Baseball Temporal Seam Recognition Study

Thesis

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

By

Daniel Richard Hagee

Graduate Program in Vision Science.

The Ohio State University

2016

Thesis Committee:

Nicklaus Fogt, O.D., Ph. D., Advisor

Aaron Zimmerman, O.D., M.S.

Gilbert Pierce, O.D., Ph. D.
Abstract

It is believed that baseball batters utilize seam recognition to gather information about baseball pitches. However, batters only have a limited amount of time to decide whether they should swing the bat. It is established that there are temporal constraints on visual acuity. Therefore, the purpose of this study was to investigate whether subjects can effectively determine seam orientation patterns in a comparable amount of time as batters face in real-life scenarios.

Subjects were tested by being seated 36 feet and 1 inch from a drill press with a spinning baseball. Each baseball used had one of three specific orientations. Subjects were asked to describe the stripes on the baseball in a 3 alternative forced choice manner. All subjects completed two trials on differing days. In the first trial, subjects had unlimited viewing time to determine the seam orientation on the baseball. In the second trial, subjects were limited to approximately 286 milliseconds of viewing time using a two aperture system. All subjects used monocular viewing in this experiment. It was found that with unlimited viewing time, subjects correctly determined the seam orientation 52.06% of the time. With limited viewing time subjects only responded correctly 37.62% of the time. This produced a significant difference (p=0.015) between unlimited viewing time and limited viewing time.

Because subjects’ performance did not meet expectations in the temporal constraint study, monocular and binocular seam recognition performance was compared...
in a second study. Testing for this was performed in a similar fashion to the first study. On one day, subjects had unlimited viewing time under binocular conditions. On the other day subjects had unlimited viewing time under monocular conditions. Subjects responded correctly on 74.29% of presentations under monocular conditions and 76.03% of presentations under binocular conditions. There was no significant difference in performance (p=0.522) between binocular and monocular viewing.

Temporal constraints resulted in a 40% reduction in the subjects' ability to accurately determine seam number and location. On the other hand, seam recognition was similar for monocular and binocular viewing.
Acknowledgments

I would like to thank Dr. Fogt for the time and guidance he has donated to the completion of this study. I would also like to thank my parents, Mark and Debbie Hagee, for their constant support throughout my entire life.
Vita

May 2008 ....................................................... Kings High School

May 2012 .......................................................... B.S. Chemical Science, Xavier University

May 2016 .......................................................... O.D., The Ohio State University

May 2016 .......................................................... M.S., The Ohio State University

Fields of Study

Major Field: Vision Science
# Table of Contents

Abstract ....................................................................................................................................................... ii
Acknowledgments ........................................................................................................................................ iv
Vita ............................................................................................................................................................... v
List of Tables ................................................................................................................................................ viii
List of Figures ................................................................................................................................................ ix
Chapter 1: Introduction ............................................................................................................................... 1
  1.1: The Importance of Seam Recognition .............................................................................................. 1
  1.2: The Effect of Pitch Spin and Types of Pitches ................................................................................ 3
  1.3: Previous Studies Involving Seam Recognition ................................................................................ 8
  1.4: Temporal Effects on Visual Acuity ................................................................................................. 11
  1.5: Purpose of Study ............................................................................................................................ 12
Chapter 2: Methods and Materials .......................................................................................................... 13
  2.1: Subject Eligibility and Enrollment .............................................................................................. 13
  2.2: Equipment and Set-Up ............................................................................................................... 13
    2.2a: Study 1 - Influence of Time Restrictions on Seam Recognition Set-Up.............................. 14
    2.2b: Study 2 – Monocular vs Binocular Set-Up .............................................................................. 18
  2.3: Determination of Shutter Speed .................................................................................................. 19
  2.4: Determination of Viewing Distance ............................................................................................ 21
2.5: Verification of Drill Press Rotational Speed..................................................21
2.6: Study Design..................................................................................................21
2.6a: Study 1 – Influence of Time Restrictions on Seam Recognition Design.....21
2.6b: Study 2 – Monocular vs Binocular Design.................................................25
Chapter 3: Results................................................................................................28
3.1: Study 1 – Influence of Time Restrictions on Seam Recognition Results........28
3.2: Study 2 – Monocular vs Binocular Results..................................................30
Chapter 4: Discussion..........................................................................................34
4.1: Additional Studies.........................................................................................41
References..........................................................................................................43
Appendix A: Luminance and Contrast of the Baseball......................................45
Appendix B: Calculation of the Spatial Frequency of the Baseball....................46
Appendix C: Illuminance of the Baseball............................................................47
List of Tables

Table 1: Duration (in seconds) the occluding shutter remained open for thirteen trials....20

Table 2: Correct responses, by subject, under monocular conditions with limited and unlimited viewing time with three orientations..............................................................29

Table 3: Correct responses, by subject, under monocular conditions with limited and unlimited viewing time with two orientations..............................................................30

Table 4: Correct responses, by subject, without the occluding or alignment apertures under binocular and monocular conditions with three orientations........................................32
List of Figures

Figure 1: A two-seam grip (left) and four-seam grip (right) ................................................. 6

Figure 2: Baseball mounted to the drill press located 36 feet and 1 inch from the
subject ........................................................................................................................................ 14

Figure 3: The headrest where subjects' heads were placed with the alignment aperture
located approximately 3 inches from the subject’s eye ............................................................. 16

Figure 4: The occluding aperture, located 4 meters from the subject’s eye, used to apply
temporal constraints on viewing time ....................................................................................... 17

Figure 5: Subject point of view of the mounted baseball through both apertures ............ 18

Figure 6: A rotating baseball with the "Two Far" orientation. The arrows delineate the
location of the seams near the edge of the baseball ................................................................ 23

Figure 7: A rotating baseball with the "Two Close" orientation. The arrows delineate the
location of the seams near the middle of the baseball ............................................................. 23

Figure 8: A rotating baseball with the "Zero" orientation. There are no arrows present
because there is no pattern of the seams ................................................................................ 24

Figure 9: Mean number (and range) of correct responses per subject, by condition ........ 33

Figure 10: Diagram depicting the spatial frequency of the baseball stripes ...................... 46
Chapter 1: Introduction

1.1 The Importance of Seam Recognition

Hitting a baseball has been described as “the single most difficult thing to do in sport” by Ted Williams, a hall-of-fame baseball player and one of the greatest hitters to ever play the game\(^1\). This task involves hitting a ball, approximately 3 inches in diameter that can travel at a variety of velocities ranging from 60 to more than 100 miles per hour depending on the type of pitch thrown. A baseball thrown at 90mph reaches home plate in less than half a second. Given that the swing requires about 160-200ms\(^2,3,4\), this leaves only 220-260ms for the batter to decide when and where the ball will arrive.

The judgement of when a ball will arrive can be made by the batter through time to contact estimations. These estimations are based on the change in the retinal image size of the baseball as it approaches the plate or the change in retinal disparity of the approaching baseball\(^5\).

The judgement of where a baseball will arrive is difficult in that the batter must judge how much the ball will drop after it is released by the pitcher. It is believed that batters use an estimation of pitch speed to estimate the height of the pitch. For example, a faster pitch is expected to drop less than a slower pitch due to less time for gravity to act on the ball. Therefore, a batter will expect a faster pitch to cross the plate at a greater height than a slower pitch\(^5\).
To determine the speed of the pitch and the likely location of the pitch when it arrives at the plate, the batter most likely uses a variety of resources before, during, and after the pitcher releases the baseball. These pre-pitch cues can help the batter to anticipate the speed and trajectory of the pitch. Pre-pitch cues to the pitch speed and trajectory might be derived from the pitch count (e.g. a fastball may be more likely if the count is 3-1 compared to a situation where the count is 1-2), the presence of baserunners (e.g. a faster pitch may be expected if a runner is on base that steals a lot of bases), analyzing previous pitches thrown, and knowledge of the types of pitches a particular pitcher is able and likely to throw\textsuperscript{1,5,6}. As the pitcher goes through his wind-up, batters may try utilize more cues to gather information about the pitch. These can include the pitcher’s grip on the baseball, the pitcher’s arm action during the pitch, and where the pitcher releases the baseball (e.g. low or high)\textsuperscript{6}.

After the pitch is released, batters may use more cues to attain additional information about the pitch. These after-release cues may include observing the seams of the baseball to attempt to see the spin on the baseball, and observing the rate of angular expansion of the ball. By combining these pre-release and post-release cues, the batter can make a better-informed decision about the pitch speed, the pitch type, and whether and when to swing the bat. If a batter were able to more effectively decide on what type of pitch was being thrown, it may provide them with a distinct advantage in their ability to hit the baseball.

After the pitch is released, batters need to be able to track the baseball to potentially be able to see the spin of the baseball. Various tracking strategies have been observed during in-lab studies. Bahill and LaRitz\textsuperscript{7} found two different tracking strategies

\textsuperscript{2}
that subjects used. In one strategy, eye movements were used in addition to head movements to foveate the baseball for as much of the trajectory as possible. The downside to this strategy is the ball can no longer be foveated near the end of the trajectory, since pursuit velocities cannot match the angular velocity of the baseball. A second strategy that was used was to follow the baseball until about 25 feet from the plate with pursuit eye movements, and very little head movement. At this point, a saccade was used to jump gaze ahead of the baseball to allow foveation of the baseball as it crossed the plate. While this strategy might allow for foveation of the ball as the ball crosses the plate, the path of the baseball in the middle portion of the pitch is not seen. Fogt and Zimmerman also studied head and eye tracking strategies used by college baseball players. This study found that, on average, batters tracked the ball with the head throughout the trajectory of the pitch and the eyes were used very little until late in the pitch trajectory.

1.2 The Effect of Pitch Spin and Types of Pitches

A pitcher releases their pitch at a distance of approximately 55.5 feet away from home plate. As soon as the baseball is out of the pitcher’s hand, gravity begins to act on the ball. Gravity is one component that affects how much a baseball will drop on its way to the plate. Other factors that influence the movement of a pitch include the speed of the pitch and the spin of the baseball. For example, if a pitcher throws a 95 mile per hour fastball, it will drop about 1.7 feet between the release point and home plate. On the other hand, a 75 mile per hour curve ball will drop about 5.7 feet⁶. A slower pitch drops more
because it takes a longer time to reach home plate, allowing more time for gravity to act on the ball.

The spin of a baseball impacts the flight of the pitch due to the Magnus Force. In this, a pitch with topspin, or spin that rotates in the same direction as the horizontal flight of the ball, will produce a wake behind the baseball that deflects air upwards. Due to conservation of momentum, if air behind the ball is being deflected upwards, the baseball itself will have to move in a downward direction. Therefore, a pitch that is thrown with topspin will deflect downwards and have more vertical movement. A pitch thrown with backspin will be “lifted” by the Magnus Force. In reality, these pitches still drop due to gravity but to a lesser extent than those thrown with topspin. This same principle can also be applied if any lateral spin is applied to a baseball; however, instead of the ball being deflected upwards/downwards, the ball will be deflected either left or right. The pitcher’s arm angle at pitch release allows lateral spin to be applied to the baseball.

The ability to recognize the seam orientation on a pitch is likely to be useful in determining the speed and trajectory of the pitch because different pitches produce various patterns on the ball. By using information from the seams on the baseball, the batter can better analyze the type of spin, spin rate, and pitch that is being thrown. Additionally, seam recognition may play a role in determining future pitches. For example, if the batter uses pre-pitch cues to predict a certain pitch will be thrown but the pitcher decides to throw a different pitch, the batter may be able to use seam recognition to determine which type of pitch is being thrown. The batter can make a note of this to help identify trends a pitcher may use.
The most commonly thrown pitch, the fastball is a pitch that is typically thrown with the index finger and middle finger on top of the baseball and the thumb on the bottom of the baseball. When the ball is released, the pitcher flicks his wrist directly forward and this produces backspin on the ball (assuming an overhand delivery). Again, due to the Magnus force, the baseball will be deflected upwards and gravity will not have as much of an effect, producing very little drop to this pitch. Fastballs can be thrown in two different ways, depending on the initial grip of the baseball. One type of fastball, the two-seam fastball, is gripped so that the index and middle fingers on top of the ball are oriented with the seams (Figure 1). When this pitch is released, the seams will produce the appearance of two vertical seams on the front of the baseball, each seam being approximately \( \frac{3}{8} \)” wide. A second type of fastball, the four-seam fastball, is gripped so that the index and middle finger are perpendicular to the seams (Figure 1). This will produce a pitch that has four horizontal seams passing in front of the baseball in one revolution. These seams blur together and to the batter no seams will be apparent on the baseball. The typical spin rate of a fastball is approximately 1,200 rotations per minute and travel approximately 90 miles per hour in professional leagues, depending on the pitcher\(^6\).
A third type of pitch, a curveball, is thrown with the pitcher’s thumb aligned across one set of seams on the bottom of the ball and the middle and index fingers together along the seam directly opposite the thumb on the other side of the ball. Pitchers will flick their wrist forward while throwing this pitch, creating a similar seam appearance to the four seam fastball as the ball approaches the batter. These pitches can be thrown with a spin rate as high as 2,000 revolutions per minute and typically travel 70-80 miles per hour. The path that the baseball follows depends on the arm delivery of the pitcher. If the baseball is thrown directly overhead, the ball will drop more on the way to the plate due to the additional top spin applied to the ball. A side arm delivery will produce a pitch that breaks more in the horizontal direction (opposite of the handedness of the pitcher) due to the side spin of the ball. A three quarter delivery can produce both a horizontal deflection and a vertical deflection of the path of the baseball.
A slider is a fourth type of pitch. To throw this pitch, a pitcher uses a fastball grip, either the two seam or four seam. As the pitcher releases the pitch, he rolls his wrist towards the outside of the ball, creating lateral spin. This pitch does not spin as much as a curveball, but more than a fastball. The velocity of the pitch is also between a fastball and a curveball. Because of the spin associated with this pitch, the baseball will again break away from the handedness of the pitcher, but not as much as the curveball. Depending on the initial grip the pitcher uses, the baseball can approach the batter with a characteristic seam appearance. With the four seam grip, the axis of rotation of the baseball falls on one of the seams of the baseball and appears to the batter as a red dot on the upper right side of the ball. A two seam slider has an axis rotation on the white portion of the baseball, and therefore no red dot is apparent to the batter. Because of this, batters could potentially look for the presence of the red dot on the ball to determine the pitch type.

A pitch that pitchers can use to change the speed of the baseball is a change-up. This pitch is designed to throw off the timing of the batter. Pitchers throw this by putting the baseball into the palm of their hand and gripping with all fingers. This pitch is thrown with the same delivery as a fastball, to try to make the batter think a fastball is being thrown. However, unlike the 90+ mile per hour velocity of the fastball, the change-up will approach the batter at a velocity of 60-70 miles per hour.

A few other pitches can be thrown that are not quite as popular as the ones mentioned above. One of these is a screwball, which has lateral spin applied to the ball, just like a curveball and slider. However, the lateral spin of the screwball is in the opposite direction from the curveball and slider. This produces a pitch that will break towards the handedness of the pitcher, and not away from it.
A knuckleball is a pitch that a pitcher can use that follows an unpredictable trajectory on its way to the plate. This pitch is thrown with the pitcher’s knuckles gripping the baseball and is released by pushing the ball, instead of flicking the wrist. This produces very little spin on the baseball and a good knuckleball will only make one revolution in the entire path to the plate. These pitches typically travel about 60 miles per hour.

Because of the multitude of pitches, arm deliveries, and velocities that can be used by a pitcher, a batter tries to use any cue he can to give more information about the type of pitch being thrown. Because various pitches can produce characteristic patterns from the seams, it is thought that batters partially rely on their ability to decipher these patterns to identify which pitch is approaching.

1.3 Previous Studies Involving Seam Recognition

There have been few studies that have investigated the ability of a batter to recognize seams and determine the rotational direction of a baseball in game situations. Bahill and Laritz\textsuperscript{6} investigated the detection of seams on a four-seam fastball vs a two-seam fastball; however, not many details were given on how these data were collected. They found that a non-athlete with normal vision could see the stripes made from a two-seam fastball at 16 feet and could identify a four seam fastball at 10 feet. These numbers were determined by one of the authors viewing simulated fastballs at particular distances and deciding when he could see the seams. They postulated that since professional baseball players would likely be able to see the seams at further distances.

Hyllegard\textsuperscript{9} also investigated the role of the seam pattern in pitch recognition. In this study, three different types of seams were used: enhanced seam balls, no seam balls,
and regular seam balls. The enhanced seam balls had the normal seams of the baseball colored over with a red marker. The no seam balls had the normal seams of the baseball “removed” by painting over them with white paint. The regular seam balls were not modified. Sixty subjects were studied; 30 college level baseball players and 30 college students who did not play baseball. Subjects were instructed to determine if each of the pitches, viewed on video, appeared to be thrown with overspin (curveball) or underspin (fastball). The baseball players were able to correctly determine the spin type 74% of the time on the no seam balls, 81% of the time on regular seam balls, and 85% on the enhanced seam balls. The non-baseball players were able to correctly determine the spin type 57% of the time on the no seam balls, 65% of the time on the regular seam balls, and 59% of the time on the enhanced seam balls. For both the baseball players and the non-baseball players, the presence of seams had a statistically significant effect on the subject's ability to detect the spin type (and therefore the pitch type).

In this same study, Hyellgard also investigated the length of time the subjects had to view the pitch. In one scenario, only the first 200 ms of the flight of the pitch was shown to the subject. In the second scenario, the full path of the pitch was shown to the subject. He determined that viewing time of the pitch did not have a statistically significant influence on the subjects’ ability to determine the type of spin on the pitch for both the baseball player group and non-baseball player group.

Gray\textsuperscript{5} investigated six experienced college level baseball players' abilities to “hit” simulated pitches displayed on a computer monitor. In the first part of his study, the pitch speed was randomly varied from 63-80 mph, in the absence of other cues (like arm motion, ball rotation, etc.). The six batters combined for a batting average of .030 in this
portion of the study, which is well below an average batting average. In the second part
of his study, instead of varying the pitch speeds anywhere from 63-80 mph, a two-pitch
pitcher was simulated. Pitches were either a fastball (traveling approximately 85 mph) or
a change-up (traveling approximately 70 mph). This is more applicable to real-life
scenarios because most pitchers cannot vary their pitch speed randomly over a 17 mph
range. He found that by simulating a two-pitch pitcher, the amount of hits batters were
able to achieve was significantly improved over the first part. However, the batting
average for this part was still below average, at .120. This suggests that batters use
expectations about pitch speed stemming from the history of previous pitches.

Gray also studied the effect of rotational cues on the batters’ ability to hit
simulated pitches. For this, the same procedure was used as the two-pitch pitcher
simulation above, with the addition of rotational cues on the simulated pitches. For fast
pitches, back spin was simulated and for slow pitches, top spin was simulated. The added
spin did not change the trajectory of the pitches; it only provided an additional source of
information relating to pitch speed. When adding the rotational cue, 4 of the 6 batters
showed a significant reduction in spatial error of their swing and 3 of the 6 batters
showed a significant reduction in the temporal error of their swing, when compared to
pitches without rotation. Additionally, batters with higher-level experience exhibited
more improvement when rotational cues were present when compared to the batters in
the study with lower-level experience.

One final study by Do, Zimmerman, and Fogt investigated subjects’ ability to
identify the seam orientation of rotating baseballs at varying distances. In this, baseballs
were mounted onto a drill and shown to 16 subjects at distances ranging from 10 to 45
feet. The subjects were asked to identify the number of stripes seen on each of the balls presented. The number of stripes (and potential responses) for each presentation was either two red stripes, one central red stripe, or no discernible stripes. Subjects had unlimited viewing time for each presentation. It was determined that at 10 feet, subjects were correct on 98% of the presentations. At 35 feet, subjects were able to accurately determine the number of stripes 90% of the time. At 45 feet, the furthest distance tested, subjects were able to determine the number of stripes 82% of the time.

1.4 Temporal Effects on Visual Acuity

The ability of a batter to be able to detect the spin of a pitch should be related to their visual acuity and contrast sensitivity. Because batters only have about 220-260 milliseconds to decide if they are going to swing at the pitch, the question becomes what affect do these time constraints have on visual acuity?

In a study by Baron and Westheimer, the effect of visual acuity as a function of exposure duration was investigated. In this study, subjects had to select where the opening of a stationary Landolt C was when both the minimum angle of resolution of the opening and the exposure duration were varied. This study found that the visual acuity of the subjects improved with an exposure duration of up to about 400 milliseconds, and then began to level off thereafter. However, only two subjects were used in this study.

Adrian also studied the effect of exposure duration on visual acuity and contrast. In this study, subjects were again asked to identify the location of the gap on a stationary Landolt C when exposure duration, contrast, and the minimum angle of resolution were all varied. The results of this study indicated that visual acuity improves for exposure
times up to and even beyond one second. Additionally, the contrast of the Landolt C against the background greatly impacted the visual acuity at given exposure durations.

Other studies\textsuperscript{13,14} exist that show similar relationships regarding visual acuity improvement with increasing exposure durations at short durations. However, these studies did not investigate the longer exposure durations investigated in the current study.

1.5 Purpose of Study

Given that seam recognition is likely to play an important role in pitch recognition and batting, the purpose of this study is to investigate if a person is able to discern the orientation of the seams on a rotating baseball when given a limited amount of time to make the determination. Pilot data from the Fogt lab indicated that subjects were able to accurately decipher the seam orientation 82\% of the time at a distance of 45 feet from the baseball. This was determined with unlimited time to view the rotating baseball. In reality, baseball hitters do not have an unlimited amount of time to make this determination. Instead, they have approximately 220-260 milliseconds. With time constraints similar to what batters face in real life, can people really decipher seam orientations accurately?
Chapter 2: Methods and Materials

2.1 Subject Eligibility and Enrollment

This study was approved by The Ohio State University Biomedical Institutional Review Board. Data was collected on 20 adult subjects (male and female) across two studies. To be eligible for this study, subjects had to be between 18 and 40 years of age, as this is the typical age of baseball and softball players. Additionally, subjects had to have a best corrected visual acuity of 20/20 or better in either spectacles or contact lenses.

Two separate studies were performed, investigating two different variables. The first study, investigating the effect of viewing time on seam detection, utilized 10 subjects with the above eligibility criteria. The second study, investigating monocular vs. binocular effects on seam detection, utilized a separate group of 10 subjects again using the above eligibility criteria. No subjects were tested in both the first and second study.

All subjects signed an IRB approved informed consent document prior to data collection. All 20 subjects that began the study also finished the study. Upon completion of the study, subjects received a gift card.

2.2 Equipment and Set-Up

Two distinct set-ups were used for the two studies. In both studies, subjects were asked to view a baseball attached to a drill bit which was inserted into a drill press (Sears Craftsman, model #E148193) (Figure 2) spinning at 1358 rpm. This rotational velocity is near that of a typical major league fastball\(^6\). The baseball was located 36 feet and 1 inch
away from each subject for all trials. The drill press was mounted onto an adjustable desk, which could be moved up, down, left or right. This allowed the baseball to be aligned to the center of each subject’s field of view. A black wood block was also mounted onto the desk, behind the baseball, to eliminate background distractions. A curtain was mounted in front of the baseball, so the baseball would be hidden from the view of the subjects in between presentations.

Figure 2: Baseball mounted to the drill press located 36 feet and 1 inch from the subject.

2.2a: Study 1 – Influence of Time Restrictions on Seam Recognition Set-Up

Two shutters were used in this portion of the study. Both shutters were Melles Grillot model #04 IES 003. The first aperture, the alignment aperture, (Figure 3) was approximately 3 inches from the subject’s eye when the subject’s head was placed in the chin rest. This aperture remained open for all trials. The purpose of this aperture was to
assist in aligning the subject’s eye onto the baseball. Proper eye alignment was critical in this scenario due to the brevity of the open aperture used on half of the presentations. The diameter of this aperture was 0.75 inches. A second aperture, the occluding aperture, (Figure 4) was located 4 meters from the subject’s eye. The purpose of this shutter was to limit the viewing time the subject could observe each spinning baseball. For the trials where no shutter was being used, this aperture remained in place; however, it remained open for the entire duration of all baseball presentations. When this occluding shutter was open, the entire baseball could be seen through the open aperture (Figure 5). The diameter of this aperture was 1.38 inches (angular subtense 0.50deg). For the trials where the shutter was closed and opened (described below), the aperture would remain open for approximately 286 ms. After the shutter closed, the subject was not allowed able to see the baseball again until the next presentation. In each of these tasks, the subject had to determine the number of seams present on the spinning baseball.
Figure 3: The headrest where subjects' heads were placed with the alignment aperture located approximately 3 inches from the subject’s eye.
Figure 4: The occluding aperture, located 4 meters from the subject’s eye, used to apply temporal constraints on viewing time.
2.2b: Study 2- Monocular vs Binocular Set-Up

Because the seam recognition performance of Study 1 did not approach the number of correct responses expected based on a preliminary study in our laboratory, a second study was completed. In this study, the effects on seam recognition of binocular viewing versus monocular viewing was examined. In this scenario, no apertures were present between the subject and the mounted baseball. Subjects had unlimited time to view the baseball in each of the two trials. The baseball was still placed 36 feet and 1 inch from the subject’s eyes.

Figure 5: Subject point of view of the mounted baseball through both apertures.
2.3 Determination of Shutter Duration

The length of time for the shutter to be kept open was based on calculations involving the length of time a batter in Major League Baseball (MLB) typically has to decide whether they should swing after the pitch is released. In the MLB, the pitching mound is a distance of 60 feet away from home plate. When a pitcher performs his windup and releases the pitch, the ball is on average 55 feet away from home plate. Assuming the batter’s eyes are near the center of home plate and not too far to the left, right, front or back, then it can be assumed that the distance from the batter’s eye to the release point of the ball is 55 feet, on average.

A typical pitch speed in the MLB is 90 miles per hour (132 feet per second). Using a 90 mph pitch, and assuming the ball is released 55 feet from the batter, a batter has approximately 420 milliseconds until the baseball reaches them. However, a swing requires 160-200 milliseconds to complete, so the batter has approximately 220-260 milliseconds to determine where the ball will arrive and if they should swing. The shutters used in this study were set to remain open for 250 milliseconds using a control supplied with the shutter.

To verify the duration that the shutter was open, a laser was shown through the shutter aperture and onto a photocell. With the aperture open, the laser output could be detected by the photocell. However, when the aperture was closed, the laser was not detected. The output of the photocell was then used to determine the duration over which the aperture was open by recording the photocell output (2000Hz) through an analog-to-digital converter.
After testing the shutter duration, it was determined that the aperture remained open for 286 milliseconds on average each time it opened. The shutter was opened thirteen times successively and the durations of each of these openings are listed in Table 1. The range of durations varied from 286-287.5 milliseconds. The average duration of the openings over these trials was 286.6 milliseconds ± 0.0004ms. Because the duration of the shutter opening is meant to represent how long the batter has to decide if they are going to swing at a pitch, the calculations for the distance of the rotating baseball to the subject was based off this number.

<table>
<thead>
<tr>
<th>Trial Number</th>
<th>Duration of Shutter Opening (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.286</td>
</tr>
<tr>
<td>2</td>
<td>0.286</td>
</tr>
<tr>
<td>3</td>
<td>0.286</td>
</tr>
<tr>
<td>4</td>
<td>0.2865</td>
</tr>
<tr>
<td>5</td>
<td>0.2865</td>
</tr>
<tr>
<td>6</td>
<td>0.2865</td>
</tr>
<tr>
<td>7</td>
<td>0.287</td>
</tr>
<tr>
<td>8</td>
<td>0.287</td>
</tr>
<tr>
<td>9</td>
<td>0.2865</td>
</tr>
<tr>
<td>10</td>
<td>0.287</td>
</tr>
<tr>
<td>11</td>
<td>0.2865</td>
</tr>
<tr>
<td>12</td>
<td>0.287</td>
</tr>
<tr>
<td>13</td>
<td>0.2875</td>
</tr>
</tbody>
</table>

Table 1: Duration (in seconds) the occluding shutter remained open for thirteen trials
2.4 Determination of Viewing Distance

As mentioned above, the subject’s eye was placed 36 feet and 1 inch away from the mounted baseball. This length was determined from a calculation involving the length from the pitcher’s mound to the batter, a typical pitch speed, and the duration of the aperture opening.

In our study, the shutter being used opened and closed completely in 286 milliseconds on average. This means that over the duration of a complete open-close cycle, a 90 mph pitch would travel a distance of 37.75 feet. Subtracting this value from 55 feet (the distance from the release point of the pitch to the batter) yields 17.25 feet. This means that in 286 milliseconds, a 90 mph pitch travels from 55 feet away from the batter to 17.25 feet away. In order to not give the subject an unfair advantage (or disadvantage) over what happens in real life, these two distances were averaged together to give 36.125 feet, or 36 feet and 1 inch. By averaging these distances, it also gives the average angular size of the ball from the batter’s point of view over the distance the ball travels.

2.5 Verification of Drill Press Rotational Speed

The drill press used in the study was set at 1300 rpm. A stroboscope was used to verify this rotational speed. The rotational speed was found to be 1358 rpm.

2.6 Study Design

2.6a: Study 1- Influence of Time Restrictions on Seam Recognition Design

Each subject returned for testing on two different days, separated by a minimum of two days. Subjects randomly performed one of two trials on each day of the study and by the end of the second day every subject had completed both trials. The day in which
each subject performed a particular trial was randomized prior to subject recruitment. Each of the two trials were distinct from each other, as one day testing was performed with limited viewing time and the other day subjects were allowed unlimited viewing time. In each of these two trials, the set-up described above was used.

After the study was explained to subjects and the subject signed the informed consent document, the age and visual acuity of each subject were checked to determine study eligibility. The subject then sat down 11 feet from the spinning, mounted baseball to observe one sample baseball from each of the three possible orientations. For each orientation, the subject was told in which orientation the baseball was spinning and given time to observe the differences in appearance between the orientations. Subjects viewed these sample balls binocularly. This portion was performed on both days of testing so subjects could become familiar with the appearance of the orientations prior to testing.

The possible orientations the baseball could spin in the drill press were as follows: “Two Far” corresponding to the orientation with two seams spread far apart on the top and bottom of the baseball (Figure 6), “Two Close” corresponding to the orientation with two seams closer together in the middle of the baseball (Figure 7), and “Zero” corresponding to the orientation with no observable seam pattern (Figure 8). Due to limitations of the drill press, the seams on the baseballs were oriented horizontally rather than vertically as one would expect in a baseball pitch. Subjects were told that every baseball presentation was going to be in one of these three orientations, and therefore this study can be characterized as a three alternative forced choice experiment.
Figure 6: A rotating baseball with the "Two Far" orientation. The arrows delineate the location of the seams near the edge of the baseball.

Figure 7: A rotating baseball with the "Two Close" orientation. The arrows delineate the location of the seams near the middle of the baseball.
After the subject was shown each of the three orientations at 11 feet, they were then moved back to the chair and headrest apparatus at 36 feet and 1 inch away from the ball. Subjects patched their left eye and used their right eye to view the baseball. Subjects were aligned properly in the headrest and were told to look through the center of the shutter near their eye. The far shutter remained open while properly aligning the subjects. Subjects looked through the opening of the far shutter to a ball mounted on the drill press. The cart holding the drill press was then moved left, right, up, or down in order to center the mounted baseball in the opening of the second shutter. After the subject was properly aligned, they were again shown one sample baseball of each of the three orientations while the baseball was spinning. Again, the subject was told in which orientation each of the baseballs were spinning and given time to observe any differences between

Figure 8: A rotating baseball with the "Zero" orientation. There are no arrows present because there is no pattern of the seams.
orientations. Subjects viewed these sample baseballs monocularly. On the days when the
trial utilizing the shutter was performed, the shutter was opened and closed three times to
give the subject an idea of how fast and what to expect during the testing. This step was
skipped on the days when the opening and closing the shutter was not performed.

For each trial, with and without the shutter, a total of 63 balls were presented to
each subject. Each of the nine balls were presented 7 times, randomly determined by a
number generator. This yielded 21 presentations of each of the three orientations for each
trial. For every presentation, a black curtain was used to hide the ball from the subject
prior to exposing the ball. After the ball was mounted in the drill press and the drill press
turned on, the curtain was moved to the side to allow the subject to view the ball. During
the trials using the shutter, the subject was notified that the shutter was about to open and
then the shutter was promptly opened. In the trial with no shutter, the second shutter was
still present, in the same location, but was left open for the duration of the trial. In that
case, subjects had as much time as needed to view the baseball. After viewing the
baseball and determining the number and location of the seams on the baseball, the
subject gave their response to the examiner and the responses were recorded on the data
sheet for that particular presentation.

2.6b: Study 2- Monocular vs Binocular Design

Testing here was very similar to that explained above in Study 1. Again, each
subject returned for testing on two different days, separated by a minimum of two days.
Subjects performed one of two trials on each day of the study and by the end of the
second day every subject had completed both trials. The day in which each subject
performed a particular trial was randomized prior to subject recruitment. Each of the two
trials were distinct from each other by using one eyed or two eyed viewing of the baseball. In each of these two trials, the set-up described in the above section was used (no apertures between the subject and baseball).

After the study was explained to subjects and the subject signed the informed consent document, the age and visual acuity of each subject were measured to determine whether the entry criteria were met. The subject sat down 11 feet from the spinning baseball to observe one sample baseball from each of the three possible orientations. For each orientation, the subject was told in which orientation the baseball was spinning and given time to observe the differences in appearance between the orientations. Subjects viewed these sample baseballs binocularly. This portion was performed on both days of testing so subjects could become familiar with the appearance of the orientations prior to testing. The possible orientations of the spinning baseball were the same as in Study 1 (shutter vs no shutter study).

After the subject was shown each of the three orientations at 11 feet, they were then moved back to the chair and headrest apparatus at 36 feet and 1 inch away from the ball. If the particular trial being performed was for monocular viewing, subjects would patch their left eye and view the baseball with their right eye. Subjects were aligned properly in the headrest and were told to look to where the baseball was mounted on the drill press. The cart holding the drill press was then moved left, right, up, or down in order to center the baseball in the subject’s field of view. After the subject was properly aligned, they were again shown one sample baseball of each of the three orientations while the baseball was spinning. Again, the subject was told in which orientation each of
the baseballs were spinning and given time to observe any differences between orientations.

For both the monocular and binocular viewing trials, a total of 63 balls were presented to each subject. Each of the nine balls were presented 7 times, randomly determined by a number generator. This yielded 21 presentations of each of the three orientations for each trial. For every presentation, a black curtain was used to hide the ball from the subject. After the ball was mounted in the drill press and the drill press turned on, the curtain was moved to the side to allow the subject to view the ball. Subjects had as much time as needed to view the baseball in both monocular and binocular conditions. After viewing the baseball and determining the orientation in which the baseball was spinning, the subject gave their response to the examiner and the responses were recorded on the data sheet for that particular presentation.
Chapter 3: Results

3.1 Study 1- Influence of Time Restrictions on Seam Recognition Results

In the trials with limited viewing time (Table 2), subjects responded correctly for 237 out of 630 of the baseballs presented (37.62%). The mean correct responses per subject was 23.7, with a range from 13 to 34. In the trials with unlimited viewing time, subjects responded correctly for 328 out of the 630 of the baseballs presented (52.06%). The mean number of correct responses was 32.8 per subject, with a range from 19 to 48. Using a paired t-test with nine degrees of freedom, and comparing the total correct in each scenario, there was a significant difference in performance (p=0.015) between unlimited viewing time and limited viewing time.

Because the success rates of both limited and unlimited viewing time was lower than expected, it was initially thought that perhaps subjects were unable to distinguish between the “Two Close” orientation and “Two Far” orientation. The same results were analyzed a second time where responses were counted as correct for either the “Two Close” or “Two Far” orientation as long as subjects said there were two seams. This simplified the task to one of presence of seams vs. lack of seams. The number of correct responses by subject can be found in Table 3. In the trials with limited viewing time, subjects responded correctly on 375 of the 630 presentations (59.52%). The mean correct responses per subject was 37.5, with a range of 31-42 correct responses. In the trials with
unlimited viewing time, subjects responded correctly on 444 of the 630 presentations (70.48%). The mean correct responses per subject was 44.4 with a range of 37-48. Using a paired t-test with nine degrees of freedom, and comparing the total correct responses in each scenario, there was still a significant difference in performance (p=0.003) between unlimited viewing time and limited viewing time. After subject responses were analyzed in more detail in Study 1, it was determined that there was not a significant propensity for subjects to mistake a two seam orientation for the other two seam orientation over the no seam orientation.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Limited Viewing Time</th>
<th>Unlimited Viewing Time</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject A</td>
<td>13</td>
<td>35</td>
<td>22</td>
</tr>
<tr>
<td>Subject B</td>
<td>24</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>Subject C</td>
<td>25</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td>Subject D</td>
<td>34</td>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td>Subject E</td>
<td>17</td>
<td>32</td>
<td>15</td>
</tr>
<tr>
<td>Subject F</td>
<td>26</td>
<td>41</td>
<td>15</td>
</tr>
<tr>
<td>Subject G</td>
<td>22</td>
<td>48</td>
<td>26</td>
</tr>
<tr>
<td>Subject H</td>
<td>20</td>
<td>19</td>
<td>-1</td>
</tr>
<tr>
<td>Subject I</td>
<td>28</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>Subject J</td>
<td>28</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>237</strong></td>
<td><strong>328</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Correct responses, by subject, under monocular conditions with limited and unlimited viewing time with three orientations.
<table>
<thead>
<tr>
<th>Subject</th>
<th>Limited Viewing Time</th>
<th>Unlimited Viewing Time</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject A</td>
<td>31</td>
<td>41</td>
<td>10</td>
</tr>
<tr>
<td>Subject B</td>
<td>38</td>
<td>37</td>
<td>-1</td>
</tr>
<tr>
<td>Subject C</td>
<td>36</td>
<td>46</td>
<td>10</td>
</tr>
<tr>
<td>Subject D</td>
<td>41</td>
<td>48</td>
<td>7</td>
</tr>
<tr>
<td>Subject E</td>
<td>32</td>
<td>45</td>
<td>13</td>
</tr>
<tr>
<td>Subject F</td>
<td>40</td>
<td>48</td>
<td>8</td>
</tr>
<tr>
<td>Subject G</td>
<td>37</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>Subject H</td>
<td>41</td>
<td>40</td>
<td>-1</td>
</tr>
<tr>
<td>Subject I</td>
<td>42</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>Subject J</td>
<td>37</td>
<td>47</td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>375</strong></td>
<td><strong>444</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Correct responses, by subject, under monocular conditions with limited and unlimited viewing time with two orientations.

3.2 Study 2- Monocular vs Binocular Results

Because our data only yielded a 52.06% success rate under monocular conditions with no shutter, we wanted to further investigate the effect that binocularity has on the success of subjects. We speculated that the performance in Study 1 was the result of the monocular viewing conditions because previous data on seam recognition from our lab\(^{10}\), obtained under binocular viewing conditions with no apertures or shutters present, produced a success rate of approximately 90% near the distances utilized in the current study.
In the monocular trials for Study 2 (Table 4), subjects responded correctly for 468 out of 630 of the baseballs presented (74.29%). The mean correct responses per subject was 46.8, with a range from 37 to 50. In the binocular trials of Study 2 (Table 4), subjects responded correctly for 479 out of the 630 of the baseballs presented (76.03%). The mean correct responses was 47.9 per subject, with a range from 43 to 54. Using a paired t-test with nine degrees of freedom, and comparing the total correct in each scenario, there was no significant difference in performance (p=0.522) between the binocular and monocular conditions.

The success rates of all conditions can be seen in Figure 9. When comparing the correct responses with unlimited viewing time in Study 1 (monocular conditions, with open apertures present between the baseball and the subject) and the correct responses with monocular conditions and unlimited viewing time in Study 2 (no apertures present between the baseball and the subject), it can be seen that a difference exists. When comparing the total correct responses of these conditions using a two-sample t-test a significant difference in performance exists (p<0.001) between the presence and lack of apertures.
<table>
<thead>
<tr>
<th>Subject</th>
<th>Monocular</th>
<th>Binocular</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject K</td>
<td>48</td>
<td>47</td>
<td>-1</td>
</tr>
<tr>
<td>Subject L</td>
<td>50</td>
<td>54</td>
<td>4</td>
</tr>
<tr>
<td>Subject M</td>
<td>46</td>
<td>42</td>
<td>-4</td>
</tr>
<tr>
<td>Subject N</td>
<td>37</td>
<td>51</td>
<td>14</td>
</tr>
<tr>
<td>Subject O</td>
<td>49</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Subject P</td>
<td>49</td>
<td>49</td>
<td>0</td>
</tr>
<tr>
<td>Subject Q</td>
<td>43</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>Subject R</td>
<td>50</td>
<td>47</td>
<td>-3</td>
</tr>
<tr>
<td>Subject S</td>
<td>50</td>
<td>47</td>
<td>-3</td>
</tr>
<tr>
<td>Subject T</td>
<td>46</td>
<td>49</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>468</strong></td>
<td><strong>479</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

Table 4: Correct responses, by subject, without the occluding or alignment apertures under binocular and monocular conditions with three orientations.
Figure 9: Mean number (and range) of correct responses per subject, by condition.
Chapter 4: Discussion

Baseball pitches are usually thrown such that they spin, reducing the contrast on the ball and producing red stripes characteristic of different pitch types. Several studies have shown that subjects may be using visual cues such as seam direction to determine pitch trajectory and ultimately to improve batting. Previous pilot data from our laboratory demonstrated that given unlimited time, subjects were able to sufficiently discern the presence and number of visible stripes on a spinning baseball at a distance so as to potentially be useful in determining the trajectory of the pitch. However, it is known that there are temporal constraints on visual acuity. Given that batters have limited time during which to decide whether and when to swing the bat, the question of whether vision is adequate to discern and therefore to potentially make use of visual cues from the ball to determine pitch trajectory remains unanswered.

The results of this study demonstrate that constraining the time that individuals have to determine the presence and location of the stripes on a spinning ball significantly reduces overall performance compared to conditions where viewing time is not constrained (Study 1). The reduction in performance with temporal constraints was on the order of 40%. 

34
Because seam recognition performance in the temporal constraint versus no temporal constraint portion of the experiment (Study 1) was measured monocularly and because this performance was substantially lower than that expected from previous pilot data, the decision was made to compare monocular performance to binocular performance. Performance was much better in this second experiment (Study 2), and monocular and binocular performance was not significantly different.

Thus, temporal constraints can have a negative impact on performance and this suggests that training of pitch recognition should include a temporal component as advocated by Fadde. Fadde investigated the effect that an interactive video-baseball pitch recognition training program had on batter performance for a college baseball team. In these training sessions, batters had to determine either pitch type or final pitch location when viewing a limited portion of the baseball path. Batters started with viewing the first 165 ms of the flight of the pitch, and when they showed mastery of this the length of time was reduced to 67 ms. He found that the batters who underwent the training sessions had a significantly better batting average than those batters who did not. The difference between on-base percentage and slugging percentage was not significantly different.

A central question that remains unanswered is what seam recognition performance is like quantitatively under conditions of temporal constraint. This is because in the temporal constraint versus no temporal constraint experiment (Study 1), performance levels were much lower than expected in both the temporally constrained and non-temporally constrained portions of the experiment. This suggests that some feature of this experiment (other than the monocular testing conditions) influenced the result. Therefore, it may be that the 40% reduction in performance found with the
temporal constraint will hold up when those features of the original experiment are eliminated. In that case, performance levels under real-world (binocular conditions with no visual field restrictions) would be expected to be around 45% with temporal constraints present.

On the other hand, perhaps the drop in performance with temporal constraints would be more or less dramatic when the features of the temporal constraint experiment in Study 1 are removed. What other features of the temporal constraint experiment might have affected performance? One thing to consider is the occluding aperture 4m from the subject. The occluding aperture remained open in half the trials in Study 1 and in the other half it would open for a short period of time. Because of this, subjects may have been accommodating onto this aperture. This aperture was located at a distance of 4 meters from the subjects open eye, meaning 0.25D of accommodation would be used, if subjects were accommodating on this target. Subjects were aligned 36 feet and 1 inch, or approximately 11 meters, from the rotating baseball. At this distance, an accommodative demand of 0.09D is required. The difference between the accommodative demands between the baseball and the occluding aperture is therefore only 0.16D.

Woods investigated the effect of optical blur on contrast sensitivity. Varying amounts of optical defocus were used to induce depressions in the contrast sensitivity function. Since the task in our study can be equated to a contrast sensitivity task, the results of Woods can be used to estimate whether the magnitude of accommodative blur (0.16D) induced by the occluding aperture in the current experiment could be a reasonable cause for the poor performance seen in the temporal constraint study. Using the luminance values of the red stripes on the baseball against the white portion of the
baseball, the average Michelson contrast was found to be 17%, giving a contrast sensitivity of 5.88 (Appendix A). On average, the spatial frequency of the baseball in our study at a distance of 36 feet and 1 inch was 4.32 cycles per degree (Appendix B). In the study by Woods, the contrast sensitivity of five subjects was measured with 0.50D of myopic defocus. Of the five subjects, two did not have a depression in contrast sensitivity with this amount of defocus. The three subjects that did exhibit a depression in contrast sensitivity with this amount of defocus only showed such a reduction at higher spatial frequencies (8, 11, 13.5 cpd) than what was found on the baseball. Thus, it is unlikely that accommodating on the occluding aperture could result in the reduction in the subjects’ ability to perceive the stripes seen in the temporal constraint study.

A second feature of the temporal constraint study (Study 1) that may have influenced performance was the alignment aperture placed close to the viewing eye. This aperture remained open throughout the duration of the trials in Study 1 and was absent in Study 2. Because of this, subjects may have potentially been accommodating on this aperture in Study 1 and not in Study 2. However, this is not likely because subjects were told that their task was to identify the number of seams present on the spinning baseball. If subjects knew that this was their task, they would most likely not be accommodating on this alignment aperture. It can be argued that proximal accommodation may have been induced from awareness of how close the alignment aperture was to the eye. Even if proximal accommodation was induced, the magnitude would likely be an insignificant amount. Woods found depressions in contrast sensitivity at 4 cpd starting with 1.5D of myopic defocus. Thorn examined contrast sensitivity depressions with up to 3D of myopic defocus. When incorporating the contrast sensitivity and spatial resolution of the
baseball into Thorn's data, subjects should have been able to resolve the number of stripes even with 3D of myopic defocus. Because of this, it is unlikely that induced proximal accommodation would have been significant enough to produce the difference in seam recognition seen between Study 1 and Study 2.

In addition to potential effects on accommodation resulting from the alignment aperture, this aperture may have influenced pupil size. Perhaps pupil size may in turn have influenced stripe recognition. One could argue that the alignment aperture was located close enough to the eye that it may cast a shadow on the eye, thus causing dilation of the pupil. With a larger pupil, more aberrations exist, producing defocus and an expected loss of contrast sensitivity. Strang\textsuperscript{19} studied the effect of pupil size and optical blur on the contrast sensitivity function. They found when subjects were in focus, a change in pupil size from 6mm, 4mm, and 2mm only produced very small changes in contrast sensitivity. When defocus of 2D was present at various pupil sizes, much variability existed between subjects in terms of contrast sensitivity. In some cases, a smaller pupil did not necessarily result in better contrast sensitivity compared to a larger pupil. Strang concluded that complex interactions exist between pupil size, defocus, and individual aberrations. In our study, subjects had to be corrected to 20/20 to be eligible for participation, indicating that a very low amount of defocus was present, if any. Therefore, it is expected that any change in pupil size resulting from the alignment aperture would most likely not produce a significant change in the subjects’ ability to detect contrast.

What then could account for the poor stripe recognition performance in the temporal constraint study? A feature that must be considered is elimination of the
background by the aperture at 4m. Perhaps there are subtle cues obtained from viewing the edge of the ball against the background that improve the subject’s ability to discern the contrast of the stripes on the ball. Clearly, there is some influence of this aperture on the results as evidenced by the improvement in performance in Study 2 (no apertures) compared to Study 1 (apertures).

Because seam detection can be classified as a task of contrast sensitivity, it can be argued that training contrast sensitivity can result in improved seam recognition ability. Deveau\textsuperscript{20} investigated the use of Gabor patches as a training method on visual performance and batting performance in college baseball players. They found that batters who underwent training showed improved contrast sensitivity and on field batting performance versus those who did not undergo the training. Perhaps this suggests that the training of contrast sensitivity can result in improved seam recognition.

While the relative comparisons in these studies (Study 1: temporal constraint versus no temporal constraint, Study 2: monocular versus binocular) give a clear indication that only temporal constraints reduce performance, the absolute levels of performance may be different in populations who are experienced in baseball.

The subjects investigated in this study were not asked if they had prior baseball experience. Because of this, the subjects that participated in this study may have had little baseball experience in their lifetime. It can be assumed that professional and collegiate baseball players have much more experience at observing pitches and seam recognition tasks. Since these players have more experience, they are likely to have an improved ability to recognize seam orientations of pitches. Gray\textsuperscript{5} found that adding rotational cues improved simulated batting performance more for higher level players than for lower-
level players. Hyllegard\(^9\) also found that college baseball players were more successful in determining the direction of spin versus non-baseball players. These data both suggest that more experienced baseball players may be better at seam recognition tasks. In addition, Laby\(^{21}\) found that professional baseball players have a mean visual acuity, distance stereoacuity, and contrast sensitivity significantly better than those of the general population. Although experienced baseball players are, on average, likely to have better seam recognition and visual abilities than the general population, it is difficult to predict what effect time constraints may have on professional hitters’ abilities to achieve this task.

From our data in Study 1, the subjects who were better at determining the number of seams with unlimited viewing time also had the largest differences in performance when comparing limited viewing time and unlimited viewing time. For example, Subject G had the most correct responses with unlimited viewing time at 48 out of 63 presentations, indicating that this subject was fairly proficient in determining the number of seams present without time constraints. When the shutter was introduced for this subject, the ability to correctly determine the number of seams dropped to only 22 correct responses (a difference of 26). This same pattern can be seen for Subject F (the second best at determining without the shutter) and Subject A (the fourth best). Of the top four performers with unlimited viewing time, only Subject D maintained a similar success rate between the presence and lack of shutter. This may suggest that even for subjects that are better at determining seam orientations (like experienced baseball players), time constraints will likely have a negative impact on the ability to resolve the number of seams on the baseball. On the other hand, perhaps these differences suggest that there are
various strategies that subjects use that work well under the conditions of unlimited viewing time that may not work as well when time constraints are introduced. If this is the case, this may not be a good prediction of how experienced baseball players may perform under time constraints.

4.1 Additional Studies

Additional studies could be performed to further investigate a batter’s ability to correctly identify the seam pattern of a baseball. Instead of using the monocular and two aperture set up to apply time constraints, as used in the current study, a system could be used to apply limitations on viewing time without occluding the background. This also may allow subjects to view the baseball binocularly and would mimic a more real life situation, since batters are able to obtain a binocular view of pitches during in-game situations. By making these changes, perhaps time constrains would be able to be applied without negatively affecting subject performance.

Another improvement that could be made to the current study is to improve the lighting on the baseball. Vizmanos\textsuperscript{22} found increased performance in contrast sensitivity tasks with a more illuminated surround. The illumination on the baseball in the current study can be found in Appendix C. Improvements in lighting could be achieved in a number of ways. First, trials could be performed outside and sunlight could be used to illuminate the baseball. This would provide the most realistic scenario, since most baseball games are played outside. However, the presence or lack of sun at the particular time of testing would likely affect results. A more controlled alternative could be to use multiple different spot lights in the laboratory aimed at the baseball. This would help increase the total illumination around the baseball and eliminate shadows. In addition, a
rotating drill press could be used to avoid overhead shadows from being cast onto the baseball.

As mentioned above, the level of baseball experience of the subject's that participated in this study was unknown. Because of this, the effect that temporal constraints have on more experienced and more skilled batters is unknown. It would be interesting to repeat a similar experiment to the current one with collegiate/professional baseball players to see the effects of temporal constraints on more experienced players.
References


Appendix A: Luminance and Contrast of the Baseball

The luminance of selected areas of the spinning baseball and background was measured with the Pritchard photometer (Model PR-1980A). A baseball with the “Two Far” orientation was measured. The luminance values were as follows: black board behind the ball 93 cd/m$^2$, top red stripe 107 cd/m$^2$, top white 132 cd/m$^2$, bottom red stripe 57 cd/m$^2$, and bottom white 99 cd/m$^2$. These values were used to determine the Michaelson contrast of the seams vs the adjacent areas on the baseball/background. The formula to attain this value is $C = (L_{\text{max}} - L_{\text{min}}) / (L_{\text{max}} + L_{\text{min}})$. The contrast of the black board vs the top red seam was found to be approximately 7%. The contrast of the top red stripe vs top white are on the baseball was approximately 10.4%. The contrast of the top white vs the bottom red stripe was approximately 39.6%. The contrast of the bottom red stripe vs the bottom white of the baseball was approximately 26.9%. The contrast of the bottom white stripe vs the black background was approximately 3.12%. The average Michaelson contrast was approximately 17%. This yields a contrast sensitivity of 5.88.
Appendix B: Calculation of the Spatial Frequency of the Baseball

The spatial frequency calculation of the baseball is based on the distance the subject viewed the baseball from and the average separation of the seams, while the baseball is spinning. Subject's sat a distance of 36 feet and 1 inch (433 inches) away from the baseball. The separation of the seams of the baseball was 1.75 inches on average (Figure 10), since the seams become closer together and then further apart while the ball is spinning. This separation represents 1 cycle of the grating on the baseball.

![Diagram](image)

Figure 10: Diagram depicting the spatial frequency of the baseball

The inverse tangent of θ can be calculated based on Figure 9 to yield one cycle filling up 0.231 degrees. Therefore, the spatial frequency of 1 grating cycle of the baseball seams is approximately 4.32 cycles per degree.
Appendix C: Illuminance of the Baseball

Before subjects began testing, the lights in the laboratory were allowed to warm up for a minimum of fifteen minutes. The illuminance of a rotating baseball was measured at various locations on the baseball using the Litemate III (Model 504). From the subjects point of view, the following are the illuminance values recorded on the baseball: top 900 lux, bottom 1100 lux, left 550 lux, right 2120 lux, and 1160 lux in the middle of the ball.