer than 8 feet from the plate, or because the bat was already in motion at these distances and eye movements would no longer be effective in guiding the swing.

Bahill performed a study on eye and head tracking movements during a baseball pitch. His study was the first to accurately quantify the amplitude of head and eye movements during the pitch. Because of technical difficulties, subjects were not allowed to swing at the pitched ball. Furthermore, complete head and eye movement data were collected from only 6 pitches. Partial data were collected from another 15 pitches.

While the data from Bahill were limited, he drew the following conclusions. The pursuit eye movements of professional baseball players (of which there was one in the study) are faster than those of novice or less experienced hitters. The professional player in the study had an eye velocity of 120deg/s. Further, the professional player used a combination of eye and head movements, while the less experienced players tended to use either primarily eye movements or primarily head movements. Finally, the professional player was thought to be more efficient at suppressing his vestibulo-ocular reflex.

A study done by Zimmerman (N. Fogt, Advisor) and so far published only as a Masters thesis investigated the tracking accuracy of batters with free-range head
motion and head-fixed conditions during a baseball pitch. A pitching machine was used to throw tennis balls. The study looked at the characteristics of the eye and head movements made during the pitch in these two conditions as well as the accuracy of color/number identification on the ball during the pitch. Data were obtained from hundreds of pitches, using a measuring technique developed at the Ohio State University. The results of Zimmerman’s study were as follows. First, in most cases pursuit eye movement was the predominant eye movement. The pursuit was preceded by a small saccade that occurred at around 155ms after the ball exited the pitching machine. There did not tend to be large saccadic eye movements until the ball was very close to the batter. Head movements were highly variable in terms of both amplitude and time at which the movement started. Head movements during the pitch were generally small.

Finally, the Zimmerman study also revealed that color/number naming accuracy was not correlated with the accuracy of ocular tracking. It was postulated that the color/number identification task may have detracted from the batter’s ability to track the ball all the way to the plate.

1.4 Visual Acuity in Tracking

To assess vision as it relates to seeing and tracking a baseball, three different visual acuity measures have been proposed. These include static visual acuity (SVA), dynamic visual acuity (DVA), and kinetic visual acuity (KVA).

SVA is the stationary acuity measured when subjects view a stationary object. Dynamic and kinetic visual acuity are dependent at least some extent on SVA. If SVA is poor, one would think that DVA and KVA are likely to be reduced.

DVA is the acuity used when an object is moving laterally in space. This is especially useful when an object moves quickly changing angle in relation to the viewer. It is known that DVA is primarily dependent upon eye movements. That is to say, more effective ocular tracking leads to better DVA. DVA is sometimes assessed by asking individuals to determine the orientation of a moving letter (a Landolt C for example).
KVA is used when objects of interest are traveling toward the person in space without a great change in visual angle. The physiological basis for changes in KVA is not clear, but might involve attention or even vergence eye movements (at least at close distances).

A batter will use both kinetic and dynamic acuities during the pitch. When the pitch begins, the change in visual angle is very small. The pitch is released at roughly 2 degrees relative to the batter. As the ball leaves the pitcher’s hand KVA is used right away. DVA is probably also utilized early on, but since the angle between the batter and the ball changes very slow initially (that is, the angular velocity is very low), DVA is less important at these lower angular velocities. Even when the ball is 10 feet from the plate, the visual angle of the ball has changed by just over 5 degrees. However, as the ball gets closer to the batter, the angle between the batter and the ball changes dramatically, and DVA becomes more critical. In other words, ocular tracking becomes more important as the pitched ball gets closer to the batter.

It is reasonable at this point to ask what advantage good DVA (eye movements) and KVA confer upon a batter. After all, there are many other attributes that are likely to be involved in hitting a pitched ball. Hand-eye coordination, bat speed and other aspects of bat control, balance, and prediction are all likely to play a role in successfully hitting a baseball. Further, according to Hubbard and Seng one must begin swinging at a pitch roughly 200 ms after the pitch is thrown. Thus, tracking the ball all the way to the plate does not seem to be necessary to guide the swing nor possible because of the high angular velocities of the ball.

We submit that there are at least two reasons to track the ball as long as possible (and to therefore have good DVA). The first is that when learning to hit, it is important to see where the ball goes on each pitch. This should ultimately lead to better prediction in hitting, which we believe is a critical element of successful hitting. The other reason to try to track the ball as long as possible is to maximize the length of time the ball is foveated. This in turn will maximize the time over which vision can be used to guide the swing of the bat.
KVA on the other hand would be important for predicting the ultimate location of the ball when it reaches the plate. Along those lines, because of the short period of time during the pitch, baseball batters must use any clues available to help them hit the ball. One such clue uses the pattern of spin on the ball. A batter may identify what type of pitch is being thrown (e.g. fastball or breaking ball) by getting a view of the pattern of spin of the laces as it leaves the pitcher’s hand. Different patterns are recognized as different types of pitches. KVA would be beneficial to help pick up the spin on the ball early in order to decide where to swing sooner.

1.5 Color Naming and Tracking Ability

Given the potential significance of DVA and KVA described above, training methods utilizing colored and numbered balls have been created. The purpose of these methods appears to be to improve KVA, to improve DVA, or both. It is reasonable, then, to ask whether studies utilizing these training methods have shown any improvement in DVA and KVA following training.

Only one study could be found that tested DVA and KVA before and after trials of naming colors on baseballs during a pitch. The color naming trials were performed for four weeks. A statistically significant improvement in color naming was noticed during this period. Two methods were used to assess DVA and KVA. Both DVA and KVA improved when one testing method was used, but they did not improve when tested by a second method. No objective measurements, however, were made of eye movements in this study. In addition, the authors argued that tracking eye movements improved subjectively at least by one subjective (DVA-type) assessment method. Therefore, no conclusive evidence points to improvements in eye movements, DVA, or KVA as reasons for improved color naming performance. The reasons behind the improvement in color naming during the pitch remain unclear.
Purpose

Given the interest in color and number naming training task and the numerous anecdotal reports that this training is beneficial, we decided to look at ocular tracking objectively during the color naming task. Specifically, the purpose of this investigation was to utilize a method we developed (N. Fogt, U.S. Provisional Patent #61/156,978) to measure gaze errors in tracking a pitched ball in three groups. The subjects’ tasks in these three groups were color/number naming of a pitched ball, tracking the ball as well as one can, and coordinating the eye and head as one would when batting. The results help in determining whether color naming promotes ocular tracking, and whether an improvement in ocular tracking is likely to be associated with the improvement in color naming noted in the study described previously.
2.1 Subjects and Conditions

Eligible subjects were males between the ages of 18 and 50 years. Subjects were required to have visual acuity of 20/40 or better either uncorrected or while wearing contact lenses. The ISCAN is not compatible with spectacles.

This study was approved by The Ohio State University Biomedical Institutional Review Board. Informed consent was obtained and appropriate forms signed prior to data collection. Objective data was collected on 30 subjects. Subjects were all between the ages of 20 and 28 years. The mean subject age was 24 years. Mean LogMAR visual acuity was -0.037 OU. Mean stereo acuity was 23.7 seconds of arc (Randot).

Illumination in the testing area was measured using the Litemate III (Photo Research, Chatsworth, California). Mean illumination over the area where the ball was released was 58.94 lumens/ft².

A brief survey pertaining to the subject’s athletic involvement was filled out by each participant. The survey asked each subject to indicate whether or not they had any organized competitive athletic experience after 9th grade. The subjects were then asked to write in the primary athletic event in which they participated. This survey was used to perform additional analyses.
2.2 Equipment

A device with an air compressor called the Flamethrower (Accelerated Baseball Technologies, Barrington, IL) was used to throw tennis balls for the batters to track. The Flamethrower is situated on a platform atop a stepladder at a height of 5 feet. Attached to the front of the Flamethrower is a 5 foot long section of PVC pipe through which the balls travel. This pipe is supported by a tripod. A wooden backstop was used to collect the tennis balls after they were launched. This backstop measured 2.5 feet wide, 2.5 feet deep, and 5 feet in height. Heavy mats and towels were used in the backstop to absorb the impact of the launched balls.

On previous trials the Flamethrower proved to be accurate enough to consistently throw tennis balls into an area 16.5 inches high by 15 inches wide. This falls within the limits of a typical baseball strike zone. The strike zone is defined as the area over the width of home plate (17 inches across) beginning at the batter’s knees and going to a height of an imaginary line that lies at the midline between the batter’s belt and shoulders. A 6 foot tall batter would have an approximate strike zone area of 17 inches wide by 27 inches high.

2.3 Velocity Calculation

The velocity of the pitched tennis balls was measured using a series of lasers and photocells. Two lasers and their corresponding photocells were mounted on the backstop with their beams oriented vertically. The photocells were separated by 2.5 inches. The lasers were mounted about 2 feet above the photocells. An additional photocell and laser combination was mounted at the end of the tube attached to the Flamethrower. Each photocell was connected to an analog to digital signal converter (USB-1208FS, Measurement Computing, Norton, MA) that sent data to a recording computer. Each time the ball crossed the plane of a laser the data would reflect a change in voltage measured at the photocell.
The point of interest for measuring ball velocity (and subsequently gaze errors) was 70 inches in front of the plate. The total distance from release point to the plate was 60.75 feet. Therefore velocity measurements were taken at 54.92 feet from the release point of the pitched ball.

2.4 Monitoring Eye, Head, and Ball Position During the Pitch

Eye position was measured using an infrared video recording device mounted to goggles manufactured by ISCAN Incorporated (Burlington, Massachusetts). The ISCAN monitors the center of the subject’s pupil to record eye movements in horizontal or vertical directions. Spatial resolution of the ISCAN is 15 minutes of arc, while temporal resolution is 120Hz. ISCAN provides its own software which records data in digital format. This output was converted to analog format using an analog-to-digital converter (CIO-DAS08, Measurement Computing, Norton, MA) and then sent to the recording computer.

Head movement was monitored by the Flock of Birds (Ascension Technology Corporation, Milton, VT). The Flock of Birds transmitter emits a magnetic field that can be picked up and translated into positional data by a receiver as it moves within the field. A small receiver was mounted to the ISCAN goggles to track horizontal and vertical head movement. The spatial resolution of the Flock of Birds is 0.5 degrees, and the temporal resolution is approximately 144Hz. The Flock of Birds signal was over-sampled (sampled at a higher frequency than 144Hz) using software written by N. Fogt.

Ball position during the pitch was determined using the laser and photocell located at the end of the tube attached to the Flame Thrower. The photocell data was routed through an amplifier. Analog data from the ISCAN and amplified laser/photocell were all routed through the analog-to-digital signal converter at 1000Hz and fed into the same computer as that used to record data from the Flock of Birds. The method used for recording allowed for temporal synchronization of the eye, the head, and the laser/photocell (Figure 1).
Figure 1. Change in head and eye position during the pitch. The graph below displays the relative change in position of the eyes (dash) and head (dotted) for subject #10 during one pitch. The Y-axis shows the change in degrees. The X-axis shows time in milliseconds beginning with the release of the ball. Notice the change in the eye graph where the two blinks occur around 1500 and 1900 milliseconds.

2.5 Data Analysis

The data were gathered using a computer program written in QuickBasic 4.5 (Microsoft Corp., Redmond, WA). This program was designed to synchronize data from the ISCAN, mini-Bird, and photocell to measure gaze error. The change in gaze was calculated from head and eye positions measured simultaneously during the pitch. Gaze error was measured at 70 inches in front of home plate based on previous baseball tracking studies by Bahill\textsuperscript{13} and Zimmerman\textsuperscript{5}.
2.6 Instrument Calibration

A search coil was used to determine whether the head and eye tracking signals from the Flock of Birds and the ISCAN respectively contained any temporal delays. The search coil uses a magnetic field generated by field coils. The subject sits inside the magnetic field while wearing a small search coil consisting of a silicone annulus with copper wiring inside. This annulus can be worn directly on the eye for eye movements or mounted to the head for head movements. Positional data is recorded as the coil moves through the magnetic field. It is assumed that the latency for the search coil is negligible\textsuperscript{5,16}, which is why it was used to check for any temporal delays associated with the Flock of Birds and the ISCAN.

The latency of the ISCAN device was determined by recording eye movements with the ISCAN and search coil (worn on the eye) simultaneously. The ISCAN data was received at an average of 35 ms after the search coil data.

The latency of the Flock of Birds device was determined by mounting the search coil and the Flock of Birds receiver to a Styrofoam head. The head was mounted on a vertical rod connected to a base. The head was rotated in a sinusoidal pattern as data was recorded from both devices. The signals received from the Flock of Birds averaged 66 ms behind the search coil.

2.7 Experimental Design

The study was designed to compare gaze tracking accuracy for subjects who were asked to pick out the color and number written on the ball to subjects who were asked to track the ball without naming color and number. It was hypothesized that subjects who were asked to name colors and numbers written on the ball would have a larger gaze error at a near distance (< 8 feet) during tracking than subjects asked to track the ball without an identification task.

Each condition tested consisted of a batter standing in a batter’s box tracking the tennis balls pitched by the Flame Thrower 60.75 feet away (Figure 2). Subjects
were 13.5 inches from the center of the plate. The identification condition (group 1) was tasked to identify a number written on the tennis ball.

**Figure 2.** Experimental Dimensions. The release point (A, left) was measured at 729 inches from home plate (C, right). Gaze error was measured as the ball reached the point 70 inches away from home plate (B, middle right). The batter stood 13.5 inches away from the middle of home plate (point D). Calculations were made to determine the angle between the batter and the release point from this information.

Subjects were assigned into one of three groups in a pre-determined pseudo-random order using a random number generator. Each group represented a condition that would be tested. The groups were pseudo-balanced with 9 subjects in group 1, 11 in group 2, and 10 in group 3. The data from one subject in group 1 is not included here, because his uncorrected visual acuity (the ISCAN is not compatible with
spectacles) was discovered after the session to be 20/50. An error in the way subjects were assigned to the groups resulted in an imbalance in the number of subjects in the groups. However, later it will be seen that a similar number of pitches was used to compare gaze errors across the groups.

Subjects were assigned to a group based on the order in which they were tested. Group 1 subjects were asked to call out the numbers and colors of these numbers written on each pitched ball. The numbers were written in red or black ink and placed on 6 sides of the tennis ball. The numbers consisted of 0 through 8 and were approximately 18 mm in height by 2 mm stroke width. Each tennis ball had a company logo printed on one side of the ball in black and red.

Group 2 was given the command, “Track the balls all the way to the plate the best that you can.” Group 3 was asked simply to “Do what you would normally do if you were batting a ball.” Subjects were not given a bat in any group, and they were not asked to simulate any type of swing.

Subjects were shown a tennis ball prior to participating. Balls were collected in a bucket at random and dumped into the loading bin of the Flame Thrower. Subjects were allowed to stand in the batter’s box in any stance they chose. Stances could be left or right handed, and the recording eye from the ISCAN was changed to reflect the eye closest to the pitching machine. During testing each subject wore the ISCAN goggles with the mini-Bird receiver attached. Subjects wore a batting helmet for protection.

Each trial consisted of 100 pitches in 2 rounds of 50. Subjects saw 50 consecutive pitches. Each pitch was approximately 5 to 7 seconds apart. Balls were collected again in random order and loaded back into the pitching machine. Then the subjects saw the second set of 50 pitches. Data were recorded on a total of 2950 pitches. Trials lasted approximately 15 minutes per subject and were performed in the third floor hallway of Fry Hall at The Ohio State University College of Optometry. The testing hallway was 8 feet wide and illuminated with 7 fluorescent lighting ballasts that were each 8 feet apart.
The investigator stood behind the backstop during testing. Subjects in group 1 were asked to shout out a color (red or black) followed by a number (0-8). Subjects were encouraged to guess if they were unsure. Subjects believed that the subjective colors and numbers were being recorded by the investigator. No subjective data was actually recorded, however, as this was not essential to the conclusion of the study. Therefore no statement of subject accuracy for color or number naming will be made. No subjective data was recorded for groups 2 or 3.

To calibrate the ISCAN, the subjects stood in the batter’s box next to home plate and were asked to look at two fixation points. One fixation point was the end of the tube where the balls were released (i.e. the release point). A second point was marked on the wall facing the batter. The wall was 5 feet from the subject, and the calibration point was 5 feet in front of the plate/batter. Thus, the angle between the calibration point and the batter was 45 degrees.

The release point of each pitched ball (that is, the end of the tube through which the ball was ejected) was 60.75 feet away from the plate. The batter was 13.5 inches away from the center of the plate. Using the tangent of these values, the angle between the release point and the plate was calculated at 88.9 degrees. The angle between the release point and the second fixation point was 43.9 degrees. The gain was determined by comparing the change in raw output from the ISCAN when the subject looked at each fixation point to the known angular change between the points (Figure 3).
**Figure 3.** Calibration Set-up. This diagram illustrates the method used to determine the gain of the ISCAN eye tracking device. Two fixation points of known distances were used to compare the change in analog output of the device with the change in degrees of eye position. The first point was the release point 60.75 feet away. The second fixation point was an “x” drawn on the wall at a 45 degree angle, 7.07 feet away from the batter. The gain was measured for each batter, and the average gain value (31.50) was used in analysis.
CHAPTER 3: RESULTS

3.1 Survey Results

The surveys given prior to each subject’s participation yielded the following statistics. Nine out of 30 participants were involved in competitive baseball after 9th grade. Three of these were college baseball players. Fourteen out of 30 were involved in competitive sports that involved object tracking as a main component (predetermined as baseball, softball, tennis, racquetball, or other racquet sports). Seven out of 30 had competitive athletic experience in college regardless of sport. Three out of 30 had no competitive athletic experience after 9th grade.

3.2 Velocity Analysis

The ball traveled a distance of 54.92 feet in 468.0 ms. This corresponds to a velocity of 117.3 feet per second or 79.98 miles per hour. The angular velocity at this distance was 199.03 degrees per second (Figures 4-5). The velocity was calculated at a distance of 54.92 feet from the release point. This corresponded to a point 70 inches in front of home plate.
Figure 4. Angular Velocity of the Ball. The above graph shows the increase in angular velocity during the pitch. At 468 ms (about 6 feet from home plate) the angular velocity becomes 199.03 deg/s.

Of note: the distance from release point to home plate used in this study was actually farther apart than the traditional dimensions of the game of baseball. The pitcher’s rubber is 60 feet 6 inches from home plate in the game of baseball. But the release point of the pitcher is usually more than 4 feet from the pitching rubber depending upon the pitcher’s height. The distance from the release point to the plate in this study was 60.75 feet. This distance resulted in a velocity of 79.98 MPH. This velocity is closer to the type of pitching seen in most high school or college pitching. Thus, if the distance over which tracking occurs leads to better tracking\textsuperscript{11}, the tracking of our subjects may have been mildly enhanced by this extra distance.
Figure 5. Ball position during the pitch. The graph above shows the angle of the ball relative to the batter from the beginning to the end of the pitch. The initial angle is 88.9 degrees. It takes 468 ms for the ball to cross 6 feet in front of home plate, at which the angle has changed 9.56 degrees.

3.3.1 Gaze Error

In order to interpret the data, the ISCAN gain was measured for each subject by having the subject look at two fixed positions of known distance. The average gain was found to be 31.55. The above mentioned QuickBasic 4.5 program output a raw data file that contained data from the laser photocell, mini-Bird, and ISCAN. Another program written in Visual Basic 6.0 (Microsoft Corp., Redmond, WA) was used to interpret this data. Using the average gain the computer program was able to output a data file containing total head movement, total eye movement, and gaze error. The
gaze error was recorded at a point 70 inches in front of home plate. Negative values indicated a gaze error behind the pitch (towards the release point), while positive values indicated gaze error in front of the ball (toward the plate).

Before any analyses on gaze error were performed, a cut-off had to be determined to eliminate outliers that could be attributed to blinking or aberrant gaze tracking. A histogram of the raw data was made. More than 95% of the data were distributed between +20.0 and -10.0 degrees in each group (Figure 5). It was also determined that any gaze error less than -9.56 degrees would be to the left of the release point. This would indicate that the subject did not track the ball at all, possibly due to a blink or equipment error. Therefore the negative cut-off value was -10.0 degrees. The positive cut-off value was set at +20.00 degrees, because we felt that only in the case of large anticipatory saccades (which were rare in the study by Zimmerman) would the error be larger than this amount.

There were 612 (31.4 %) pitches analyzed from group 1. The mean gaze error for group 1 was -4.81 degrees (StDev 4.30) behind the pitch (that is, the gaze lagged behind the ball) at a point where the pitch was 70 inches in front of the plate. The mean amount of head movement at 70 inches in front of the plate was 2.08 degrees (StDev 4.31). The mean eye movement at 70 inches in front of the plate was 0.22 degrees (StDev 3.43).

There were 678 (34.8 %) pitches analyzed for group 2. The mean gaze error at 70 inches in front of the plate was -2.20 degrees (StDev 6.08). The mean head movement was 3.25 degrees (StDev 4.62). The mean eye movement was 1.96 degrees (4.82).
Figure 6. Histograms of Gaze Error by Group. The graphs above show the frequency of gaze errors in Groups 1 through 3.
Table 2. Gaze error for a given group from session to session.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>-4.91</td>
<td>-2.14</td>
<td>-2.83</td>
</tr>
<tr>
<td></td>
<td>(StDev 4.31)</td>
<td>(StDev 5.43)</td>
<td>(StDev 6.00)</td>
</tr>
<tr>
<td>Session 2</td>
<td>-4.73</td>
<td>-2.22</td>
<td>-3.18</td>
</tr>
<tr>
<td></td>
<td>(StDev 4.30)</td>
<td>(StDev 6.65)</td>
<td>(StDev 5.66)</td>
</tr>
<tr>
<td>P value</td>
<td>0.614</td>
<td>0.871</td>
<td>0.446</td>
</tr>
</tbody>
</table>

There were 658 (33.8 %) pitches analyzed for group 3. The mean gaze error was -3.02 degrees (StDev 5.82). The mean head movement was 3.62 degrees (StDev 5.12). The mean eye movement was 0.66 degrees (StDev 5.25).

Using a one-way analysis of variance with Tukey’s post-hoc testing, the gaze error analysis showed statistically significant differences for each group (P<0.001). Finally, for a given group, mean gaze error did not improve for the second set of 50 pitches compared to the first set of 50 pitches. Therefore, learning effects were not apparent (Table 2).

3.3.2 Gaze Error Additional Analyses

Using data from the subject surveys given prior to the each subject’s participation, additional analyses of note were performed. These analyses were not the primary focus of this study.

The gaze error was determined for subjects with any competitive baseball experience after 9th grade. With a total of 238 pitches measured, ballplayers in group 1 had a mean gaze error of -6.73 degrees (StDev 2.88). With a total of just 78 pitches measured, ballplayers in group 2 had a mean gaze error of -0.01 degrees (StDev 5.96). With a total of 116 pitches measured, ballplayers in group 3 had a mean gaze error of -6.18 degrees (StDev 3.90) (P<0.001).
Mean gaze error was compared regardless of group between subjects with competitive baseball experience after 9th grade and those without competitive baseball experience. With a total of 509 pitches measured, the mean gaze error for ballplayers regardless of group was -5.17 degrees (StDev 4.33). With a total of 1437 pitches measured, the mean gaze error for non-ballplayers was -2.82 degrees (StDev 5.63) (P<0.001).

Gaze error was also compared by group among subjects who indicated that they had some competitive athletic experience (regardless of sport) beyond high school. The mean gaze error for subjects with competitive athletic experience beyond high school was -7.65 degrees (StDev 1.83) for group 1 (73 total pitches), -7.06 degrees (StDev 2.59) for group 2 (284 total pitches), and -6.11 degrees (StDev 3.23) for group 3 (122 total pitches) (P<0.001).

While the differences in mean gaze error of ballplayers between the three groups appear significant, one should use caution in interpreting this data due to the limited number of ballplayers (and number of pitches) in group 2. A similar situation applies to the gaze error analyses of ballplayers versus non-ballplayers, and it also applies to gaze error analyses of those with competitive athletic experience beyond high school. The additional analyses were performed to reveal information that may provoke future studies. No merit was given to the significance of these findings, however, as there were too few data points distributed among the groups tested.
CHAPTER 4: DISCUSSION

This study sought to examine the tracking ability of subjects when given a color/number identification task during the pitch. The primary outcome measurement was mean gaze error for each group. Group 1 was given the color/number identification task. In group 2, subjects were asked to “track the ball the best that they can all the way to the plate.” In group 3, subjects were asked to “do what they would normally do while batting a ball.”

4.1 Gaze Error

Subjects in group 1 had a mean gaze error of -4.81 degrees, which was significantly farther behind the ball than subjects in groups 2 or 3. The gaze errors for those groups were -2.20 and -3.03 degrees respectively. The gaze error for group 1 (-4.81 degrees) translates into the batters being approximately 5 feet behind the pitch. In other words, when the ball is 70 inches in front of the plate, their gaze is about 11 feet in front of the plate.

Thus, these data suggest that the color/number naming task does not promote ocular tracking to a greater degree than simply telling people to try to track the ball. Further, simply allowing individuals to act naturally during the pitch led to better tracking than that associated with the color/number naming task. This latter result suggests that the color naming/number task actually results in less efficient tracking at very close distances.

In a previously published study, it was shown that color naming could improve with practice. The reasons behind this improvement most likely do not include
improved ocular tracking. The results of the study described in this thesis suggest that this improvement is associated with an increase in kinetic visual acuity, the physiological basis of which is not understood. Kinetic visual acuity may be, for example, largely related to attention. Dynamic visual acuity at far distances (beyond 10 feet) might also improve, but dynamic visual acuity at near distances is not likely to improve with the color naming/numbering task.

This is not to say that training in some way with the color naming/numbering task is not beneficial for hitting. Since an individual generally has no reason to track the ball to distances very close to the plate (because they must already have initiated their swing), color/number naming may improve kinetic visual acuity and dynamic visual acuity over the time prior to swing initiation.

As mentioned in the introduction, we believe that there are at least two reasons to track the ball as long as possible. The first is when learning to hit. In that situation, it is important to see where the ball goes on each pitch to improve prediction in hitting. The second is to maximize the length of time the ball is foveated so as to guide the swing visually. Thus, we suggest that ocular tracking should be exercised to the fullest degree, especially in players who are learning.

A possible explanation for batters in the color/number naming task having a larger mean gaze error is that these subjects had to concentrate on two very different tasks simultaneously. The only instruction was to identify and call out the color and number written on the ball. In order to do this, however, the subjects had to track the ball as it moved toward the plate. Baseball batters need to have precise concentration and attention during the pitch to hit the ball. Perhaps the extra energy spent on trying to identify the number on the ball took some of the focus away from tracking the ball.

As the ball approaches a point 6 feet in front of the plate, the subject tracking the ball will have had to begin making a saccade to re-foveate the target due to the large increase in angular velocity. The subjects in group 1, having a mean gaze error almost 5 degrees behind the ball, may have waited later to begin the saccade due to
the brain trying to process different types of information. In other words, perhaps the subjects in group 1 were so focused on identifying and calling out the number on the ball that it detracted from their ability to make the appropriate eye or head movement at the critical time. It is as if the subjects in groups 2 and 3 were able to devote more attention to tracking the ball, minimizing any delay in making the appropriate eye movement to stay on target as long as possible.

4.2 Limitations

During this study one limitation was that the tennis balls used had a brand logo printed on the ball in black ink. This may have detracted from the subject’s ability to distinguish the numbers written on the sides of the balls in red or black ink. This should not be a significant factor, however, as color identification accuracy was irrelevant for the outcome. Gaze error was the primary focus for each group. The only possible effect that the logo would have on subjects in group 1 would be emotional (i.e. increased frustration due to poor number recognition translating to poor performance).

4.3 Conclusions

Tracking performance was worse in subjects given a color naming task than in subjects told to track the ball alone. A possible explanation for the decreased performance by the color naming subjects is that tracking a baseball pitch is best done with as few distractions as possible. It may be likely that color/number naming during a tracking exercise presents a cognitively demanding task that detracts from the subject’s ability to focus on tracking the ball.

It is also possible that color naming works to improve visual aspects important to hitting a baseball such as kinetic visual acuity or dynamic visual acuity at far distances (greater than 10 feet).
Because hitting a baseball is a task that requires a high level of attention to execute effectively, it cannot be ruled out that attention is more important than tracking ability in hitting the ball. Given the possible relationship to kinetic visual acuity and attention, further work needs to be done to determine if such a relationship exists and what role, if any, it may play in hitting a baseball.
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