AN ABSTRACT OF THE THESIS OF

Randy Hyllegard for the degree of Doctor of Philosophy in Education presented on September 18, 1987.

Title: An Analysis of Visual Discriminatory Skill of Baseball Players during the First 200 Milliseconds of a Pitch.

Redacted for Privacy

Abstract approved: ______________________________
Dr. Michael Maksud

The primary goal of the study was to determine if and how baseball players discriminate the rotational direction of an approaching pitch during the first 200 milliseconds of the flight of the ball. In addition, college-level baseball coaches were surveyed to assess the level of agreement between coaches relative to what are the most useful cues in batting. Pitches thrown in six professional baseball games were also analyzed to determine the frequency of different types of pitches, and to measure how successful professional batters are in hitting the ball.

Sixty subjects viewed film of pitches and recorded whether the pitch was thrown with overspin or underspin. The independent variables were direction of rotation, viewing time, seam type, and pitching agent.

Thirty college-level baseball coaches were surveyed to establish their opinion's on the importance of the different perceptual cues available to a batter in making a

swing decision. First, the coaches rated the usefulness of cues in pitch identification during the early flight of the ball. Second, they rated which cues are most useful in making a swing decision. Finally, they rated the relative importance of perceptual versus conceptual cues in batting.

The following results were noted: (1) the baseball group could discriminate the rotational direction of a pitch within the first 200 milliseconds of the flight of the ball; (2) the baseball group used information detected from the seams of the ball to discriminate between pitches; (3) the baseball coaches were divided on which cues are most useful for discriminating between pitches during the early flight of the ball; (4) the coaches agreed that the single most important factor in making a swing decision is location; and (5) the coaches were divided on whether perceptual or conceptual information is most important in batting.

It was recommended that coaches, teachers, and instructors should teach their players to use rotational information to help them discriminate between pitches. Additionally, baseball players should understand the basis of ball dynamics in order to understand how rotation affects the flight of the ball.

An Analysis of Visual Discriminatory Skill of Baseball Players During the First 200 Milliseconds of a Pitch

by

Randy Hyllegard

A THESIS

submitted to

Oregon State University

In partial fulfillment of
the requirement for the
degree of

Doctor of Philosophy

Completed September 18, 1987

Commencement June 1988

APPROVED:

Redacted for Privacy

Professor of Physical Education in charge of major

Redacted for Privacy

Chair of Department of Physical Education

Redacted for Privacy

Dean of School of Education

Redacted for Privacy

Dean of Graduate School

Date thesis is presented September, 18 1987

Acknowledgements

Most importantly, I would thank my parents, parents in-law, and family for their never wavering support of my pursuits. They provide my greatest source of motivation and my main goal is to please them.

I would also like to thank my committee for their time and support of my education. In particular I would thank Dean Michael Maksud for his guidance, and Dr. Carol Saslow for her endless patience, willingness to help, and consistently good advice. I also thank the Department of Physical Education, and it's members for their support and encouragement.

Finally, last but not least, I would also thank the friends of mine who helped in innumerable ways; Donna and Mike, Karen, Dave, Sandy, and Sandy.

'I walk home, thinking of another place, of seemingly long endless summers and the shade of different kinds of trees; and then of winters when the branches of the trees were bare, so bare that, recalling them now, it seems inconceivable to me that I looked at them and did not think of the summer just gone, and the spring soon to come, as illusions, as dreams, never fulfilled, never to be fulfilled.'

- Paul Scott -

'As early as the middle of Chapter One he had discovered that there is a lot more to this writing business than the casual observer would suppose. Dante could have told him, and so could Juvenal, that it does not come easy. Blood, they would have said, is demanded of the man who sets pen to paper, also sweat and tears.'

- P.G. Wodehouse -

TABLE OF CONTENTS

CHAPTER I	PAGE
INTRODUCTION	1
Statement of the Problem	6
Need for the Study	7
Hypotheses	8
Delimitations of the Study	9
Limitation of the Study	9
Terms	10
CHAPTER II	
REVIEW OF LITERATURE	11
Authoritative Advice about Batting	11
Visual Research Directly Related to Baseball	16
Visual Tracking of a Baseball	22
Visual Reaction Time for Correction of Quick Movements	28
Short Time Frame Perception	32
The Dynamics of a Baseball	38
Movement Correction	47
Batting as a Conceptual vs a Perceptual Skill	50
Batting Success	54
Summary	55
CHAPTER III	
METHODS AND PROCEDURES	56
Subjects	56
Apparatus	57
Filming	58
Design	60
Procedures	61
Survey of College Baseball Coaches	62
Analysis of Pitches Thrown in Professional Baseball	64

CHAPTER IV

RESULTS 65

Experimental Results 66

Survey Results 90

Observational Results 101

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS 104A

Summary of the Study 107

Summary of the Findings 108

Conclusions 113

Implications 117

Recommendations 118

REFERENCES 122

APPENDIX A. Baseball Coaches Survey 131

APPENDIX B. Coach's Comments 133

APPENDIX C. Schools Surveyed 135

APPENDIX D. Analysis of Survey Question # 1 136

APPENDIX E. Analaysis of Survey Question # 2 137

APPENDIX F. Analysis of Perceptual versus Conceptual Aspects of Batting 139

APPENDIX G. Analysis of Pitches 140

APPENDIX H. Subject Instructions 141

APPENDIX I. Table of Subjects 142

APPENDIX J. Subject Information Form 143

APPENDIX K. Vision Screening Form 144

LIST OF FIGURES

Figure		Page
1.	Two proposed basic strategies that baseball players may employ in order to track the flight of the ball to the plate.	26
2.	Treisman's Feature-Integration Model.	36
3.	The influence of rotation on the flight of a ball.	44
4.	Flight trajectory of a curveball as viewed from an angle.	45
5.	Flight trajectory of a curveball as viewed from the batter's perspective.	46
6.	Batting averages and standard deviation in professional baseball from 1910 through 1984.	54
7.	Diagram of the McAlexander Fieldhouse batting cage and position of equipment for the filming of the trials.	59
8.	Baseball players percent of correct responses to pitches in the 200 msec and full flight time frames.	69
9.	Baseball players percent of correct responses to pitches in the three ball conditions.	72
10.	Non-baseball players percent of correct responses to pitches in the 200 msec and full flight time frames.	76

11. Non-baseball players percent of correct responses to pitches in the three ball conditions. 79
12. Non-baseball players percent of correct responses to pitches thrown with overspin or underspin. 81
13. Baseball versus non-baseball in the 200 msec and full flight time frames 85
14. Baseball versus non-baseball in the three seam conditions. 87
15. Baseball versus non-baseball in the pitching agent trials. 88
16. Baseball versus non-baseball in the direction of rotation trials. 90
17. Mean ranking for the responses to the items in survey question # 1. 93
18. Bar graph of mean rankings for survey question # 2. 97
19. Mean score of each coach surveyed to the perceptual and conceptual items in question # 2. 100
20. An analysis of pitches for 6 six professional baseball games. 103
21. An analysis of pitches that batters attempted to hit. 104

LIST OF TABLES

Table		Page
1.	Baseball specifications.	58
2.	Baseball players percent correct responses to trials in the 200 msec versus full flight frame time.	67
3.	Baseball players percent correct response to trials in the 200 msec and full flight time frame when thrown by the pitcher.	67
4.	Baseball players percent correct responses to trials in the 200 msec versus full flight times frames when thrown by the pitching machine.	68
5.	Two-way ANOVA between the pitching agents and direction of rotation for the baseball group.	70
6.	One-way ANOVA between the three seam conditions for the baseball group combining pitcher and machine thrown trials.	71
7.	Bonferroni Multiple Comparison test between the percent of correct responses in the three seam conditions.	72
8.	Two-way ANOVA between the viewing time versus the seam conditions for the baseball group.	73
9.	Two-way ANOVA between the rotation versus the seam conditions for the baseball group.	73
10.	Non-baseball players percent correct responses in the 200 msec and full flighttime frames.	75

10. Non-baseball players percent correct responses to pitches in the 200 msec and full flight time frames. 76
11. One-way ANOVA between the three seam conditions for the non-baseball group. 78
12. Two-way ANOVA between the pitching agent versus the time for the non-baseball group. 80
13. Two-way ANOVA between the pitching agent versus the direction of rotation for the non-baseball group. 80
14. Non-baseball players percent correct response to trials thrown with overspin versus underspin. 82
15. Non-baseball players percent correct response to trials thrown with overspin versus underspin by the pitcher. 82
16. Non-baseball players percent correct response to overspin versus underspin trials by the pitching machine. 83
17. Two-way ANOVA between the subject groups and the viewing time. 84
18. Two-way ANOVA between subject groups by seam conditions. 86
19. Two-way ANOVA between subject groups by pitching agents. 88
20. Two-way ANOVA between subject group by rotation. 89

21. Responses by percentage to survey question # 1. 91
22. Kruskal-Wallis test on survey question # 1. 92
23. Response by percentage to survey question # 2. 95
24. Kruskal-Wallis test on survey question # 2. 96
25. Rank ordering for responses for survey questions 1 and 2. 98
26. Wilcoxon signed-rank test between perceptual and conceptual factors. 99
27. Summary of pitches for six major league baseball games. 102

An Analysis of Visual Discriminatory Skill of Baseball Players During the First 200 Milliseconds of a Pitch

CHAPTER I

INTRODUCTION

Much of what is thought of as sound coaching advice in sports and athletics is opinion or wisdom built up over years of simple observation. Some common examples include; From baseball, watch the bat hit the ball. From tennis, snap your wrist at the top when serving. And from golf, keep your hands in front of the face of the club. Although most common advice is probably accurate and useful, few of these opinions have been treated experimentally in order to determine if indeed the performer is actually able to make the necessary sensory discriminations or motor responses.

One difficulty with relying on experience is that the visual system is susceptible to phenomenon which are actually illusions (Attneave,1971). Two examples from baseball are the "rising fastball," and the perception that a curve-ball breaks as if "it were falling off the edge of a table" (Allman,1982). The illusion of a rising fastball is due to the aerodynamic lift produced when a ball rotates in the opposite direction of its line of flight. This type spin is called underspin, and is the spin characteristic of a pitch thrown as a fastball. However, the impression that the ball actually rises, that is, gains altitude during its trip to the plate, is an illusion. The aerodynamic lift of a rotating baseball is not sufficient to produce the necessary lift to overcome gravity. (Selin,1952 ; Briggs,1959). Selin (1952) points this out:

> The action of the forces that resulted from the clockwise rotation of the pitch apparently caused the fastball to appear to the batter to hop or rise as it approached the plate. During its flight the ball fell toward the ground, but it did not fall as rapidly as the batter expected it to fall; and thus was created, on the part of the batter, the illusion that the ball rose or hopped during the latter part of its flight.

The sensation that a curveball breaks sharply and suddenly is an illusion that occurs because of the batter's perspective. A curveball as viewed from the side, follows a gradually curving path. If given the right conditions, i.e. if the earth wasn't in the way and there were no gravity, the curving force on the ball would eventually produce a perfect circle (Watts, 1975). But when viewed as a batter sees it, in line with the pitcher, the ball appears to break sharply. Allman (1982) describes the effect:

> The curving force also results in what appears to be a movement that is greater in the second half of the pitch than the first. It occurs because the hitter is standing near the circle formed by the curving ball. Think of a train traveling at a constant speed on a circular track. If a viewer stands at the center of the circle, the train appears to be moving at a constant rate. If the viewer stands near the circle however, the train first appears to be traveling in a straight line as it comes towards him and then seems to move sideways as it passes him and heads downward. This illusion is what causes the apparent break in a curve ball.

Even though it is known, from the batters perspective, that the perception of a sharply breaking curve ball is a visual illusion, the illusion is irresistible nevertheless. The visual system is subject to a wide range of illusions whether we cognitively understand the basis of the illusion or not. The Necker Cube, the Muller-Lyer illusion, Mach Bands, and perspective are all examples of illusions that can be explained conceptually, but cannot be resisted perceptually. Explanations of illusions range from cultural influences in the case of the Necker Cube, (Deregowski,1968) to the neurophysiological makeup of the retina and associated cells in the eye to explain Mach

Bands, (Cornsweet,1970) and laws of perspective geometry to explain perspective (Johannson,1975).

It is commonly accepted that baseball players can read the rotation of the ball over the full flight of a pitch. Or at least, they infer the type of rotation from the movement of the ball. What is not known, is if and how batters read the spin of the ball during the first 200 msec of the pitch. If the perception, from the batter's point of view, is that a curveball breaks suddenly and sharply during the last portion of the flight, then a ball with either over or underspin would be virtually indistinguishable during the early flight. The only differences, disregarding the pitcher, between a curveball and a fastball would be the velocity, trajectory and the direction of rotation.

The perceptual situation that the batter faces is complex: The batter must determine the initial velocity of the pitch in order to time the arrival of the ball, extrapolate from the initial location of the ball its probable location when it reaches the hitting zone, and finally must initiate the swing of the bat at the precise moment to meet the approaching ball (Rosenbaum, 1975). Add to these the task of detecting the direction of rotation of the ball to other information needed and you have a complex case of motion prediction and motor skill execution. The task difficulty is extenuated by the time available within which the batter must function. The complete trip from the pitcher's release point to the hitting zone takes from approximately 380 milliseconds (msec) at 95 miles-per-hour (mph) to 460 msec at 80 mph. However, the important factor is that the batter does not have the entire time frame to view the pitch before making a swing decision. Owing to the time required to move the bat from the ready position to the hitting zone, and the decision time needed to commit to a swing, the batter is left with approximately 200 msec of viewing time within which the swing decision must be made (Slater-Hammel,1950 ; Hubbard & Sang, 1954 ; Sage, 1984).

The observation that batters can, and should read the direction of rotation of an approaching pitch is a subject where opinions are divided. Some of the greatest hitters and batting instructors in baseball history, such as Pete Rose, Rod Carew, Charley Lau and Ted Williams differ on whether the batter should, or can discriminate the rotational direction of the ball (Carew, 1986 ; Lau, 1984 & 1984a ; Rose, 1985 ; Williams, 1982). Rose and Carew state that they could in fact see the rotation of the ball. Lau and Williams are noncommittal on the subject; they do not deny that players can use rotational information, nor do they support that they can.

The reason given why a batter should attempt to identify the rotational direction of the ball is to provide them with early information on what type of pitch has been thrown. If indeed, from the batter's perspective, a curveball appears to break only when near the batter, then it would be to the batters advantage to read the spin early in the flight of the ball.

Perceptual psychology would consider batting as a discrimination task. From a cognitive psychology point of view, batting is an attentional task. The attentional question would be; What are the limits on the amount of information that the batter can use? The perceptual question would be; What are the limits on the discriminations that the batter can make?

Direct research into the perceptual aspects of batting in baseball is limited (Bahill, 1984 ; Burroughs, 1984 ; Hubbard & Sang,1954). However, research into vision is extremely extensive. Vision has historically been the most intensely studied sensory system (Marrocco,1986). Application of certain areas of visual and perceptual research can be applied to the batting situation and will be used in this study as the research base.

Statement of the Problem

The question to be investigated is; Whether college-level baseball players can accurately discriminate the rotational direction of a pitch during the first 200 milliseconds of the flight of the ball toward the batter. If the baseball players were found to accurately discriminate between pitches then, an analysis of the cues available to them will attempt to determine on what basis they discriminate between pitches. The question was investigated by experimentally varying the cues that are available to the batter in discriminating between pitches. These cues include pitching agent, direction of ball rotation, viewing time, and the seams of the ball. In addition to the experimental phase of the study, a survey of college-level baseball coaches was taken to determine if the experimental results of the study coincided with the coaches opinions regarding the usefulness of the various cues in batting. Lastly, pitches thrown in six professional baseball games were charted to determine first, the ratio of overspin pitches to underspin pitches at that level, and second, to determine how successful professional batters are in making contact with the ball when they attempt to hit it.

Need for the Study

The purpose of this investigation is to provide experimentally based information which may be adopted by teachers, coaches, and baseball professionals on how baseball players discriminate between pitches. If it is found that batters cannot discriminate rotation well, then it may be advisable for batting instructors to coach the players to focus on other cues. If indeed batters can discriminate rotation accurately, that would reinforce the basic concept and could be interpreted as a recommendation for specific training in order to enhance perceptual skills in batting. In any case, the evidence, in either direction, if conclusive, would provide concrete information on which course to follow. This may help to eliminate some confusion and uncertainty as to the advisability of coaching players to try to read the spin.

Research Hypotheses

The following hypotheses were tested in this study:

Ho 1: There will be no difference in the percent of correct responses during the full flight time frame versus the 200 msec time frame for both groups.

Ho 2: There will be no difference in the percent of correct responses between the three types of seam conditions for both groups.

Ho 3: There will be no difference in the percent of correct responses between the two pitching agent conditions for both groups.

Ho 4: There will be no difference in the percent of correct responses between the two directions of rotation for both groups.

Ho 5: The baseball group and the non-baseball group will be equally accurate in discriminating between pitches.

Delimitations of the Study

The study was delimited to the following parameters:

1. To college-level baseball players.
2. To males.
3. To college-level baseball coaches.

Limitations of the Study

The study was subject to the following limitations:

1. The use of film for the presentation has the disadvantage of reducing a three dimensional activity to two dimensions. The advantage of this method was that all subjects viewed identical pitches eliminating the inevitable variability that would exist if each subject were to view individual pitches.

2. The film used was black and white. Differences in the results due to the use of color film is not known.

3. The survey respondents may not have completed the questionnaire personally.

4. The samples may not be representative of the population of which they were a part.

Terms

1. Saccadic eye movements : rapid movements of the eye from one fixation point to the next.

2. Smooth pursuit eye movements : movements of the eye when tracking a moving object against a stationary background.

3. Vergence eye movements : movements of the eye when the angle between the lines of sight changes.

4. Vestibulo-occular eye movements : movements of the eye when the head or the body is also moving.

5. Overspin : a forward rotation of a ball.

6. Underspin : a backward rotation of a ball.

7. ANOVA : analysis of variance.

8. Bonferroni Multiple Comparisons Procedure : a multiple contrast procedure which is applicable to pairwise comparisons of means. It is an appropriate ad hoc procedure in situations where null hypotheses have been rejected in analysis of variance testing.

9. μ : 'mu', the population mean.

CHAPTER II

REVIEW OF THE RELATED LITERATURE

Authoritative Advice About Batting

Much of the conventional wisdom in sports and athletics is handed down from those individuals who have obtained the greatest success as participants in the sport. These individuals often become media figures, coaches, write instructional books, and are generally regarded as authorities on their particular sport. Examples from other sports include Jack Krammer on tennis, or Jack Nicklaus on golf. Many of these individuals benefited from the best coaching available during their formative years along with being gifted with the prerequisite attributes that combine to produce an elite performer. However, most of what is considered sound coaching and teaching advice has not been put to experimental verification. That is not to say that the authority figures are wrong. Indeed, they are probably correct in their opinions more often than not; however that does not preclude the advisability of experimental investigations of popular conceptions. At best, the results would simply confirm what they have been saying all along. At worst, the results may provide evidence to question that which seems intuitively correct but is experimentally questionable. Either result would prove experimentally questionable. Either result would prove beneficial to the overall understanding of the situation. Only ambiguous results would cloud the issue, which certainly are not beyond the realm of possibilities.

Recently published baseball authorities are divided as to whether baseball players can in fact read the rotation of the ball and, therefore if players should attempt to do so. Pete Rose (Rose,1985) strongly supports the advisability of reading the spin:

> When I'm at bat I can tell as soon as the ball leaves the pitchers hand what it is going to do just by the way the ball is spinning. You must train yourself to concentrate on the ball so hard that you can literally see the rotation. You don't have much time. You have to try to pick up the ball just as soon as you can. (pg.36)

Unfortunately, Rose does not provide specific advice on how to train a batter to read the spin, other than "concentrate on the ball."

The well respected batting coach, Charley Lau emphasizes the importance of watching the ball very carefully, but he makes no mention of the necessity of reading the rotation of the ball. Lau describes what he calls "the Ten Absolutes of Good Hitting" (Lau, 1984 ; Lau, 1984a) including, "putting your head down when you swing"(pg.95). Of the ten absolutes, Lau considers this one to be the most important. The reason for this is that all of the other aspects of batting he talks about, e.g., balance, weight shift, lack of tension, are designed in his system to help the batter see the ball. By putting the head down he means that the batter should keep his head as still as possible when viewing the ball in order to maintain as accurate a perception as possible:

> Allowing you to watch the ball is the second and more obvious purpose of putting your head down. If your head is any place else but down, aimed directly at the spot where the ball and bat will make contact, you're not going to see the ball, and you're not going to hit it. (pg.95)

Lau's advice for determining what type of pitch to expect is based on a conceptual schema of the particular pitcher. Lau maintains that virtually all pitchers throw in patterns, and if the batter can learn which type of pitch a certain pitcher will throw in certain situations, he will be better off than attempting to evaluate each pitch based strictly on a sensory impression of the flight characteristics of each pitch.

Recently retired, Rod Carew was one of the most successful batters in baseball history. (His lifetime batting average, expressed as a Z-score compared to the average of all the other players in the league of the same era, is a phenomenal 9.25) Carew supports the notion of reading the spin of the ball, and also describes how a batter may be trained to accomplish this skill (Carew,1986). Carew first describes where the batter should look, i.e., at the pitchers release point and not at the pitcher himself. Second, he describes when to look, which is just when the pitcher's hand leaves the glove during the wind-up. Carew points out that the task of reading the spin is not an easy one:

> The prospect of picking out rotation on a baseball from a distance of some 55 feet, traveling at a speed approaching 90 mph is enough to boggle the mind. And well it should. If that isn't tough enough, few ball players, particularly at the lower levels, know what to look for, even if they are looking. They don't know how a certain pitch rotates when thrown, say, across the seams, or how a curve or slide spins. Reading the spin is a delicate science. (pg. 51)

Carew describes in detail the rotational characteristics of each of the five main pitches thrown in the major leagues and just what the batter should look for to read spin. He also explains the relationship between certain basic types of pitching mechanics to certain pitches and why one pitch is likely to be thrown with one type of motion as opposed to another. Carew also describes the importance of the conceptual side of batting, as Lau does, and concurs that pitchers do pitch in patterns. At the professional level, however, pitchers often have a wide repertoire of pitches that they may thrown in any situation. Therefore, Carew feels it's important not to try and out-guess pitchers too much. But rather, try to respond to each pitch individually based on what you can discriminate about the pitch, and not on what you "expect" the pitcher to throw in a given situation.

Ted Williams is considered the second greatest hitter in major league history (Thorn & Palmer,1985). His lifetime batting average was nearly 20 percentage points higher than Rod Carew's. Of course they played in different eras, but the significance of that is debatable. Williams (1982) does not either support or reject the possibility of reading the spin of the ball. He suggests that fine visual acuity is an advantage, but rejects the popular notion that he could see the ball meet the bat. Williams' advice to hitting consists of three principles: "get a good ball to hit, use proper thinking, and be quick with the bat" (pg. 24). This advice is rather abstract. The main emphasis is to only attempt to hit pitches that are within a well defined and restricted area of the strike zone. Selectivity is his basic key to batting, with no mention made of rotation or any other flight characteristic of the ball.

Visual Research Directly Related to Baseball

Research into perceptual aspects of batting in baseball is limited to a small number of studies (Shank & Haywood,1987 ; Burroughs, 1984 ; Bahill, 1981 ; Bahill & LaRitz, 1983 ; LaRitz, Hall & Bahill, 1983 ; Bahill, 1984 ; Hubbard, 1954 ; Slater-Hammel,1950 ; Winograd,1942). One reason for this is that field research into vision can be difficult. Eye movements, comparatively speaking, are very small, of short duration between movements, and can be extremely quick. Eye measurements have been made using two primary methods, noncontact and contact (Robinson,1981). Noncontact methods include photography, electrooculogram, corneal reflection, differential limbus reflection, and double-image tracking devices. Electrooculograms are based on natural differential positive potential across the cornea. Skin electrodes placed at the corner of the eye react to eye movements by becoming more or less positive depending on which direction the eye is pointing. The problem with the electrooculogram is that the electrodes pick up noise from contractions of the face muscles. Corneal potentials also vary depending on the state of dark adaptation (Robinson,1981).

Differential limbus reflection (along with electrooculograms) was the method used by Bahill (1984) in investigating visual movements in baseball players. Differential limbus reflection uses light reflected off the iris-sclera border which is in turn detected by photodiodes positioned at each corner of the eye. When the eye moves laterally the detector in that direction receives less reflected light because the relatively dark iris is exposed. The opposite diode receives more reflected light off the white conjunctiva tissue surrounding the iris.

Contact methods include optical levers and magnetic search coils. Neither method would be practical for field work in baseball as special contact lens are worn which impair normal vision. (Robinson,1981)

The earliest study directly investigating visual tracking of a baseball was by Hubbard & Seng (1954). They ingeniously filmed baseball batters via a complicated system of mirrors to record both the batters body and eye movements while hitting actual pitches. As best as they could determine, batters tracked the approaching ball with smooth pursuit eye movements. It appeared that the batters were able to track the ball accurately to about five feet from home plate. Hubbard & Seng concluded that once the ball was closer then about five feet to the plate, the visual tracking system was no longer able to track the ball at the needed angular velocities. They hypothesized that either the batter could no longer track the ball at those velocities or, any information available at that point would be of no use to the batter anyway.

Hubbard & Seng realized however, that there was a contradiction in what they found and what could be expected based on knowledge available at the time regarding the ability of the visual system to track objects. They recognized that the angular velocity of a ball as it approaches the plate is well in excess of 400° per second depending on the ball velocity. They also knew that smooth pursuit eye movements were relatively slow, although the upper limit was not known at the time. Therefore, they were unsure how it was that the visual system could track the ball without saccadic eye movements since the angular velocity of the ball well exceeded what they could only suppose was the maximum tracking rate of the smooth pursuit system.

Bahill (1981, 1983, 1984) was able to answer the questions posed by Hubbard & Sang. Bahill took the question back into the laboratory where subjects tracked a ball pulled along a string and with their eye movements directly monitored with infrared photodetectors. Bahill's results essentially confirmed Hubbard & Sang's results that batters track the ball primarily with smooth pursuit eye movements. However, he also found in some instances batters used an anticipatory saccadic eye movement to jump ahead of the ball to an expected contact point.

Bahill tested one professional baseball player and found he tracked the ball more accurately when standing close to the plate than nonbaseball players. The professional player used a combination of smooth pursuit and head movement which resulted in a 150°/sec smooth pursuit capacity. Nonbaseball players were able to track with smooth pursuit eye movements up to 70° per second. The velocity of the ball for the trials was 60,67, and 70 mph. Bahill confirmed Hubbard & Sang's conclusion that at these velocities batters effectively lose tracking capacity when the ball is about 5 feet from the plate. At higher velocities the batters would presumably lose the ball further from the plate. A problem with Bahill's study was that the subjects tracked a ball that moved in a very predictable straight line, unlike the flight of a real baseball. This compromise had to be made in order to make accurate measurements of eye movements in relation to the movement of the ball. It is not known if the visual system tracks the ball differently in an actual baseball situation.

The study that most closely models the present study is Burroughs (1984). Burroughs purpose was to determine if college level baseball players could improve their skill in extrapolating the final location of a pitch in the hitting zone based on information about the first 18 to 22 feet of the pitch. Burroughs used a combination of film and a visual interrupt system to both train and measure batters skill in making final location predictions. The first 14 to 22 feet of the pitch corresponded to time frames of 170 or 190 msec depending on the velocity of the ball. The time frame was always held constant, therefore batters would see more or less of the pitch depending on the particular velocity.

The aspect of Burroughs' experiment that resembles the present study is that batters were also tested for their skill in identifying whether a curveball or a fastball had been thrown as viewed on film. Results indicated that batters averaged 90% accuracy in identifying whether a pitch was a curveball or a fastball when viewing the first 170 msec of the flight of the ball. What cannot be determined by the results of this experiment was how batters were able to discriminate between a curveball and a fastball. The possible cues available to the batters were; the pitchers motion and release, rotation, trajectory, and velocity of the ball. Since none of these factors were experimentally varied, it cannot be established how the batters were able to accomplish the task. Also, only baseball players were tested, so there is no way of determining if the identification accuracy was a trainable skill, or simply an easy perceptual task.

This result was actually secondary to the main goal of the experiment, which was to determine how well batters could estimate final location based on initial location. Batters averaged 40 to 50% accuracy based on the first 190 msec of the flight, considerably less than the 90% accuracy discriminating a curveball from a fastball.

The most recent study on baseball investigated the correlation between reaction time (simple and choice) and movement time to batting and slugging average (Nielsen & McGown,1985). The goal was to determine if reaction and movement time could be used as predictors of batting and slugging average. The results indicated very little correlation between these factors ($r = -.16$ to $.14$). The interpretation given was that it is not possible to predict athletic success by determining a general information processing ability or by measuring choice reaction time.

Visual Tracking of a Baseball

Of the five oculomotor systems that the visual system uses to locate or keep objects fixated on the fovea, saccadic, smooth pursuit, vergence, vestibulo-oculomotor, and optokinetic, three have been found to be used in the baseball situation: Smooth pursuit, saccadic, and vestibulo-oculomotor tracking of the ball have been observed in baseball players. (Bahill 1984, ; Hubbard & Seng, 1954) Neither Bahill (1981, 1983, 1984) nor Hubbard & Seng (1954) found any evidence that the vergence or optokinetic system is used to track an approaching pitch. Intuitively, it would seem that the vergence system would be involved to some degree since this is the system used to track targets as they move toward or away from the observer. Bahill concluded that vergence is not needed to track an object between 60 and 6 feet, which are the distances that a batter sees the ball from (1984, pg. 252). (Bahill based this statement on a normal pitch that the batter would swing at with arms extended. There are instances when the ball is much closer to the eyes than six feet, as when the ball is traveling directly at the batter's head. In those situations however, the batter is not attempting to hit the ball, but rather, attempting to get out of the way of the ball.

The vestibulo-oculomotor reflex is mediated through the vestibular apparatus of the inner ear and functions to stabilize the eye while the head or body moves. Both Bahill and Hubbard & Seng found that batters used a small amount of head movement to track the ball. Bahill measured from 10° to 20° of head movement during the later portion of the flight of the ball. Hubbard & Seng were not able to quantify the degree of head movement with their method, but the movement of the batters heads was easily observable from their filmed observations.

Hubbard & Seng expressed doubt that batters utilized saccadic eye movements while tracking the ball. They found the eye movements of the batters to be smooth throughout the entire flight of the ball, indicating smooth pursuit eye movements. They state that since saccadic eye movements normally last 200 msec between fixations, saccadic tracking would be a poor strategy because a ball, with a velocity of 90 mph, would travel 29 feet between one fixation and the next (pg.55). In such case, the batter would lose foveal tracking of the ball for over one-half of the flight of the ball.

Bahill, using more sophisticated methods, found that batters, is some instances, used an anticipatory saccadic eye movement in order to move the fixation point ahead of the ball to a point in space where the batter calculated the contact would be(1984,pg.251). In order to do this, the batter would have to use early velocity information to extrapolate the probable arrival time of the ball in the hitting zone. Once the batter saccades to the contact point, foveal vision of the ball would be lost until the ball arrives in the hitting zone. The practicality of this strategy in batting does seems questionable. If the batter has committed to a swing, it is extremely doubtful that a corrective movement of the swing could be made during the very short period of time in which the ball and bat are within a few feet of each other. (Osman, Kornblum & Meyer, 1986 ; Cooke & Diggles, 1984) If it is important for the batter to see the bat hit the ball, as is often suggested, the saccadic method would be the tracking strategy that would most likely allow the batter to do so.

Both Bahill and Hubbard & Seng agreed that smooth pursuit eye movements are the primary means by which the visual system tracks the ball in the batting situation. The smooth pursuit system is a linear and continuous system that requires a moving target fixated on or near the fovea to function (Fuchs, 1971). The smooth pursuit system is thought to have evolved in conjunction with the fovea and, overlapping vision for stereopsis. Interestingly, the smooth pursuit is not under voluntary control in humans. We cannot elect to use smooth pursuit eye movements when there is nothing moving in the environment. However, we can select which target to track in a field of moving targets (Robinson,1981). When the batter uses a combination of head and eye movement the vestibulo-oculomotor reflex would take over and produce an equal but opposite pursuit movement in the opposite direction to keep the ball on the fovea (Bizzi,1981).

At the time of Bahill's study (1984), it was thought that the maximum tracking velocity of the smooth pursuit system was up to 70°/sec (Schalen,1980). More recent evidence has shown a capacity to track accurately up to 90°/sec (Meyer, Lasker, & Robinson, 1985). One of Bahill' subjects, a professional baseball player was able to track a ball with less than 2° error to within 9 feet of the plate with smooth pursuit movements to 120°/sec. Combined with a 30°/sec head movement, he was able to achieve a 150°/sec total tracking capacity (1984, p.251); a result that Bahill acknowledged was faster than anything previously reported in the literature.

Based on the finding of the above studies it may be proposed that batter's usually use one of two basic strategies in order to track the flight of the baseball.

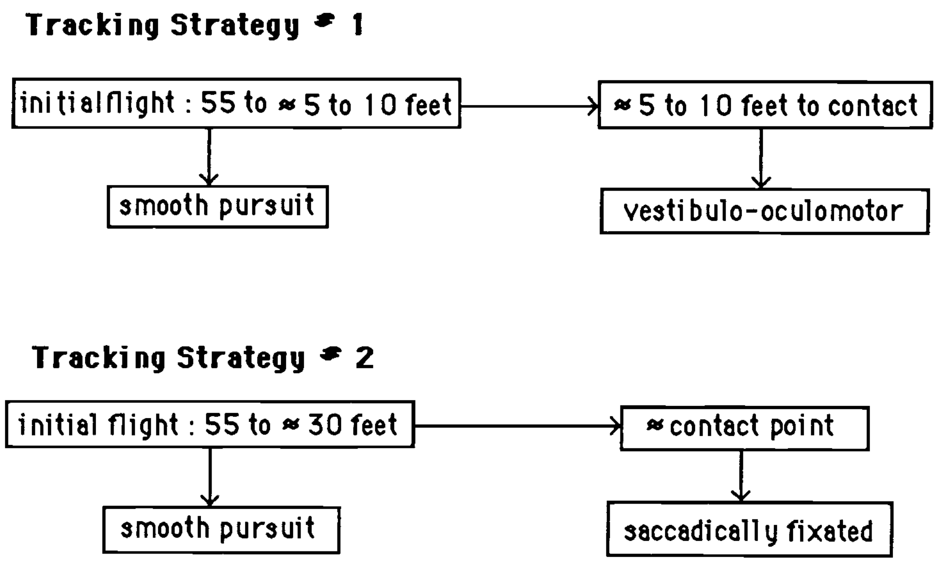

Figure 1. Two proposed basic strategies that baseball players may employ in order to track the flight of the ball to the plate. In strategy # 1, the batter tracks the ball with smooth pursuit eye movements until the ball is approximately 5 to 10 feet from the plate, then the vestibulo-oculomotor reflex takes over when the batter begins to turn his head. In strategy # 2, the batter tracks the ball with smooth pursuit eye movements until the ball is approximately 30 feet from the plate, then makes an anticipatory saccadic eye movement to a spot calculated where the ball and bat will probably meet.

A potential problem with method # 2, the saccadic method, is that large amplitude saccadic eye movements tend to consistently underestimate the distance to the target, and a second corrective saccade is needed in the same direction as the original (Bizzi,1981). In the baseball situation however, the batter does not make the first saccade to a specific target as such. Rather, the movement is made to a point in space where the batter anticipates where the ball and bat will meet. If the predicted contact point is incorrect, the batter would not have sufficient time to make a corrective saccade.

A problem with tracking method # 1, is that smooth pursuit velocity is known to consistently lag behind target velocity from 10 to 30% (Schalen,1980 ; Meyer et al, 1985). These smooth pursuit studies used targets moving at right angles to the subject. The baseball situation is different in that the target moves towards the batter. Bahill (1984) found that the professional baseball player was able to keep the ball within 2° of the fovea until the ball was 5.5 feet from the plate. Because the amplitude of the eye movement in the batting situation is small, skilled batters seem to be able to track the ball accurately until the ball is within about five feet from the plate (Bahill,1984).

The visual system is able to sense and locate moving objects with specific motion sensitive neural networks. The sensitivity of the visual system to movement is mediated at the retinal level by Y-type ganglion cells. (Van Essen, 1979) Axons from Y-type ganglion cells form the Y-magnocellular pathway which leads to the occipital cortex (Brodmann's areas 17 & 18) through the lateral geniculate nucleus. Brodmann's area 18, V5 located in the middle temporal area in the superior temporal sulcus at the rostal border of the occipital lobe is the motion sensitive area of the visual system thought to control smooth pursuit eye movments (Van Essen, 1979 ; Marrocco, 1986). The Y-magnocellular pathway, which runs in parallel with the X-type parvocellular pathway, is the pathway for detail, form and color information (Van Essen,1979).

While smooth pursuit eye movements are mediated through the occipital cortex, saccadic eye movements are mediated primarily through the superior colliculus of the mesencephalon (Kandel,1985). Target selection however, in a complex field, is controlled by higher brain centers and selection signals are sent to the superior colliculus which define visual activity within a certain field (Moltler & Wurtz, 1976)

Visual Reaction Time for the Correction of Quick Movements

The batting situation in baseball is interesting because of the time frames available to view the ball, to make a swing decision, and to execute the swing. The flight time of the ball ranges from approximately 380 msec for a 95 mph pitch to 460 msec for an 80 mph pitch. Batting reaction time has been reported at 206 msec, (Slater-Hammel,1950) which leaves the batter with viewing and decision times of approximately 180 to to 253 msec at these velocities. (These numbers are approximate because they do not take into account the differences in release point between pitchers and to what degree the ball slows due to air resistance on the way to the plate.) Craik (1947) concluded that humans are capable of ballistic movements at the maximum rate of one per .5 seconds. Ballistic movements are defined as movements initiated by vigorous agonist contraction, which are carried through by momentum, and terminated by either an obstacle or by reaching the end of maximum range of motion by the joints (Luttgens & Wells, 1982). A fully committed swing in baseball is defined as a ballistic movement. Even if a batter could respond ballistically faster than one movement per .5 second, the amount of time needed to correct a movement based on visual correction times would not provide the batter with enough correction time during the flight of the ball.

The time needed to correct a visually guided movement has been reported to be in the range of 190 to 260 msec after the initiation of the movement (Keele & Posner, 1968). More recently that estimate has been revised downward to somewhere between 100 and 150 msec (Zelaznik , Hawkins & Kisselburg,1983 ; Carlton, 1981 ; Smith & Bowen, 1981). Zelaznik et al (1983) replicated Keele and Posners' (1968) experiment to determine if Keele and Posner somewhat biased their results with their experimental design. Keele and Posner had subjects make movements to a target with half of the trials with the lights on through out the movement, and half with the lights going out at some point during the movement. Zelaznik et al felt that the lights out uncertainty might have slowed the responses to some degree. By eliminating the lights out uncertainty condition, Zelaznik et al found the subjects could decrease their correction times to approximately 100 msec.

In the batting situation, something between Keele and Posner's estimation and Zelaznik's result would be realistic. The batter isn't in a light variable situation as Keele and Posner's subjects were, but they have to make a more dynamic movement with more inertia involved than simple hand movements as in Zelaznik's study. In any case, once a batter has initiated a full ballistic swing it would be virtually impossible for the batter to make corrective movement based either on visual reaction time, or on ballistic correction time frames. This is why batters need to discriminate as much information as possible during the early flight of the ball. If a batter has initiated a swing, and then realizes he made a mistake, he will not be able to alter his swing in a meaningful way. Batters occasionally attempt to inhibit a swing shortly after it has been initiated, but when watched in slow motion, it is clear that it is very difficult for them to do so. Conversly, if a batter fails to initiate the swing in time, once that single opportunity has been missed there is not enough time remaining to initiate a new motor sequence.

How the visual system calculates the arrival of an approaching target is important to the timing of a swing. Two studies (McLeod,McLaughlin & Nimmo-Smith, 1985 ; Lee, 1980) concluded that velocity calculation is an automatic process based on retinal information. Lee (1980) noted that as an object approaches, its image expands on the retina. Thus, the time of arrival was given as the ratio of the size of the retinal image, to the rate at which the image is expanding.

McLeod et al (1985) proposed a learning model called"information encapsulation" which says that velocity calculation becomes an automatic process occurring at a subconscious level based on retinal stimulation. McLeod et al found that timing of objects was much more accurate for objects moving towards the subject than to an arbitrary point in space. Sixty-six percent of estimates fell within ± 5 msec of the correct value and 88% within ± 10 msec for an object moving toward the subject. For an object moving to an arbitrary point in space, 88% accuracy had a variablity of ± 60 msec and 66% accuracy had a variability of ± 30 msec. They concluded that with practice, certain processes can become "informational encapsulated" in that they function automatically while the performer attends to other features of the task. This basic concept of automatic processing is supported by Schneider and Shiffrin's (1977) and Shiffrin and Schneider's (1977) extensive research into the development of automatic processes.

Short Time Frame Perception

An important aspect of the current question is: how quickly can the visual system recognize features in a scene? If a batter has 200 msec of viewing time before a swing decision must be made, how much information can be processed in that time? Several researchers have investigated how accurately the visual system extracts information from brief displays.

Potter (1975) concluded that subjects could detect a specific visual pattern with greater than 70% accuracy with a 125 msec stimulus, and over 95% accuracy with a 167 msec stimulus. An interesting result of the study was that even though subjects could detect a target accurately, they were not able to recall what the other stimuli in the series were. Potter concluded that visual scenes are processed rapidly at an abstract level before being selected for further analysis at an attentional or memory level.

In a follow up study, (Potter,1976) it was concluded that preliminary identification of a complex scene can occur as quickly as 100 msec, although identification will not necessarily result in retention. An additional 300 msec of further processing was thought required to allow fuller analysis of the scene.

A more recent study, (Imada & Yodogawa, 1985) revised Potters' estimate down to 60-70 msec as the time required to initially extract a feature from a scene. They concluded that feature extraction is a parallel process (meaning 2 or more elementary features at the same time) so that the entire feature extraction process can be completed as quickly at 80-100 msec.

Intraub (1981) modified Potter's experiment to confirm the hypothesis that pictures are momentarily understood but immediately forgotten during rapid presentation. Intraub found that for rapid rates of presentation, 114, 172, and 258 msec, significantly more pictures were detected than remembered ($F(1,84)=64.0$, $p<.001$).

In a series of experiments, the ability to recognize inappropriate features in a scene during brief exposures was examined (Biederman, Mezzanotte & Rabinowitz, 1981 ; Bieberman, Teitelbaum & Mezzanotte, 1982). Subjects viewed complex scenes for either 100 or 150 msec. The task was to identify an object in the scene that violated the normal relational characteristics of the various objects. These violations included; Support,e.g. an object floating in space that shouldn't, interposition, e.g. when the background can be seen through a normally solid object, probability, e.g. an object that would not normally be present in that scene, position, e.g. an object that appears in a scene that is normal, but not in proper position, size, e.g. when an object is incorrectly sized for a scene. They found that improbable objects could be detected 75% of the time with a 150 msec presentation, but that there was no clear priority assigned to one violation over another (Biederman et al,1981). They concluded that subjects use a "frame" or "schema" that stores information about the composition or familiar scenes. Apparently, this frame is used to speed identification of objects in the scene. Normal objects are accepted, unusual objects are noted for further examination, time permitting.

Feature-integration theory (Treisman,1979 ; Treisman & Gelade,1980 ; Treisman & Schmidt 1982 ; Triesman,1986) proposes an explanation for how the visual system discriminates features of a scene at the preattentive level. Various features in a scene are discriminated early in visual processing, then selective attention integrates the features at an attentional level. Separable features include, closure, size contrast, tilt, curvature and line ends (Treisman & Galade,1980) luminance difference but not hue (Ranachandran & Gregory, 1978) and stereopsis (deWeert,1979).

Treisman (1986) proposed a visual processing model in which emergent features at the preattentional level are matched to a recognition network in memory for scene identification and updating shown in figure 2.

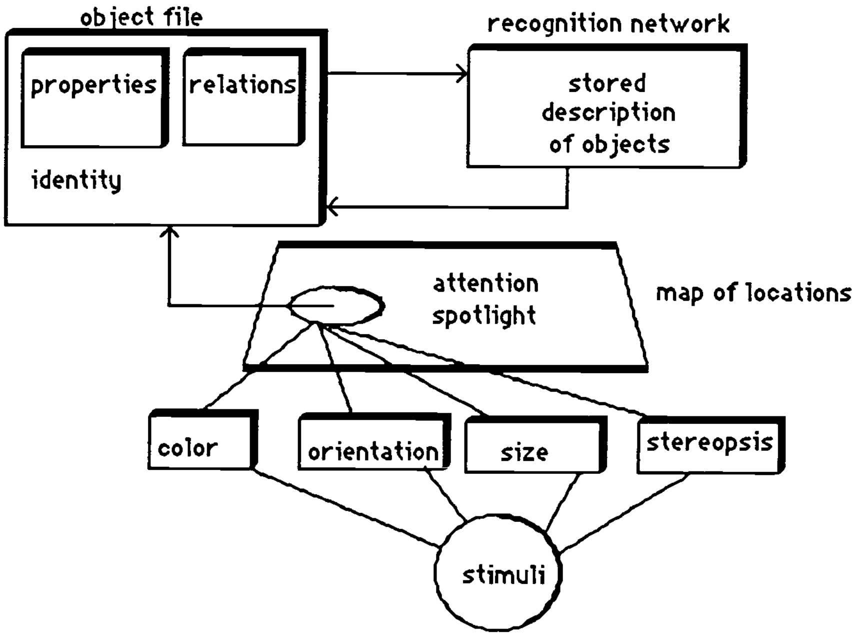

Figure 2.Feature-integration model (Treisman,1986). The early stages in visual processing encode simple properties of a scene into feature maps. Focused attention selects and integrates the particular features. Intergrated information is used to update current files and are compared to memory based descriptions.(adapted from Treisman,A. Features and Objects in Visual Processing, Scientific American,255,114-125.)

One possible explanation for how the visual system stores an image initially is that the rods in the retina function as a short term storage site (Sakitt,1975). The idea is that there is a rapidly decaying, short term visual store in the rods of an image, called an icon. It was suggested that the retinal icon can be used at higher levels for feature extraction. One difficulty with this is rods are saturated in normal daylight illumination levels, although the author maintains that saturation does not interfere with the icon process.

A discrepancy was noted between information extraction times which seem to be approximately 100 msec, and the normal latency between saccadic fixations which usually range from 200 to 400 msec (Salthouse, Ellis, Diener, & Somberg, 1981). Salthouse et al tested two theories on why there is a 100 to 300 msec time period between feature-extraction and the onset of the next fixation. The first theory proposed that the additional time was due to saccadic suppression between fixations. The additional time is needed to complete the scene analysis because the scene is suppressed just prior to the onset of a saccade and just at the finish of the saccade. The second theory was that it is not saccadic suppression, but rather higher level cognitive processing that was occurring during the 100 to 300 msec interval. The authors found no evidence of either pre or post eye movement saccadic suppression. They felt this was due to the fact that they used longer exposure and higher intensity stimuli than used in saccadic suppression studies.

They did support the notion that the discrepancy in feature-extraction time and eye movement time was due to additional cognitive processing during the later viewing time. They supported the cognitive processing view by showing subjects could detect increasing numbers of stimuli within the same time frame, but need additional time for comprehension of all the targets.

The Dynamics of a Baseball

The basic question of this study was how well can baseball players read the spin early in the flight of an approaching pitch. The question may be asked; Why would a batter be concerned with reading the spin of the ball? The answer is so that the batter can gain early information on what type of pitch has been thrown. Based on that early information, the batter should then be able to better predict the flight of the ball as it arrives in the hitting zone.

Skilled pitchers can effectively influence the flight of the ball depending of the type of spin that they impart to the ball. The pitcher's objective is to either induce the batter to swing at a pitch that will be out of the strike zone when it arrives, or to deceive the batter into thinking a pitch will be out of the strike zone, but actually ends up as a strike. In the former case, the pitcher initially directs the ball toward the strike zone, the batter commits to a swing, but due to the rotation of the ball, by the time it arrives in the hitting zone it cannot be hit effectively. In the latter case, the pitch is directed well out of the strike zone, typically directly at the batter. The tendency of the batter in that situation is, naturally, to bail-out of the batters box. If thrown well, the ball will then curve into the strike zone, leaving the batter unable to execute a swing. Effective breaking-ball pitchers are able to induce the batter to swing at a pitch that "breaks" downwards, the result being that the batter hits the top part of the ball producing a ground ball to the infield which is usually converted into an out.

Interestingly, there was a certain amount of popular controversy in the 1940s' and 50s' as to whether a curveball actually did curve, or if the sensation is an illusion. Titles of articles from popular magazines at the time illustrate the point: "Baseball's Curve Balls: Are they Optical Illusion?" Life,1941, "Camera and Science Settle the Old Rhubarb About Baseball's Curveball."

Life, 1953, "Curve is a Curve." New Yorker, 1949, and "The Hell it Don't Curve." American Mercury, 1953.

The first article addressing whether a baseball can indeed curve due to spin imparted to it by the pitcher was an 1886 Scientific American article (Chadwick, 1886). The article was in response to a challenge from the editor of a magazine called World, in which the editor expressed the opinion that a curveball is, "scientifically absurd:"

> The baseball enthusiasts claim for Getzein (a professional pitcher at the time, parentheses mine) that he is able to pitch a ball that will describe the arc of a circle on a horizontal plane before reaching the catcher, and that therein lies the secret of his marvelous pitching, which has done so much to secure victory to the Detroit Club. Scientifically, this theory is utterly absurd. The forces that act upon a ball pitched by Getzein are not different from those which operate upon a projectile thrown from any other source, and the results must be the same, and governed by the same laws. The curves are in the imagination of Getzein's admires. When the ball leaves his hand it is beyond his control, and it moves forward from the impulse last given it as it leaves his hand. It is then controlled by the force of propulsion, the resistance of the atmosphere, and gravitation ...the resistance of the air simply retards its motion or may change its direction; but the change is entirely beyond the pitcher's control ordinarily. Getzein's antic and deceptive motions may deceive the batter, so that he is unable to discover the exact course of the ball in time to strike it, but he cannot throw the a ball so as to make a curve on a horizontal plane.

The author is essentially correct from a Newtonian point of view. The pitcher indeed cannot influence the ball once it leaves his hand. However, at the time, little was known about fluid dynamics, which is the basis for the explanation of the curveball. Chadwick replied that it is essentially differential friction across the surface of the ball which, depending on the direction of rotation can, in fact, result in horizontal deflection of the ball. Chadwick went on to describe to aspiring pitchers the technique involved in throwing a curve. At the time according to the rules of baseball, pitchers were not allowed to pitch in the current way, overhand, but had to pitch essentially underhanded.

Verwiede (1942) reported one of the first empirical studies to determine if a curveball does, in fact, curve. Verwiede rather cleverly constructed an experiment whereby actual pitches were thrown through five frames along the flight path of the ball. Each frame held a screen of fine black cotton thread strung into a grid of vertical and horizontal threads. A combination of curveballs and fastballs were thrown, each through a new set of screens. Verwiede traced the path of the ball by recording which strings were broken in each frame. They found that curveballs deviated from 3.5 to 6.4 inches, at the plate, from a straight line path due to the spin imparted on the ball.

Selin (1954) studied velocity and rotational characteristics of baseballs thrown by college level pitchers. Fastballs ranged from 59.5 mph to 82.28 mph with a mean of 70.72 mph. Curveballs ranged from 50.32 to 75.48 mph with a mean of 61.88 mph. The rate of rotation for a fastball was 20.8 to 31.7 revolutions/sec (rps) with a mean of 26.6. Curveballs rotated from 19.2 to 38.5 rps with a mean of 29.9 rps. Viewed from right angles to the path of the ball, with the ball moving from left to right, a fastball rotates counterclockwise and a curveball rotates clockwise.

Selin measured a positive vertical deviation for a fastball and a negative vertical deviation for a curveball. That is, a fastball falls at a rate slower than would be expected due to the pull of gravity alone. Curveballs fall toward the ground at a rate slightly more than is expected due to gravity alone. Horizontal deviation, that is to the right or left, from the pitchers point of view showed that for a right handed pitcher, a curveball deviates to the left and a fastball deviates somewhat to the right. In a sense, a perfectly straight pitch is unlikely.

The explanation for why the rotation of a ball influences the flight path of the ball was investigated by Briggs (1959). The deflection of the ball due to its rotation is known as the Magnus effect, after the physicist who first explained it. The Magnus effect works in accordance with Bernouilli's Principle and states that the pressure in a moving fluid decreases as its speed increases (Luttgrens & Wells, 1982). A ball moving through the air, a fluid, will move to the area of least resistance. As a ball rotates, a thin layer of air, known as the boundary layer, is either accelerated or slowed depending on the rotation of the ball. If a ball is traveling from left to right, and is rotating in a clockwise direction, the velocity of the boundary layer at the bottom of the ball increases, thus decreasing the pressure beneath the ball. The boundary layer at the top of the ball is slowed thus increasing pressure. In accordance with Bernouilli's principle, the ball will move toward the low pressure region and thus curve downward (Briggs,1959). Figure 3 demonstrates pictorially Bernouilli's principle.

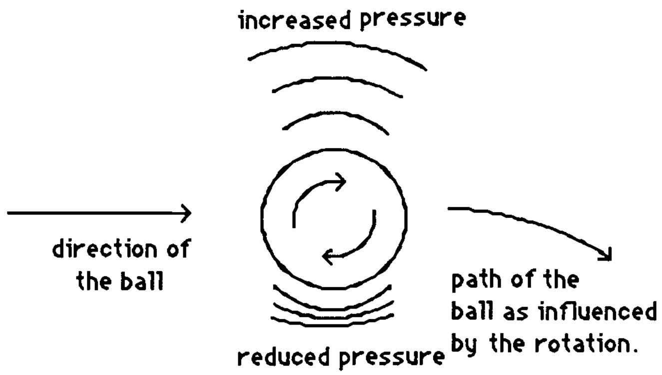

Figure 3. The influence of rotation on the flight of a ball. As the ball spins clockwise the air beneath the ball is accelerated thus reducing the pressure beneath the ball. The pressure above the ball is increased as the air is slowed, thus the ball moves from an area of high pressure to an area of low pressure.

The most recent work on flight characteristics of a baseball used stroboscopic high speed photography to record the precise flight path of the ball (Allman,1982). It was concluded that the combination of rotation and gravitation produced a curving effect that was greater than either component alone. They also concluded that the impression that a curveball breaks suddenly is an optical illusion.

The perception of a sudden break is due to the perspective of the batter looking directly at the ball. When viewed from the side, the curve is seen to break gradually throughout the flight of the ball (Figure 4).

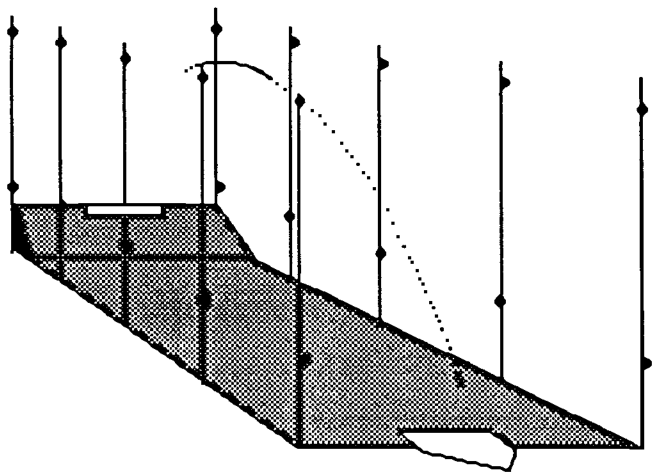

Figure 4. The flight trajectory of a curveball as seen from an angle. The flight path is smooth with no sharp break. (adapted from Allman,W.(1982) Pitching Rainbows, Science 82, Oct. 32-39.)

When viewed from the batter's perspective, the flight trajectory appears much more sharp. The ball seems to drop quickly and suddenly during the latter portion of the flight (Figure 5).

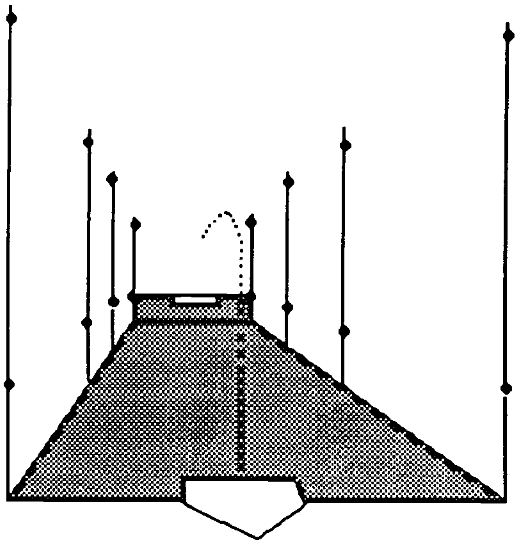

Figure 5. The flight trajectory of a curveball as seen from the batter's perspective. The flight path appears abrupt with a sharp break as the ball nears the plate. (adapted from Allman,W.(1982) Pitching Rainbows, Science 82, Oct. 32-39.)

Clearly, a baseball can indeed deviate from a flight trajectory as dictated by gravity and air resistance alone due to the application of spin to the ball by the pitcher. The essence of pitching and batting in baseball is the skill in the application of spin to the ball by the pitcher versus the skill of the batter in responding to a wide variety of pitches in the attempt to hit the ball.

Movement Correction

Once a baseball player initiates a full swing, how likely is it that he will be able to inhibit the swing if he suddenly chooses to do so? Several studies have investigated the inhibition characteristics of movement inhibition.

Quinn and Sherwood (1985) investigated the difference in processing time required to either speed up or, reverse a 400 msec movement. In response to a signal of either 0, 100, or 200 msec after the initiation of an arm movement, the subjects had to modify the movement by either increasing the movement speed, or reversing the movement. Quinn and Sherwood found that on average an additional 50 msec was required to initiate the reversal of a movement as opposed to simply accelerating the rate of the movement. At zero msec delay, the median reaction time to accelerate was 122 msec, while the reverse signal delay was 192 msec. The 200 msec delay had a median acceleration reaction time of 169 msec and 200 msec for reversal.

They also found that the probability of actually making the correction decreased as the time to the signal increased. A zero msec delay for acceleration had a probability of .9, while reversals had a probability of .93. For a 100 msec delay, the probability of acceleration was .78 and reversal was .75. And at 200 msec delay the probability of acceleration was .12 while reversal was .07.

Logan, Cowan, & Davis (1984) examined the ability to inhibit responses in simple and choice reaction time tests. Logan et al also found that the probability of inhibition decreases as the delay to the signal increases. Stop reaction times were an average of 17 msec slower for a choice reaction time as compared to a simple reaction time. They concluded that additional processing time is needed to inhibit a response in a choice reaction situation.

Osman, Kornblum, & Meyer (1968) investigated the possiblity of a "point of no return" in a ballistic choice reaction time task. Osman et al proposed a so called "race model" whereby the processes to inhibit a movement competed with the processes to initiate a movement on stop trials. When one of the two processes is initiated a point of no return is reached and the other process is excluded. This was supported by the finding that the processing of stop signals and go signals did not compete for limited resourses and that the time course of the ballistic processes was unaffected by failed attempts at inhibition.

Buckolz, Hall, & Alain (1982) investigated the ability to suppress a response initiation in choice reaction time tasks. Buckolz et al found that as the time between a go and an inhibit signal increased, the probability of inhibition decreased. At 50 msec, the probability of reversing a movement was .65. At 200 msec the probability went down to less than .1. Similarly, as the delay between the go signal and the stop signal increased, reaction time to inhibit the movement reversal increased. At 50 msec the reaction time was 260 msec. At 200 msec the reaction time was approximately 350 msec. These results support the results of Logan et al (1984).

Cooke and Diggles (1984) investigated whether error correction was based on feedback from the proprioceptors, or if central nervous system monitoring is responsible for the early stages of error correction. Using electromyographic recording of muscle activity, Cooke and Diggles found suppression of the agonist muscle occurring as soon as 20-40 msec after the initiation of an error movement. This 20-40 msec was as much as 50 msec prior to any overt movement in the limb. Since average proprioceptive reation time is assumed to be 80-90 msec after the initiation response inhibition, it was concluded that the control of movement correction was based on cental nervous system monitoring. The authors hypothesized that prior to a movement, two motor programs are readied. One is responsible for error, the second is responsible for correction. If the response is determined to be incorrect, the first motor program is inhibited and the second is initiated. The authors did not specify exactly where in the nervous system this control emanates, however the cerebellum is thought to be the primary source of control for fast movements(Eyzaguirre & Fidone,1984).

Batting as a Conceptual vs a Perceptual Task

Perceptual psychology would consider batting as a discrimination task. From a cognitive psychology point of view, batting is an attentional task. The attentional question would be; What are the limits on the amount of information that the batter can use? The perceptual question would be; What are the limits on the discriminations that the batter can make?

The cognitive question is one of divided attention. A baseball is a single object, but when thrown by a pitcher in a batting situation, it has several separable characteristics: Location, both initial and final, rotation, velocity, and trajectory all comprise separate elements that define a given flight of the ball. These elements essentially comprise the "data-driven" aspects of batting. These are the features that the batter, in some respect, must preceive, determine their significance, and decide which course of action to take. Along with these data-driven elements, there are also the "conceptually-driven" elements of batting.

Conceptually-driven elements are knowledge or experiential based information with which the batter is equiped. The batter somehow combines conceptually-driven elements in conjunction with the data-driven information to form an individual response. Conceptually-driven elements include; knowledge of the pitcher, the game situation (number of outs, game score, men on base, environmental conditions), the count (number of balls and strikes), coaching information, the previous pitch or pattern of pitches, psychological factors and what ever else that the batter would consider in a given batting situation. This isn't to imply that all batters think about all of these factors all of the time, but it would seem that these factors would come into play in varying degrees with all batters.

The conceptually driven aspects of batting could be considered as resources from which the batter draws upon and somehow uses in conjunction with the available data. It becomes a data and resource situation as described by Norman and Barrow (1975). Norman and Barrow described performance as being limited in two ways: Data-limited, which says performance depends on the quality of the incoming information and the quality of the mental representation to which it is matched. And resource-limited, which are capacities of the individual including things like memory capacity, processing and communications, interest and other factors that define the abilities of the performer which may or may not be quantifiable (The use of Normans & Barrow's concept of data-driven and resource driven process as an example does not necessarily imply support for their basic model. It is used simply to illustrate the perceptual and cognitive aspects of the task. For criticism of Norman and Barrow see Navon,1984).

The question about the batting situation becomes; How much of the task is conceptually-driven and how much of the task is data-driven? Does a batter actually discriminate the rotation of the ball, then based on that information conclude the particular pitch will be a curve and thus respond accordingly? Or, does a batter make a probability estimate based on the various conceptual aspects of the situation? If the batter predicts a curve will be thrown, one is thrown and he swings, his response was, in a sense, prepared in advance and with only a minimal reliance on the data-aspects of the pitch. Conversly, the batter must at some point make discriminations, no matter what his probability estimate was. If a player does not have the ability to integrate and control perceptual and data aspects of batting, it seems unlikely he will be successful.

These are questions that are difficult to answer conclusively. Both concepts are intimately tied and not easily separable. A batter's skill in recognizing the rotation of the ball, and being able to act based on consideration of that information, depends on the accuracy of the discrimination and the resources available to him. If a batter cannot discriminate well, then that information will not be reliable. Conversly, if a batter can discriminate well, but cannot use that information in a constructive manner, then it would not be a particularly worthwhile discrimination. The capacity of the batter to discriminate rotation is a perceptual skill, the ability to use that information is a conceptual process.

Batting Success

Ted Williams said that hitting successfully in baseball is the most difficult skill in sports (Williams,1982). That claim comes from the man who is considered the second greatest hitter of all time (The first greatest hitter was Babe Ruth) (Thorn & Palmer,1985). The mean batting average for all players in professional baseball since 1910 is .265 with a standard deviation of .14. Since 1960, batting average and standard deviation has remained relatively consistent. Prior to 1960 batting averages were more variable (see figure 6).

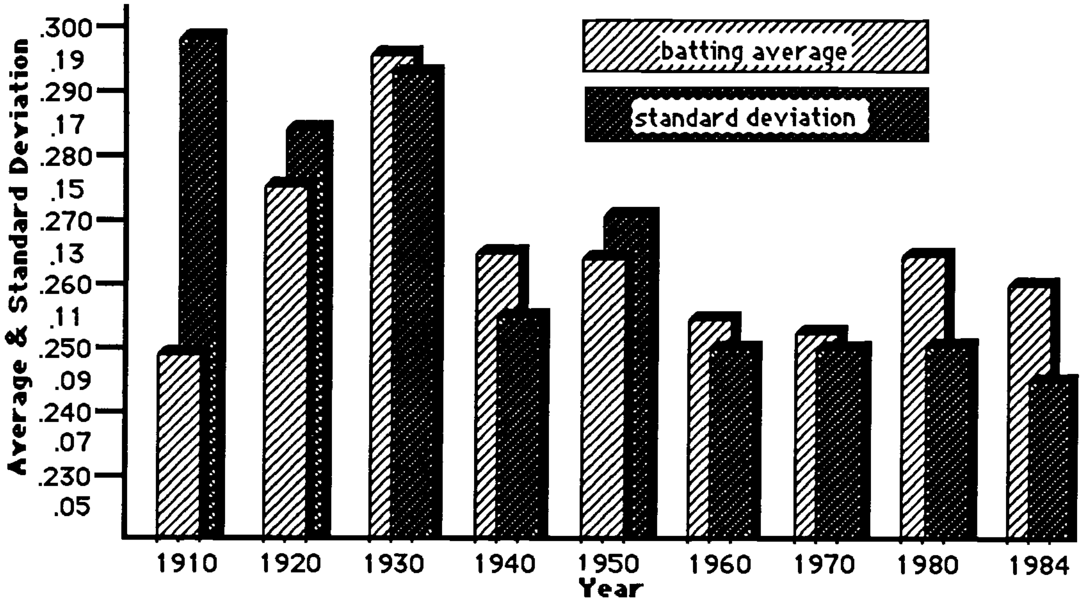

Figure 6. Batting average and standard deviation for all players in professional baseball from 1910 to 1984 inclusive (adapted from Thorn and Palmer,1985)

<u>Summary</u>

Based on the review of the literature, it is reasonable to expect that that baseball players can discriminate between pitches during the first 200 msec of the pitch. What was not know is how the seams of the ball influence the batter's skill in making these discriminations.

CHAPTER III

METHODS AND PROCEDURES

The study consisted of three parts: 1) the experimental section whereby subjects viewed film of pitches and made decisions on whether the ball was rotating with overspin or underspin; 2) a survey of college-level baseball coaches regarding their opinions on the importance of the various perceptual factors in batting; and 3) an analysis of pitches thrown in professional baseball. The following describes the methods used in each of the areas of the study.

The Experimental Analysis of Pitch Recognition

Subjects

The experimental group of subjects consisted of thirty (30) college level baseball players. Baseball players were defined as individuals with at least one year of college-level experience and four years minimum experience in organized baseball (little league, high school, Babe Ruth, American Legion etc.). The control group of subjects consisted of thirty (30) college-age, non-baseball players. Non-baseball players were defined as those individuals who had less than two years high school baseball experience and no college experience (Appendix J). All subjects were volunteers with no conditions placed on their participation and they were not compensated for their time.

Subjects from both groups were screened regarding their vision with the use of a questionnaire. Any individual who reported a history of visual problems, or who normally wore glasses but did not have them with them at the time of testing, were excused. Subjects were to wear glasses if they normally did so while playing baseball or for nearsightedness (Appendix K).

Apparatus

Four Wilson A1082 baseballs were used in the trials. Three of the balls were visually modified and one ball was not modified. The visually modified balls were called: The No-Seam ball, the Enhanced-Seam ball, and the Half-Black ball. The No-Seam ball was produced by painting the seams of a ball with antique-white, opaque, acrylic paint. This resulted in a ball with a visually uniform surface. The Enhanced-Seam ball was produced by painting the normal seams of a baseball red with a permanent maker to make a solid and continuous band 14 millimeters wide following the normal stitch pattern of the ball. This resulted in a ball with seams that appeared much more pronounced then a normal baseball. The Half-Black ball was painted black with a permanent marker over one half of the surface of the ball. The Regular-Seam ball was not modified in any manner. The baseballs were measured for diameter and weight both prior to, and after the filming process. Table 1 shows the baseball specifications.

Table 1. Baseball specifications.

Ball	Weight Pre/Post	Diameter Pre/Post
Normal	4.9oz/4.9oz.	228mm/228mm
No-Seam	5.2oz/5.1oz	230mm/230mm
Enhanced	5.2oz/5.2oz	231mm/231mm
Half-Black	4.9oz/4.9oz	228mm/228mm

Filming

The camera used to film all trials was a 16 mm Redlake Locam II, model 51-002, high speed motion picture camera. The camera was fitted with a Canon TV Zoom, V6x16, 18-108mm, 1:2.5 lens. The camera was set at 24 frames/sec (fps) for all trials. For all trials the F-stop was set at 4, the focus was set at ∞, and the zoom was set at 35. The camera was 65 feet from the pitching rubber, the lens center was 5'10" above the ground, and positioned in the right batter's box. Kodak 16 mm 7277-4-X reversal motion picture film was used for all trials. The film has a 400 ASA rating and was processed normally.

Filming took place in the baseball team's indoor batting cage inside of a multipurpose recreation building. Four high-intensity lights were used to illuminate the filming stage and to supplement the permanent overhead lights in the batting cage. The level of illumination was taken off the ball for the purpose of setting the F-stop on the camera. The background was a dark-green tarp which appeared black in the film (Figure 7).

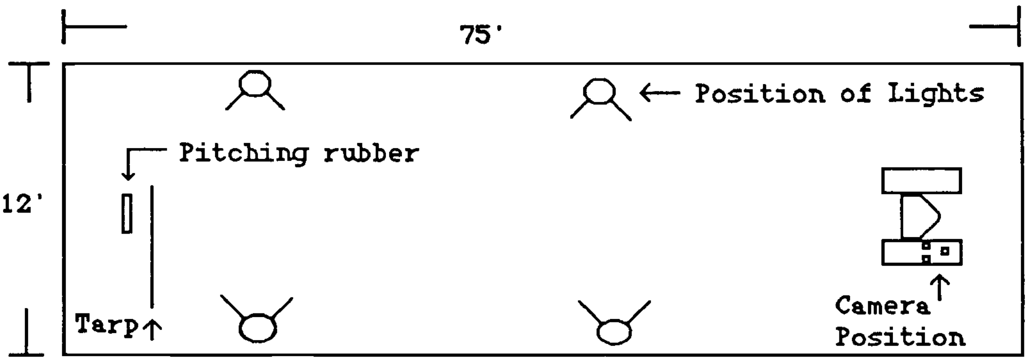

Figure 7. Diagram of the McAlexander Fieldhouse batting cage and position of equipment for the filming of the trials.

The pitcher for the human thrown trials was a professional minor league level baseball player and assistant coach of the Oregon State University Baseball Team. A Jugs Curvemaster Pitching Machine was used for the machine thrown trials. The Curvemaster can be set to throw a wide range of pitches. However, to throw a curveball, the angle of the machine has to be different than when throwing a fastball. This is a potential confounding variable since it would be possible for subjects to "read" the angle of the machine prior to the pitch. In order to eliminate this variable, a black tarp was suspended directly in front of the ball machine with a slot cut through the fabric through which the ball passed. The tarp effectively eliminated any chance of the subjects utilizing cues from the angle of the machine.

Design

The design used was a two-group, within subjects completely repeated measures design. Four independent variables were used, producing a total of 32 conditions. The variables were: pitching agent, ball type, direction of rotation, and exposure period. There were two pitching agents: the human and the machine. There were four ball types: no-seam, regular-seam, enhanced-seam, and half-black. There were two directions of rotation: overspin and underspin. Finally, there were two exposure periods: the initial 200 msec, and the full-flight of the ball.

The 32 best pitches from the total number filmed were edited into 4 experimental film strips each containing 8 pitches. The strips were called trials A, B, C, & D.

Trials A and C were pitches thrown by the human. Trials B and D were pitches thrown by the machine. The sequence of pitches within each strip was randomized. The order of presentation of film strips was balanced according to a Latin Square design conducted within each subject group.

One-factor within-subjects analyses of variance were used to test for differences within conditions. Two-factor analyses of variance were used to test for interactions between variables and to test for differences between subject groups. The Boneferroni multiple comparison procedure was used to test for differences between the seam conditions (Devore,1987). An alpha level of .05 was used throughout as the minimum acceptable error probability for rejection level of the null hypothesis.

Procedure

Subjects began the experiment by filling out a two part questionnaire. First, subjects answered questions detailing their experience playing organized baseball (Appendix J). Second, subjects answered questions regarding their vision (Appendix K). Once the vision questionnaire was completed, the experimentor reviewed each subject's responses and if a subject was found to not satisfy the vision requirements, they were excused. A total of four individuals were screened out of the study for various vision related reasons. After the questionnaires were completed, instructions were read to all subjects explaining their role in the experiment and what they were to do (Appendix H). At that point, subjects viewed a practice film-loop of pitches to become familiar with the format. The loop consisted of two pitches thrown by the human pitcher and two pitches thrown by the machine. The loop was run through twice.

Subject viewed the film one trial at a time, and recorded on a score sheet whether the ball was rotating with overspin or underspin immediately after each trial. The film was stopped between each trial for approximately five seconds to give the subjects an opportunity to record their response. No feedback was given to the subjects during the trials. Responses were scored as either correct or incorrect.

Survey of College-Level Baseball Coaches

A survey was taken of 30 college-level baseball coaches regarding their opinions on various perceptual and cognitive aspects of batting (Appendix A). The coaches surveyed were randomly selected from colleges in the western-half of the United State. The Blue Book of College Athletics served as the source from which the schools surveyed were selected. The coaches selected were not aware that the present study was investigating the importance of rotational cues in batting. The goal of the survey was to assess the degree of agreement between experienced baseball coaches as to their opinions on the relevance of the various cues available to a batter. A total of 22 surveys were returned for a response rate of 73%.

The first question was designed to assess opinions on which cues are most useful to batters in determining which type of pitch has been thrown during the early flight of the ball. These cues included: the pitchers motion and release, velocity, spin, initial location, and trajectory.

The second question had two purposes; the first was to determine which cue is thought to be most important in early pitch recognition. Second, the question was designed to assess whether the coaches surveyed felt conceptual or conceptual aspects of batting were most important to baseball players.

Statistical analysis was done using the Kruskal-Wallis procedure to test if the mean ranking of the items in survey questions 1 and 2 were significantly different from each other. (Devore,1987 ; Marascuilo & McSweeney 1977) A Wilcoxon-Signed Rank procedure was used to test whether there was a significant difference in opinions on the importance of perceptual cues versus conceptual cues (Devore,1987).

Analysis of Pitches Thrown in Professional Baseball

A record of pitches was made for six randomly selected television broadcasts of major league baseball games during the 1986 baseball season. The objective of this analysis was to determine the approximate ratio of fastballs and breaking balls that are thrown at the professional level. Also recorded was the rate of success that batters, at the professional level, when attempting to make contact with the ball. These data were not expressed as batting average, but rather as percentages of missed swings, swing which resulted in a foul-ball, and swings which resulted in a fair-ball. This way of analyzing the data should provide a more representative picture of how the proficient professional baseball players are in making contact with the ball.

CHAPTER IV

RESULTS

The primary goal of this study was to determine if baseball players can discriminate the rotational direction of an approaching pitch during the first 200 msec of the flight of the ball. The secondary goals were to determine: 1) if baseball players use information available from the seams of the ball in pitch identification; 2) if baseball players use cues given by the pitcher to help in pitch identification; and 3) if baseball players discriminate equally well between overspin and underspin.

The results are divided into three sections: 1) results from the baseball group of subjects; 2) results from the non-baseball group of subjects; and 3) comparisons between the two groups of subjects. In each section the data from the ball seam conditions (no-seams, regular-seams, and enhanced seams) were used in the analysis. The half-black ball condition was not used because its primary purpose was for the experimentor to determine the rate of revolution of each class of pitch. Because the pitches were filmed in black-and-white film, and because the background for the filming was black, the half-black ball produced a strobe effect when viewed. Responses by the subjects to the half-black ball were very erratic and were not included in the overall analysis of the results.

The overall percent of correct response was 80% for the baseball group and 60% for the non-baseball group. The analysis in the following sections will show that the baseball players used seam cues in making discriminations between pitches while the non-baseball group appeared to rely on velocity cues. The results obtained in the experimental portion of the study support the opinion of the baseball coaches surveyed that spin information is the most important cue in pitch recognition. The results also show that the baseball players were able to identify the type of pitch within the first 200 msec of the flight of the ball.

Section I : Baseball Players

Results of the study indicate that baseball players can discriminate the rotational direction of a pitch during the first 200 msec of the flight of the pitch. A one-way within subject group ANOVA was run to test the hypothesis:

$Ho1 : \mu_f = \mu_2$

where,

μ_f = full flight time frame

μ_2 = 200 msec time frame.

Table 2 shows that there was no difference between percent of correct responses by baseball players to pitches viewed in the 200 msec and full flight time frames.

Table 2. Baseball players percent correct responses to trials in the 200 msec versus full flight frame time.

SV	df	SS	MS	F	p
Viewing Time	1	.82	.82	.48	.50
Subjects	29	96.35	3.32		
Error	29	49.68	1.71		
Total	59	146.85			

Group:	Trials	Percent Correct:
Pitcher and Machine		
200 msec	360	79 ±14
Full Flight	360	81 ±12

Tables 3 and 4 show that when the data for the pitcher thrown trials and the machine thrown trials is analyzed separately, there still was no significant difference between the 200 msec and full flight time periods.

Table 3. Baseball players percent correct response to trials in the 200 msec and full flight time frame when thrown by the pitcher.

SV	df	SS	MS	F	p
Viewing Time	1	.15	.15	.19	.67
Subjects	29	66.68	2.30		
Error	29	23.35	.81		
Total	59	90.18			

Group:	Trials	Percent Correct:
Pitcher		
200 msec	180	78 ±22
Full Flight	180	76 ±20

Table 4. Baseball players percent correct responses to trials in the 200 msec versus full flight times frames when thrown by the pitching machine.

SV	df	SS	MS	F	p
Viewing Time	1	1.07	1.07	1.83	.19
Subjects	29	25.73	.89		
Error	29	16.93	.58		
Total	59	43.73			

Group:	Trial	Percent Correct:
Pitching Machine		
200 msec	180	80 ±15
Full Flight	180	85 ±14

Figure 8 shows that there is little or no change in the percent of correct responses with viewing time. This results supports the hypothesis, $\mu_f = \mu_2$ and shows that the baseball group was able to identify the pitch type within the first 200 msec of the pitch.

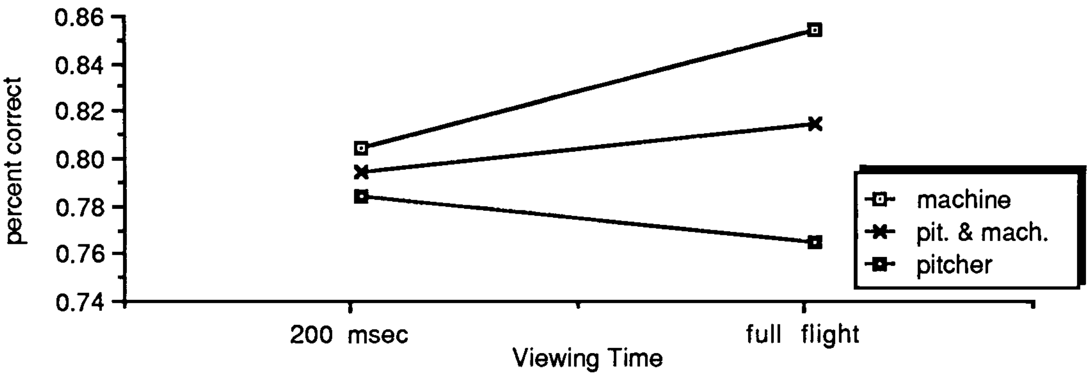

Figure 8. Baseball player's percent of correct responses in the 200 msec and full flight time frames.

A two-way within subjects ANOVA was calculated to determine if there was a difference in percent of correct response to trials thrown by the pitcher versus the pitching machine, and between overspin versus underspin. Table 5 shows that there was no difference between pitching agents, there was no difference between directions of rotation, and that there was no significant interaction.

Table 5. 2-way ANOVA bsetween the pitching agents and the direction of rotation for the baseball group.

SV	DF	SS	MS	F	p
Pitching Agent(A)	1	2.70	2.70	2.07	.16
Rotation(B)	1	.83	.83	.72	.40
Subjects(S)	29	49.70			
AB	1	1.20	1.20	1.19	.28
AS	29	37.80	1.30		
BS	29	33.67	1.16		
ABS	29	29.30	1.10		
Total	119	155.20			

Although there was no difference in pitching agent or direction of rotation, the analysis of the three seam conditions showed a significant difference. As seam information increased, there was a significant increase in the percent of correct responses. This result indicates that the baseball players were able to use seam information to discriminate between pitches.

A one-way within subjects ANOVA was run to test the hypothesis:

Ho2 : $\mu_n = \mu_r = \mu_e$

where,

μ_n = no-seam ball

μ_r = regular-seam ball

μ_e = enhanced-seam ball.

Table 6 shows that the hypothesis, $\mu_n = \mu_r = \mu_e$ was rejected. There was a significant difference between the percent of correct responses by baseball players to the pitches in the three seam conditions.

Table 6. One-way ANOVA between the three seam conditions for the baseball group combining pitcher and machine thrown trials.

SV	df	SS	MS	F	p
Seam Condition	2	11.82	5.91	4.21	.02
Subjects	29	70.06	2.42		
Error	58	81.51	1.41		
Total	89	163.39			

Group: Pitcher & Machine	Trials	Percent Correct
No Seams	240	74 ±17
Regular Seams	240	81 ±15
Enhanced Seams	240	85 ±18

Because there was a significant difference between the three conditions, a Bonferroni Multiple Comparison test was run to determine how the three conditions differed from each other (Devore & Peck,1987). Table 7 shows that there was a significant difference between the no-seam condition and the enhanced-seam condition with the percent of correct responses in the enhanced seam condition being significantly greater than in the no-seam condition.

Table 7. Bonferroni Multiple Comparision test between the percent of correct responses in the three seam conditions.

74%	81%	85%

Figure 9 shows graphically that there was a consistent increase in the percent of correct responses as seam information was added. The difference between the no-seam and the enhanced seam conditions was statistically significant.

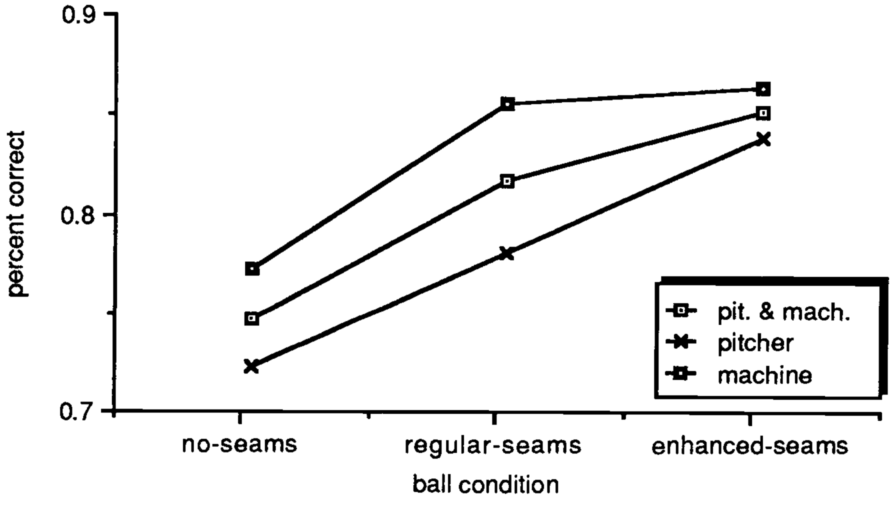

Figure 9. The percent of correct responses by the baseball players to pitches thrown in the three different ball conditions.

Because there was a significant difference between seam conditions, the relationship between viewing time and seam condition and rotation and seam condition was tested to find if the difference was dependent on either of those factors. Tables 8 and 9 show that there was no significant interaction between those factors.

Table 8. 2-way ANOVA between the viewing time versus the seam conditions for the baseball group.

SV	DF	SS	MS	F	p
Viewing Time(A)	1	1.61	1.61	1.71	.20
Seam Condition(B)	2	5.34	2.67	4.27	.02
Subjects(S)	29	34.03	1.17		
AB	2	.21	.11	.26	.77
AS	29	27.23	.94		
BS	58	36.32	.63		
ABS	58	23.46	.40		
Total	179	128.19			

Table 9. 2-way ANOVA between the rotation versus the seam conditions for the baseball group.

SV	DF	SS	MS	F	p
Rotation(A)	1	.36	.36	.67	.42
Seam Condition(B)	2	5.43	2.72	4.02	.02
Subjects(S)	29	33.13	1.14		
AB	2	2.34	1.17	2.52	.09
AS	29	15.31	.53		
BS	58	39.23	.68		
ABS	58	26.99	.47		
Total	179	122.80			

The overall finding from the analysis of the results from the baseball group was, first, that there was no significant difference in the percent of correct responses in the 200 msec versus the the full flight time frame. Second, that there was a significant difference in the percent of correct responses between the three seam conditions. And third, that there was no significant difference in the percent of correct responses between pitching agents or types of spin.

Section II - Non-Baseball Players

The results from the non-baseball group showed that, across all trials, their percent of correct responses was 60 percent. Section three will show that this was significantly lower than the baseball group which had an 80 percent correct response rate. The most important finding was that the non-baseball subjects did not use seam information nearly as well as the baseball group did in discriminating between pitches. Instead, it appeared that the non-baseball subjects discriminated between pitches on the basis of velocity differences between pitches thrown with overspin versus underspin. The baseball subjects may have also used velocity information, but they were able to use seam information that the non-baseball group appeared not to use effectively in discriminating between pitches.

As with the baseball group, the non-baseball showed no difference in the percent of correct responses in the 200 msec versus the full flight time frames. However, the overall percent of correct responses was siginifcantly lower than the baseball group.

As with the baseball group, the non-baseball group showed no difference in responses to trials in the 200 msec and full flight time frames. Table 10 shows the results of the one-way ANOVA testing the hypothesis:

Ho3 : $\mu_f = \mu_2$

where,

μ_f = full flight time frame

μ_2 = 200 msec time frame

comparing the percent of correct responses between the 200 msec and the full flight time frames as thrown by the machine and the pitcher combined.

Table 10. Non-baseball players percent correct responses to pitches in the 200 msec and full flight time frames.

SV	df	SS	MS	F	p
Viewing Time	1	8.07	8.07	2.32	.14
Subjects	29	154.60	5.33		
Error	29	100.93	3.48		
Total	59	263.60			

Group: Combined	Trials	Percent Correct:
200 msec	360	58 ±17
Full Flight	360	63 ±18

Figure 10 shows that there was a increase in percent correct as viewing time increased, but the difference between the percent correct in the two time frames was not statistically significant. Figure 10 and figure 8 both show no difference between the 200 msec and the full flight time frames for both groups. However, the non-baseball group's percent of correct response of 58% for the 200 msec and 63% for the full flight time frame was well below the baseball group's 79% and 81% correct response rate. The baseball group was accurately discriminating between pitches at a significantly higher rate than the non-baseball group.

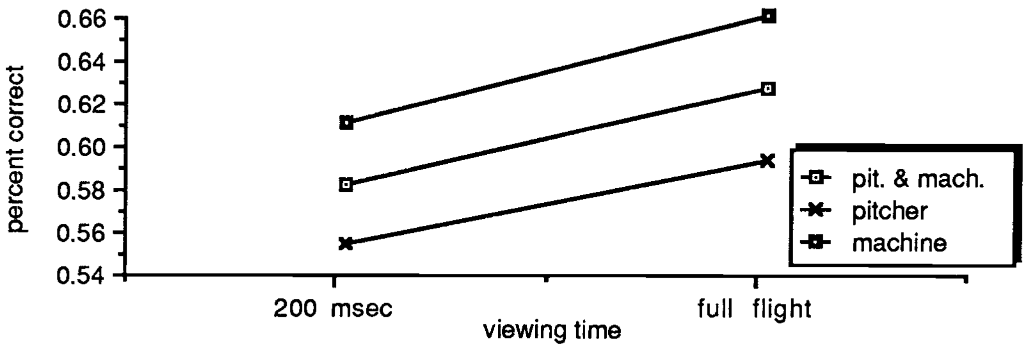

Figure 10. Non-baseball players percent of correct response to pitches in the 200 msec and full flight time frames.

For the baseball group, the seam conditions were the key variables in percent of correct responses. For the non-baseball group, seam information did not appear to be as useful in making discriminations between pitches. The main finding for the baseball players was they were able to discriminate between pitches on the basis of the difference in seam conditions. The non-baseball group did not demonstrate the same degree of skill as the baseball group. Table 11 shows the results of the one-way within subjects ANOVA to test the hypothesis:

Ho4 : $\mu_n = \mu_r = \mu_e$

where,

μ_n = no-seam ball

μ_r = regular-seam ball

μ_e = enhanced-seam ball

comparing the percent of correct responses between the three ball conditions.

Table 11. One-way ANOVA between the three seam conditions for the non-baseball group.

SV	df	SS	MS	F	p
Seam Condition	2	6.87	3.43	2.22	.12
Subjects	29	101.73	3.51		
Error	58	89.80	1.55		
Total	89	198.40			

Group:	Trials	Percent Correct:
Pitcher & Machine		
No-seam	240	56 ±18
Regular-seam	240	65 ±17
Enhanced-seam	240	59 ±21

The hypothesis, $\mu_n = \mu_r = \mu_e$ was retained, there was no difference in the percent correct response for the non-baseball group to trials in the three seam conditions. Figure 11 shows that the additional information provided by the seams of the ball that the baseball player group were able to use in pitch identification, did not appear as useful to the non-baseball group.

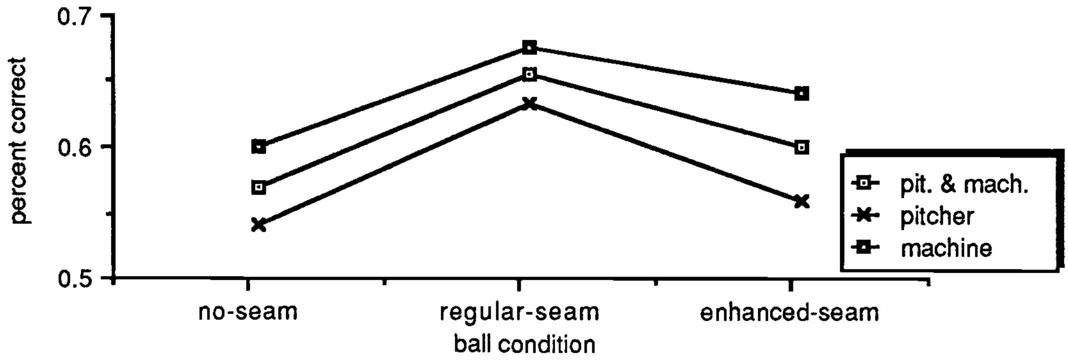

Figure 11. The non-baseball players percent of correct responses to the pitches thrown in the three ball conditions.

Two-way ANOVAS were calculated to determine if there was a significant difference between pitching agents by time intervals and pitching agents by direction of rotation. Table 12 shows that there was no significant difference between pitching agents and time intervals and that there was no interaction between the two variables.

Table 12. Two-way ANOVA between the pitching agent versus the time for the non-baseball group.

SV	DF	SS	MS	F	p
Pitching Agent(A)	1	2.13	2.13	1.31	.26
Viewing Time(B)	1	4.03	4.03	2.32	.14
Subjects(S)	29	77.30	2.67		
AB	1	.03	.03	.02	.88
AS	29	47.37	1.63		
BS	29	50.47	1.74		
ABS	29	39.47	1.36		
Total	119	220.80			

Table 13 shows that there was a significant interaction between pitching agents and direction of rotation. Figure 12 shows that the non-baseball players were most accurate in responding to pitches thrown with underspin by the pitching machine. There was no difference in their responses to the trials thrown by the pitcher.

Table 13. Two-way ANOVA between the pitching agent versus the direction of rotation for the non-baseball group.

SV	DF	SS	MS	F	p
Pitching Agent(A)	1	4.80	4.80	2.80	.10
Rotation(B)	1	24.30	24.30	14.62	.0006
Subjects(S)	29	78.30	2.70		
AB	1	9.63	9.63	6.37	.02
AS	29	49.70	1.71		
BS	29	48.20	1.66		
ABS	29	43.87	1.51		
Total	119	258.80			

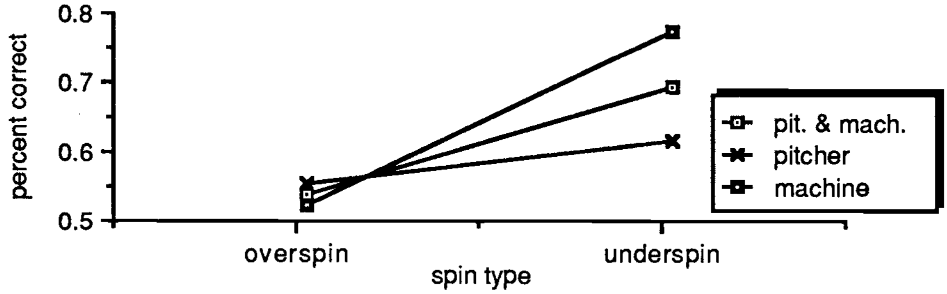

Figure 12. Non-baseball players percent of correct responses to the pitches thrown with overspin or underspin.

Because the was a significant interaction between directions of rotation, a one-way within subject ANOVA was calculated to determine how the two directions differed from each other. Table 14 shows that non-baseball players were significantly more accurate in percent of correct responses to pitches thrown with underspin than to pitches thrown with overspin.

Table 14. Non-baseball players percent correct response to trials thrown with overspin versus underspin.

SV	df	SS	MS	F	p
Rotation	1	48.60	48.60	14.62	.0006
Subjects	29	156.60	5.40		
Error	29	96.40	3.32		
Total	59	301.60			

Group:	Trials	Percent Correct:
Combined		
Overspin	360	53 ±19
Underspin	360	68 ±16

Table 15 shows that when the data for the pitcher thrown trials is analyzed separately, there was no difference between the overspin versus the underspin trials.

Table 15. Non-baseball players percent correct response to trials thrown with overspin versus underspin by the pitcher.

SV	df	SS	MS	F	p
Rotation	1	1.67	1.67	.80	.38
Subjects	29	60.40	2.08		
Error	29	60.33	2.08		
Total	59	122.40			

Group:	Trials	Percent Correct:
Pitcher		
Overspin	180	54 ±19
Underspin	180	60 ±16

However, Table 16 shows that when the data was analyzed separately for the machine-thrown trials that there was a highly significant difference between the overspin and underspin judgement. The non-baseball group was significantly more accurate in trials thrown with underspin than the trials thrown with overspin.

Table 16. Non-baseball players percent correct response to overspin versus underspin trials by the pitching machine.

SV	df	SS	MS	F	p
Rotation	1	35.27	35.27	35.59	.0001
Subjects	29	67.60	2.33		
Error	29	28.73	.99		
Total	59	131.60			

Group:	Trials	Percent Correct:
Pitching Machine		
Overspin	180	51 ±26
Underspin	180	76 ±22

These results indicated that the non-baseball group was not able to use seam information as well as the baseball group could. The non-baseball group appeared to discriminate between pitches on the basis of velocity differences between trials.

Section III - Baseball Players versus Non-Baseball Players

The intragroup comparisons that were made within baseball and non-baseball player groups were also made between the two groups. The purpose of these comparisons was to determine if there was a difference between the two groups in their skill in making the discriminations in the trials. Two-way ANOVAS were calculated to test if there were significant differences between the two groups for the four variables, viewing time, seam condition, pitching agent, and direction of rotation.

Table 17 shows that the baseball group was statistically significantly more accurate than the non-baseball for the two time frame conditions. But there was no difference within each group to the two time frames. Also, there was no interaction between subject groups and viewing time.

Table 17. 2-way ANOVA between the subject groups and the viewing time.

SV	DF	SS	MS	F	p
Groups (A)	1	172.80	172.80	34.04	.0001
Viewing Time (B)	1	4.80	4.80	1.69	.20
S	29	106.80	3.68		
AB		1	.53	.53	.26
.61					
AS		29	147.20	5.08	
BS		29	82.20	2.83	
ABS	29	58.47	2.02		
Total	119	572.80			

Figure 13 shows the percent of correct responses for the baseball and non-baseball groups at the two time intervals.

There was a significant difference between the groups, there was no difference between the conditions, and the there was no significant interaction.

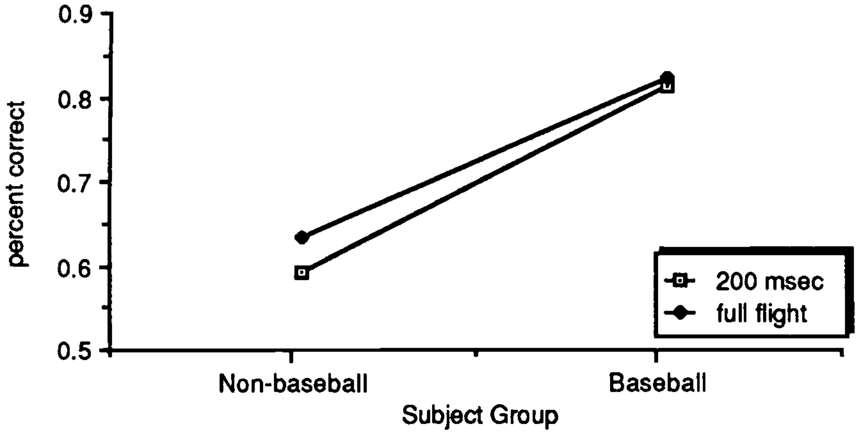

Figure 13. The percent of correct responses by the baseball group and the non-baseball group in their response to pitches in the 200msec and full flight time frames.

The relationship between subject groups and the seam-condition variable was tested with a two-way ANOVA. Table 18 shows that there was a significant difference between the subject groups but there was no overall difference between seam conditions. Also, there was no significant interaction between the two sets of variables.

Table 18. Two-way ANOVA between subject groups by seam conditions.

SV	DF	SS	MS	F	p
Groups(A)	1	115.20	115.20	34.87	.0001
Seams(B)	2	13.43	6.72	6.77	.002
S	29	72.20	2.49		
AB	2	4.30	2.15	1.13	.33
AS	29	95.80	3.30		
BS	58	57.57	.99		
ABS	58	110.70	1.91		
Total	179	469.20			

Figure 14 shows the percent of correct responses for the two groups by the seam conditions. There was a significant difference between groups but there was no difference in seam conditions. In addition, there was no significant interaction between groups and seam conditions.

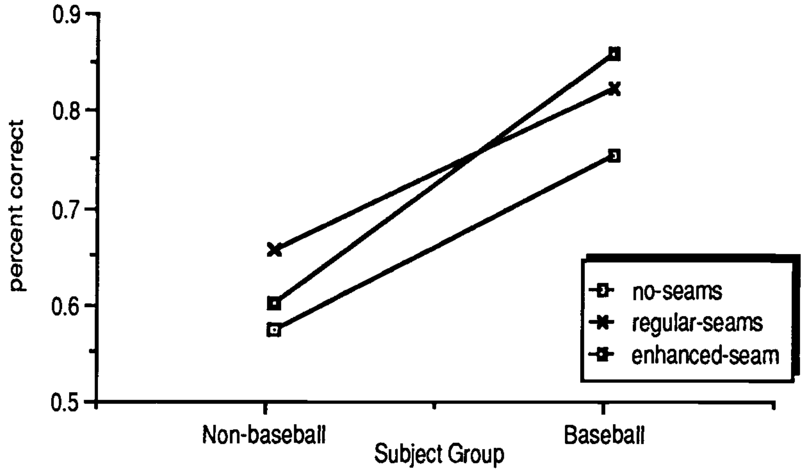

Figure 14. Comparison of the percent of correct response to the three different ball conditions by the baseball and non-baseball groups.

The relationship between the subject groups and the pitching agents was tested with a two-way ANOVA. Table 19 shows that there was a significant difference between the subject groups and that there was no difference between pitching agents. Furthermore, there was no significant interaction between the subject groups and the pitching agents.

Table 19. Two-way ANOVA between subject groups by pitching agents.

SV	DF	SS	MS	F	p
Groups(A)	1	170.41	170.41	32.87	.0001
Pitching Agent(B)	1	14.01	14.01	3.67	.07
S	29	108.34	3.74		
AB	1	.41	.41	.17	.68
AS	29	150.34	5.18		
BS	29	110.74	3.82		
ABS	29	70.34	2.43		
Total	119	624.59			

Figure 15 displays the results from Table 24 which shows there was a significant difference between the two groups, but there was no difference between pitching agents. Also, there was no significant interaction between the two.

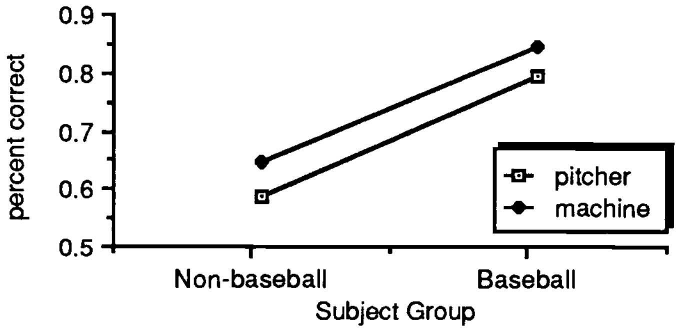

Figure 15. Comparison of the percent of correct respones to trials thrown by the human and the pitching machine by the baseball and non-baseball groups.

Table 20 shows that there that was a significant difference between the groups, that there was no significant difference between rotation conditions, but there was a significant interaction between subject group and rotation.

Table 20. Two-way ANOVA between subject groups by direction of rotation.

SV	DF	SS	MS	F	p
Group (A)	1	172.80	172.80	33.59	.0001
Rotation (B)	1	16.13	16.13	6.51	.02
S	29	106.80	3.68		
AB	1	34.13	34.13	10.78	.003
AS	29	149.20	5.14		
BS	29	71.87	2.48		
ABS	29	91.87	3.17		
Total	119	642.80			

Finally, Figure 16 shows the relationship between the subject groups and directions of rotation. There was a significant difference between groups, but there was an interaction between the variables indicating that rotation influenced response rates by the non-baseball group more than it did to the baseball group.

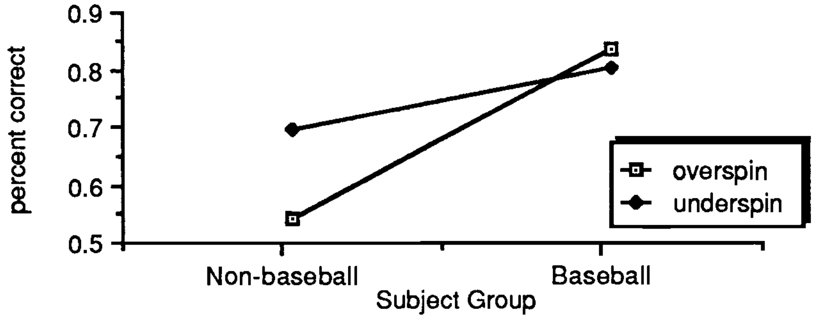

Figure 16. A comparison of the percent of correct responses to pitches thrown with overspin or underspin by the baseball and non-baseball groups.

Survey Results

The main purpose of the survey was to sample the opinions of college-level baseball coaches as to which cues are most important in batting to aid the hitter in determining what type of pitch has been thrown. The usefulness of spin information was the primary cue of interest. The second objective of the survey was to evaluate whether coaches felt that perceptual cues are more or less important to the batter as conceptual information available to the batter. The results of the survey of college level baseball coaches is summarized in the following tables and figures. Table 21 presents the responses to question number 1 expressed as a percentage of the total number of responses.

Table 21. Responses by percentage to survey question #1.

Question # 1. Which cues are batters most able to use during the first half of the flight of the pitch to determine which type has been thrown.

	least	somewhat	more	most
a. Motion	9%	36%	22%	32%
b. Velocity	5%	41%	41%	14%
c. Spin	5%	32%	32%	32%
d. Location	14%	32%	27%	27%
e. Trajectory	9%	27%	36%	27%

Table 22 presents the results of Kruskal-Wallis distribution free analysis of variance to test if any of the responses to the questions differed significantly from each other (Devore, 1987).

Table 22. Kruskal-Wallis test on survey question # 1.

Kruskal-Wallis 5 X variables

DF	4
# Columns	5
# Cases	110
H	1.097
H corrected for ties	1.204
# tied groups	4

Name:	# Cases:	Σ Rank:	Mean Rank:
motion	22	1226	55.727
velocity	22	1121	50.955
spin	22	1321	60.045
location	22	1171	53.227
trajectory	22	1266	57.545

Of the different cues, spin, obtained the greatest mean rank of 60.045, but it was not significantly greater than the mean ranking of the other cues.($H < x^2$ 9.49, NS) The implication of this result is that in the opinion of the coaches surveyed, batters do not rely solely on a single cue to determine which type of pitch has been thrown during the early flight of the ball. Rather, it seems likely that a combination of information is used by the batter during the early flight of the ball in deciding whether or not to swing.

The cues surveyed in question 1 were only concerned with the perceptual aspects of batting, disregarding the conceptual factors which a batter may also utilize in making the swing decision. Figure 17 presents a bar graph of the mean ranking of the responses to survey question # 1.

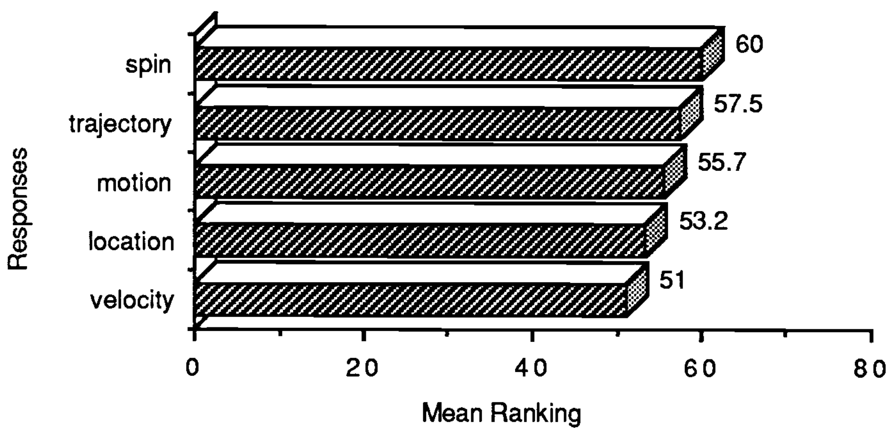

Figure 17. Mean ranking for the responses to the items in survey question # 1.

Survey question number 2 had two purposes; the first was to assess which factors the coaches surveyed felt were most important to the batter in making a swing/no swing decision. These included both perceptual factors regarding the flight of the ball from question one, and conceptual factors relating to information the batter has prior to the release of the particular pitch. These conceptual factors include knowledge of the pitcher, the game situation, the count and looking for a certain pitch. The second purpose of question number 2 was to compare the importance of conceptual cues vs. perceptual cues in the opinion of the coaches in making a swing decision.

Table 23 presents a analysis of the responses expressed as a percentages. Clearly, location was judged to be the single most important factor in a batter's swing decision with highest mean ranking of 142.

Table 23. Responses by percentage to survey question # 2.

Question # 2. Rate the following factors as to their importance to the batter in making a swing/no swing decision.

	least	somewhat	more	most
a. Motion	27%	45%	18%	9%
b. Certain pitch	9%	14%	59%	18%
c. Spin	5%	27%	55%	14%
d. Count	0%	14%	59%	27%
e. Location	5%	14%	14%	68%
f. Situation	14%	41%	36%	9%
g. Trajectory	0%	23%	55%	23%
h. Knowledge	5%	41%	36%	18%
i. Velocity	9%	50%	9%	32%

A Kruskal-Wallis distribution free analysis of variance was run to test if any of the responses to the questions differed significantly (Devore, 1987). Table 24 presents the results of the test.

Table 24. Kruskal-Wallis test on survey question # 2.

Kruskal-Wallis 9 X variables

DF	8
# Columns	9
# Cases	198
H	29.966
H corrected for ties	32.877
# tied groups	4

Name:	# Cases:	Σ Rank:	Mean Rank:
motion	22	1331	60.5
certain pitch	22	2264	102.909
spin	22	2154	97.909
count	22	2593	117.864
location	22	3124	142

Name:	# Cases:	Σ Rank:	Mean Rank:
situation	22	1753	79.682
trajectory	22	2502	113.727
knowledge	22	2082	94.636
velocity	22	1898	86.273

The results of the test indicated that there was a significant difference in the rank order response to the items on question number two. (H $>x^2$ 26.12 significant at

.001) Figure 18 presents a bar graph of the responses to survey question number two.

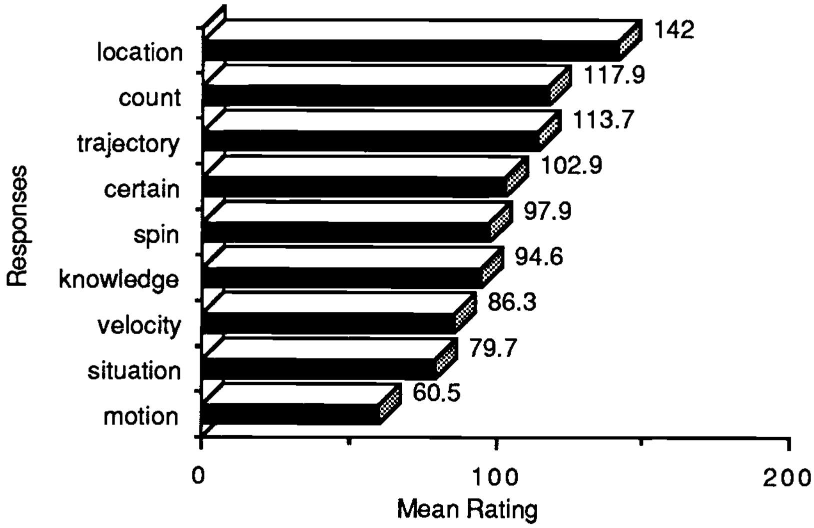

Figure 18. Bar graph of mean ranking for survey question # 2.

Table 25 presents a rank ordering of the responses to survey question 1 and 2. The purpose of the table is to allow for comparison of the responses to the questions that were common to both question 1 and 2. For instance, location was rated as the most important factor in question # 2 but ranked 4th out of 5 in question # 1.

Table 25. Rank ordering of the responses to survey questions 1 and 2.

Factor	Rank O # 1	Rank O # 2	Mean # 1	Mean # 2
Location	4	1	57.5	142
Spin	1	5	60	97.9
Trajectory	2	3	57.5	113.7
Count	-	2	-	117.9
Certain	-	4	-	102.9
Motion	3	9	55.7	60.5
Knowledge	-	6	-	94.6
Velocity	5	7	51	86.3
Situation	-	8	-	79.7

Table 26 presents the results of the Wilcoxon signed-rank test was calculated between the mean responses on the perceptual factors versus the mean response on the conceptual factors. This was done to determine if in the opinion of the coaches surveyed, there is a significant difference in the importance of conceptual factors and perceptual factors in making a swing decision.

Table 26. Wilcoxon signed-rank test between perceptual and conceptual factors.

Wilcoxon signed-rank X : perceptual Y : conceptual

	Number:	Σ Rank:	Mean Rank:
+ Ranks	11	113	10.273
- Ranks	10	118	11.8

note 1 cases eliminated for difference = 0.

Z	-.087
Z corrected for ties	-.087
# tied groups	5

The results of the Wilcoxon signed-rank test shows that there was no significant difference between the perceptual versus the conceptual aspects of batting. The Wilcoxon signed-rank test showed no difference between mean responses on perceptual vs conceptual factors. Figure 19 presents a scatter plot of each respondant's mean score for the perceptual and the conceptual items in the question.

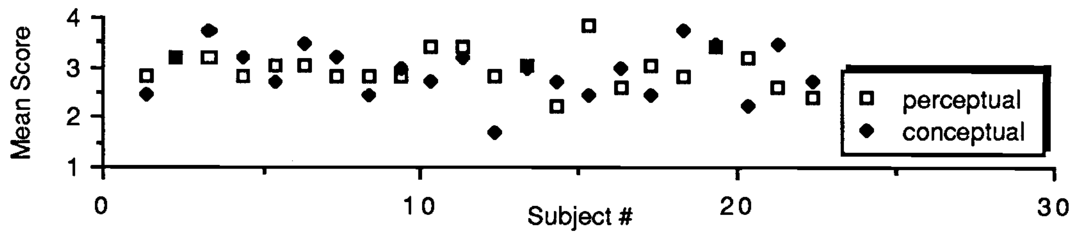

Figure 19. Mean score of each coach surveyed to the perceptual and conceptual items in question # 2.

Of the 22 coaches surveyed, 11 judged the conceptual factors as more important in batting, while 10 judged the perceptual factors as more important (1 tie score). The results indicate that in the opinion of the coaches surveyed, both conceptual factors and perceptual factors are considered important to the batter in making a swing decision.

Observational Study Results

An analysis of the pitches thrown over the course of six major league baseball games was done in order to obtain information on the typical pitching and hitting patterns at the professional level. This analysis had two primary purposes: first, to measure the approximate percentage of fastball and breaking-ball pitches thrown over the course of a game. Second, to measure the degree success which of professional batters have in making contact with a pitch when an attempt to do so was made. Attempted swings at the ball were classified three ways; pitches swung at and missed, pitches swung at and hit into foul territory, and pitches swung at and hit into fair territory.

Whether the ball hit into fair territory was a base-hit or not was disregarded. Many times a ball hit extremely well results in an out, and occasionally a ball hit poorly results in a base-hit. Therefore, batting average does not always reflect how frequently batters actually make contact with the ball when attempting to hit a pitch. Table 27 presents a analysis of the pitches thrown during six major league games.

Table 27. Summary of pitches for six major league baseball games.

Pitch	N	Mean	S	% Total	% Group
Total pitches	N=1621	270.16	38.86	100%	
fastball	n=1035	172.5	24.14		63.85%
breaking ball	n=586	97.67	19.91		36.15%
Pitches not swung at:					
not swung at, ball.	n=540	90	18.23	33.31%	66.50%
not swung at, strike	n=272	45.34	7.58	16.78%	33.50%
Pitches swung at:					
swung at, missed	n=151	25.17	3.76	9.32%	18.67%
swung at, fair	n=346	57.67	6.47	21.34%	42.77%
swung at, foul,	n=312	52	12.38	19.25%	38.57

The distinction between fastball and breaking-ball has to be viewed carefully. Virtually all pitches thrown at the professional level exhibit some degree of "movement." Pitchers are able to utilize a wide range of spins and velocities to achieve different effects. It would be an over-simplification to classify all pitches into two categories. There are several pitches thrown with underspin, and many pitches thrown with overspin. In addition, some pitches are thrown with little or no spin. However, all pitches can be broadly classified as having either overspin or underspin. The range of spins within each category is wide. Figure 20 presents a bar graph of the pitches thrown over the course of six professional baseball games:

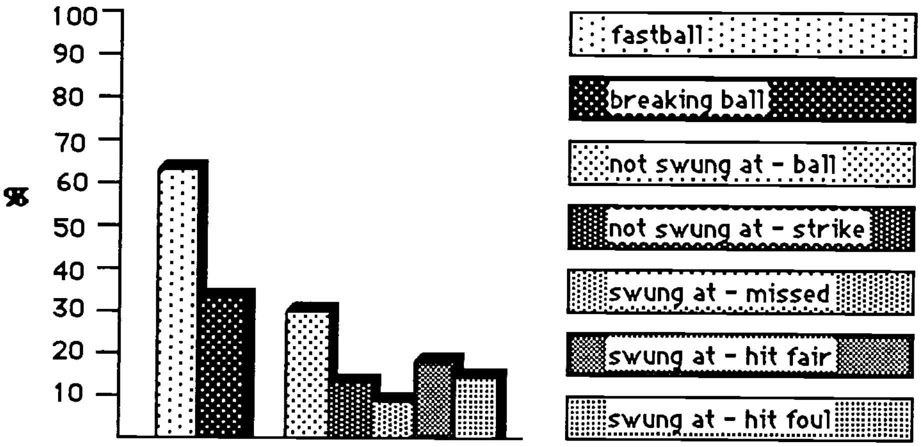

Figure 20. An analysis of pitches for 6 professional baseball games. 63.85% of the pitches thrown were fastballs, 36.15% of the pitches were breaking balls.(first 2 columns at the left) Batters swung at 49.9% of all pitches thrown, they missed the ball on 9.32% of the swings, hit the ball fair 21.34% of the time, and hit the ball foul

19.25% of the time.

Figure 21 presents a graphic representation of the pitches that batters attempted to hit expressed as a percentage of the total swings made.

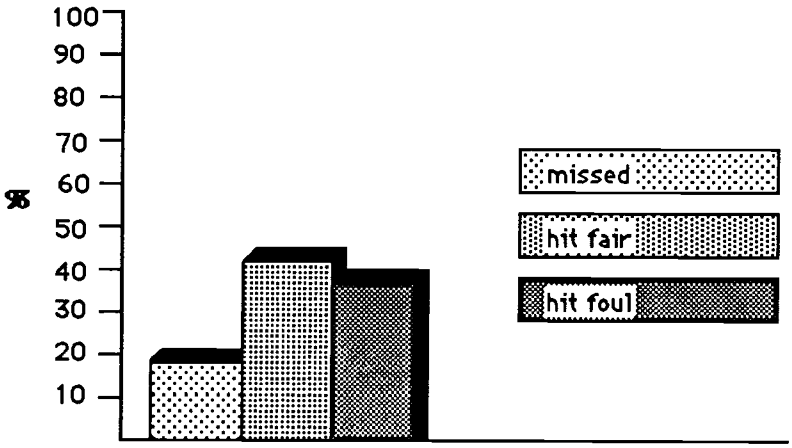

Figure 21. Of the 809 pitches batters attempted to hit, they made contact to some degree 81.34% of the time. Of that 81.34%, 42.77% were hit into fair territory. They completely missed the ball 18.67% of the time.

Chapter V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Perceptual studies into short time frame pattern recognition have demonstrated that the visual system can extract and identify features of a scene in 200 msec or less (Imada & Yodogawa, 1985 ; Triesman, 1986 ; Potter, 1976) Studies of baseball players have shown that they can discriminate between pitches based on early information about the flight of the ball (Burroughs,1984). It has also been shown that baseball players are more skilled in visually tracking the ball than non-baseball players (Bahill, 1981). During batting, the player has approximately 200 msec to view the pitch and then make a swing decision. This is within the time needed by the visual system to recognize patterns. However, batting places special demands on the visual system not found in the laboratory setting. The batter must make several simultaneous, or nearly simultaneous judgements based on visual information to discriminate ball velocity, location, and rotation. These decisions must be made about a ball that is 3 inches across, from 30 to 60 feet away from the batter, traveling up to 95 mph, and rotating at a rate of about 30 revolutions per second (Selin,1954). Clearly, discriminating between pitches places special demands on the individual's perceptual abilities and decisions making skills.

Professional baseball players are divided on whether batters can discriminate rotational information early in the flight of the pitch. Carew, Williams, and Lau acknowledge that the batter is faced with a difficult task in attempting to discriminate between the wide variety of pitches thrown in professional baseball today (Carew, 1986 ; Williams, 1982 ; Lau, 1984a&b) Rose specifically states that he can read the rotational direction of a pitch immediately after the pitcher releases the ball based on spin information (Rose,1985). Of the baseball coaches surveyed in the present study, spin was judged as the most important cue in early pitch identification. However, the results of the survey indicate that the consensus of opinion is not solidly in favor of the usefulness of spin cues (Figure 17). This result may reflect some degree of doubt, even though their intuition tells them that spin is the key cue.

If batters do evaluate spin, location, and velocity within the first 200 msec after the release of the ball, it suggests parallel processing of the cues. Conversly, if batters do not process information in a parallel fashion, it implies that they may not attend specifically to certain cues, but rather to patterns of cues which elicit a response to swing or not. Conversly, batters could process the cues sequentially, and respond to a specific cue, such as location, rather than to a pattern of cues. It would seem likely that both parallel processing of cues occurs early in the flight of the ball, followed by selective attention to specific cues which trigger a swing decision. It has been shown that feature extraction processes of vision are accomplished in parallel, or simultaneously, while focused attention occurs sequentially (Treisman, 1980).

The initial response baseball players have to the ball may be a feature extraction process whereby patterns are quickly recognized. Once the initial pattern has been recognized, the serial information processing mode may be used to further evaluate the pitch and be the basis on which a swing decision is made. Unfortunately, the present study was unable to answer questions about how batters process visual information and then use that information to trigger a specific response. Rather, the study addressed the question of what baseball players perceive when viewing a pitch. The decision making process that the baseball player goes through once the sensory information is processed was beyond the means of this study.

It is to the baseball players advantage to accurately "read" the rotational direction of the ball early in the pitch. When a swing decision is made, the batter makes both a temporal judgement estimating the arrival of the ball, and a spatial estimate of where the ball will be when it arrives in the hitting zone. The skill of predicting the location and arrival of the ball is based on what the batter can perceive about the ball. Using information about ball rotation would provide an important cue to the batter in judgements about the flight of the ball. By combining the perceived information about the ball, with an established understanding about baseball dynamics, the player will have the resources that will aid him in recognizing and using information effectively.

Professional baseball players have reported that they can discriminate the rotational direction of the ball early in the flight of the pitch (Rose,1985). How early they make the discrimination, and how they utilize the different cues available to them has not been studied systematically. The purpose of this study was to provide experimentally based evidence about how batters discriminate between pitches which may be of use in teaching and coaching baseball players.

Summary of the Study

The experimental phase of this study tested 60 subjects, 30 college-level baseball players, and 30 college-aged non-baseball players, who viewed films of pitches thrown in 32 trials. The trials were varied by seam type, pitching agent, viewing time, and direction of rotation. The task of the subjects was to identify whether each trial was thrown with overspin or underspin.

The questionnaire phase of the study surveyed 30 college-level baseball coaches on their opinions about which of the cues available in batting are most important in pitch recognition, in making swing decisions, and on perceptual and conceptual aspects of batting. A total of 22 surveys were returned for a response rate of 73%.

The observational phase of the study charted the pitches thrown in six professional baseball games to determine the approximate ratio of fastball pitches to curveball pitches in professional baseball. In addition, the outcome of each pitch was recorded to determine how successful professional batters are in making contact with the ball.

Summary of the Findings

The main finding of the experimental phase of the study was that the baseball players could discriminate the rotational direction of an approaching pitch during the first 200 msec of the flight of the ball. There was no significant difference in the proportion of correct responses by the baseball players to pitches viewed in the 200 msec versus the full flight time frames. This finding coincides with Burrough's and Shank and Haywood's finding that baseball players can discriminate between pitches early in the flight of the ball (Burroughs,1984 ; Shank & Haywood, 1987). The overall percent correct in this study by baseball players was 80%, less than the 90% found in the Burrough's study and the 89% found in Shank and Haywood's study. However, in both studies the subjects only viewed pitches thrown by a familiar pitcher, and with baseballs with normal seams. In the present study, the subjects viewed certain trials that were more difficult to accurately discriminate then the trials in the other studies. The finding that baseball players could discriminate between pitches within the first 200 msec was true whether the pitcher or the pitching machine threw the ball. The non-baseball players also showed no difference between the 200 msec and full flight time frames, but they were significantly less accurate than baseball players in the proportion of correct responses in both times frames.

Evidence from the second finding indicates that it was seam information that was used by the baseball players to discriminate between pitches. Baseball players demonstrated a significant increase in proportion of correct responses from the no-seam trials to the enhanced-seam trials. The skill in reading the spin of the ball appears to require training because the non-baseball group did not show a significant increase in proportion of correct responses across the conditions. The ability of the baseball players to read the rotation of the ball supports the view of the baseball coaches in the survey portion of the study that rotation information is the most important factor in pitch identification. The baseball group was significantly more accurate than the non-baseball group in proportion of correct responses to trials in all three seam conditions.

While the baseball group utilized seam information to discriminate between pitches, it appeared that the non-baseball group used velocity information for pitch discrimination. The baseball group was equally accurate in discriminating between pitches thrown with overspin and underspin. The non-baseball group was significantly more accurate in identifying pitches thrown with underspin. The trials thrown with underspin, particularly the underspin pitching machine thrown trials, were the highest velocity pitches in the study. The baseball group was significantly more accurate than the non-baseball group in identifying pitches thrown with either overspin or underspin.

The finding of the experimental section of the study supported the opinions of the coaches responding in the survey section. In survey question number one, spin was judged to be the most important factor in pitch identification while velocity was judged as being least important. Results of the experiment showed that the baseball group did increase their proportion of correct responses as seam information increased. The non-baseball group did not show a significant increase in proportion of correct responses as seam information increased. Also, velocity was regarded as the least important factor in pitching identification. The non-baseball group appeared to be most sensitive to velocity cues and not as sensitive to seam cues. This could explain why the non-baseball group had a significantly lower proportion of correct responses compared to the baseball group. The baseball group attended to and used seam information in discriminating between pitches, the non-baseball group was not able to use that same information as effectively as the baseball group.

There is no reason to suggest that there was any difference between the two groups in their ability to "see" the rotation of the ball. The difference between the two groups was their skill in utilizing the information in a meaningful way. Subjects in the baseball group have learned to decipher the information derived from the rotation of the ball while the subjects in the non-baseball group were less skilled in interpreting the same cues.

The main finding of the survey section of the study was that the baseball coaches surveyed did not generally agree on what they considered the most important visual cues in batting. Of all the factors, the factor on which there was the most agreement was the location of the ball in the hitting zone which determines whether a batter will swing or not. The coaches did tend to feel that rotation of the ball during the early flight of the ball was important in pitch identification. However, rotation was not seen as significantly more important than the other factors influencing judgements about the pitch. This division of opinion may reflect a degree of doubt about how useful or detectable rotational information actually is to the batter. Contrarily, the most important cue in making a swing decision was clearly pitch location in the opinion of the coaches. However, batters do not always attempt to hit pitches in the strike zone, nor do they always refrain from swinging at pitches out of the strike zone. That is the essential struggle between the pitcher and the batter in baseball. The batter wants to hit a pitch in a certain area in the strike zone, the pitcher wants the batter to attempt to hit either a pitch that is in a difficult location in the strike zone, or preferably, a pitch out of the strike zone. The purpose of varying spin, velocity, and location by the pitcher is to induce the batter to swing at the "pitcher's pitch."

There was no difference between the perceptual versus the conceptual aspects with opinions divided within the coaching sample, 11 coaches favoring conceptual factors and 10 favoring perceptual factors, with one tie score. It was clear that both perceptual factors and conceptual factors are seen as important in batting skill. Opionions were divided as to whether one or the other is the most important factor. A few of the respondents rated either one or the other as clearly more important, while the majority of the coaches rated the two factors roughly equal in importance. The implication of this finding is that baseball players should be actively trained in both aspects of batting. They should be trained to discriminate between pitches on the basis of what they can perceive about the ball during batting, and they should be trained to attend to conceptual factors so that they may anticipate the most likely occurrences in given situations.

The obsevational section of the study found that in professional baseball the fastball is thrown approximately 64% of the time and breaking pitches are thrown about 36% of the time. It was also found that professional batters make contact with pitches swung at approximately 82% of the time. Of the pitches that batters made contact with, 53% of those pitches are hit into fair territory. The batters swung at but completely miss the ball about 18% of the time.

Conclusions

On the basis of the analysis of the data from the experimental and survey sections of the study, the following conclusions can be stated within the scope of the study:

1. The baseball group was significantly more accurate than non-baseball group in correctly identifying the type of pitch in both the initial 200 msec of the flight of the ball, and over the full flight of the ball. This result was not unexpected; the skill the baseball group demonstrated in discriminating between pitches is not unlike any other specialist skill in using specific information peculiar to their profession.

2. Baseball players could identify the rotational direction of a pitch during the first 200 msec of the flight of the ball. This result is consistent with Burroughs' (1984) finding who also found that baseball players can discriminate between pitches within the first 200 msec of the flight of the pitch.

3. Baseball players can use information derived from the seams of the ball to make pitch identification. The baseball group in this study significantly increased their percent of accurate pitch identification as visual seam information from the ball increased. The non-baseball group did not significantly increase their percent of accurate pitch identification as seam information increased. There is no reason to suspect that there was any difference between the two groups in their ability to see the seams of the ball. The difference between the two groups reflects their skill in understanding the information that the seams was conveying.

4. Baseball players did not appear to rely on cues from the pitcher's delivery for discrimination between pitches. There was no significant difference in the percent of correct response between the pitching machine and the human pitcher. This indicates that the subjects did not rely on cues from the pitcher's wind-up or delivery to discriminate between pitches. This information would be important for baseball coaches in trainging batters to look at the ball and not at the pitcher when batting.

5. Baseball players were equally accurate in discriminating pitches thrown with either overspin or underspin. There was no significant difference in the percent of correct responses between pitches thrown with overspin or underspin by the baseball group. The non-baseball group was significantly more accurate in discriminating pitches thrown with underspin. This indicated that the non-baseball players tended to use velocity information rather then seam information. The baseball group may have been using velocity information in combination with seam information, but seam information did not appear useful to the non-baseball group.

6. College-level coaches were divided in opinion as to what the most important factors are in batting except for the importance of the location of the ball in the hitting zone. This indicates that there is not a strong consensus of opinion as to which cues in batting are more important.

This may be due to a lack of evidence to confirm or deny whether certain cues are either detectable or useful. The location of the ball in the hitting zone is obviously important within the rules and the context of the sport, but other cues are less easily evaluated for their importance to the batter in hitting. Results from this study support the opinion take seam information can be used in early pitch identification.

7. The results of the experimental portion of the study supported the responses to survey question number one. The results that non-baseball players tended to use velocity information while baseball players used rotation information supported the opinion expressed by the coaches that spin information is most useful and velocity information is least useful in early pitch identification. Since the baseball group was significantly more accurate than the non-baseball group, and that the baseball group was able to use seam information supports the coaches in saying spin information is key in early pitch identification.

8. The baseball coaches surveyed felt that perceptual and conceptual factors in batting are equally important sources of information to the batter. This result indicates that in the opinion of the coaches surveyed, both the perceptual-motor aspects, and the cognitive understanding of the game are important in developing a player's overall

batting skill. Cognitive aspects include an understanding of pitching and what pitchers will likely do in given game and count situations, defensive and offensive batting, and other factors.

9. Professional baseball players make contact with the ball over 80% of the time. This indicates that professional baseball players are more proficient in hitting the ball than batting average alone would indicate. Three base-hits in ten at-bats is considered to be outstanding, when actually batters are making contact with the ball about 80 percent of the time. Hitting in baseball has been traditionally considered to be one of the most difficult tasks in sports, but based on a contact rate of 80 percent, it appears that professional baseball players are more skilled than batting average alone would indicate.

Implications

Based on the findings of the study, the following implications seem justified:

1. Baseball players should be actively trained in the perceptual aspects of batting including 1) how to read the rotation of the ball, 2) to read the rotation quickly, 3) the physical reasons for why a ball curves due to rotation, and 4) to ignore information that does not seem to be important in pitch recognition. Baseball players are

evaluated on the basis of their motor skill, however, it may be a player's perceptual skill that keys their motor skills. Baseball players should be trained as to the implications of ball rotation and to understand how rotation influences the flight of a ball. It would be of little benefit for a baseball player to be able to read the rotation of the ball without understanding what exactly rotation does to the flight of the ball and why pitchers use rotation to try to keep batters from effectively hitting the ball.

3. Baseball players should be trained to attend to the ball and not to the pitcher's delivery. Shank and Haywood (1987) found that novice baseball players fixated on the pitchers head at the moment of release while college-level players fixated on the release point of the ball. Shank and Haywood felt that the baseball players were more accurate in pitch identification than novice baseball players because they knew where to look to obtain information about the ball. Results from this study found that the baseball group did not use information from the pitcher to identify pitches. Coaches in youth baseball should train young baseball players to look at the release point of the pitch during their early training.

4. Baseball players should be trained in the perceptual and the conceptual aspects of batting. Based on the results of the survey in this study, college-level

baseball coaches expressed the opinion that a cognitive understanding of batting is equally important to the perceptual-motor aspects of batting. Batters can be trained to anticipate certain pitches in certain situations based on the particular tendencies of a given pitcher, the game situation, the count and many other factors.

Recommendations for Further Study

Due to the findings of this study, the following suggestions are made for further research:

1. The 200 msec time frame used in this study should be systematically reduced to find the minimal amount of time baseball players need to identify a pitch. Research in perception indicates that the visual system can recognize objects as quickly as 70 msec. A study could be done with the presentation time varied to determine the minimum amount of time needed by baseball players to discriminate between pitches. A correlational study could be done between pitch recognition time and batting skill to test the relationship between these two factors.

2. Conduct the experiment with live pitches rather than on film for the purpose of generalizing the results back to actual batting as much as possible. An important limitation in this study was the use of film for the trials. The use of a two-dimensional, black-and-white

representation of an event that occurs naturally in three dimensions probably reduces the subject's chance of using the full range of information available in the normal baseball environment. The advantage of using film, and why it was used for this study, was that all subjects were exposed to identical trials. A live experiment would have the advantage of being able to estimate actual perceptual capabilities more closely to actual baseball conditions.

3. A similar study could be done with professional baseball players. Results of this study show a highly significant difference between college-level baseball players and non-baseball players in their skill in discriminating between pitches. Results from this study could be used to compair how well professional-level baseball players would score on a similar test to determine the degree to which perceptual skill continues to increase with increasing experience and training. College-level baseball players have been reported to be from 80 to 90 percent accurate in recognizing pitches during the early flight of the ball. It is not known what the point of asymptote is, or if professional baseball players are significantly more accurate than college-level players in pitch identification.

4. A study could be done to find if there is a relationship between an individual's skill in reading the rotational direction of the ball early in the flight of the

pitch and their hitting skill. If it is found that there is a strong correlation between perceptual skill and batting skill possibly a screening test could be developed to test players. Also a training program could be developed to teach batters how to read pitches which may shorten development time in players.

5. Professional baseball should be encouraged to support research into baseball. Currently, evaluation of players is done primarily on the basis of an individuals motor skill, little if any evaluation of perceptual skills is done. If it could be shown that though a program of perceptual evaluation and training that baseball players could improve their motor skill, it may be seen as in baseball's best interest to support research. With the high salaries and relatively small number of years of peak performance of baseball players, it may be of financial benefit to baseball teams to increase the rate of skill development and improve the screening of players for selection to a team.

REFERENCES

Allman, W. (1982) Pitching Rainbows. Science 82, 3, 32-38.

Allman, W. (1983) Twisting Slowly in the Wind. Science 83, 6, 92-93.

Attneave,F.(1968) Triangles as Ambiguous Figures. The American Journal of Psychology, 81-3, 447-453.

Bahill,T, Clark, M. & Stark, L. (1975) Dynamic overshoot in saccadic eye movements is caused by neurological control signal reversals. Experimental Neurology, 48, 107-122.

Bahill, A. (1981) Does a baseball player "Keep His Eye on the Ball?" In Modeling and Simulation: Proceedings of the 12th Annual Pittsburg Conference, ed. W. Vogt & M.Mickle, Pittsburg: Instrument Soc. Am. 1201-1206.

Bahill, A., & LaRitz, (1983) Do baseball and cricket players keep their eyes on the ball? Proceedings of the 1983 International Conference on Systems, Man and Cybernetics (India). IEEE., 79-83.

Bahill, A. & LaRitz,T. (1984) Why can't batters keep their eye on the ball? American Scientist, May, 249-253.

Bizzi, E. (1981) Eye-Head Coordination. In V. B. Brooks (ed) Handbook of Physiology - Nervous System II. Baltimore: Williams & Wilkins, 1321-1336.

Biederman, I., Mezzanotte, R. & Rabinowitz, J. (1982) Scene Perception: Detecting and Judging Objects Undergoing Relational Violation. Cognitive Psychology, 14, 143-177.

Biederman, I., Teitelbaum,R, & Mezzanotte, J. (1983) Scene Perception: A Failure to Find a Benefit From Prior Expectancy or Familiarity. Journal of Experimental Psychology: Human Perception and Performance, 9, 411-429.

Briggs, L. (1959) Effect of spin and speed on the lateral deflection (curve) of a baseball; and the magnus effect for smooth spheres. American Journal of Physics, 27, 589.

Brown, Brian (1972) Dynamic Visual Acuity, Eye Movements, and Peripheral Acuity for Moving Targets. Vision Research, 12, 305-321.

Brown, Brian (1972) The Effect of Target Contrast Variation on Dynamic Visual Acuity and Eye Movements. Vision Research, 12, 1213-1214.

Buckolz,E., Hall,C. & Alain, C.(1982) Suppressing Response Initiation in a Choice RT Task. Canadian Journal of Applied Sport Sciences, 7(1), 49-54.

Burroughs, W. (1984) Visual simulation training of baseball batters. International Journal of Sports Psychology, 15, 117-126.

Calton, L. (1981) Processing visual feedback information for movement control. Journal of Experimental Psychology: Human Perception and Performance, 7, 1019-1030.

Carew, R.(1986) Art and Science of Hitting. Penguin: New York. 45-58

Chadwick, H. (1886) The art of pitching in baseball. Scientific American, 71-72 .

Cooke, J. & Diggles, V. (1984) Rapid Error Correction During Human Arm Movements: Evidence for Central Monitoring. Journal Of Motor Behavior, 16(4), 348-363.

Cornsweet, T. (1970) Visual Perception. Academic Press, New York. 304-310.

Craik, K. (1947) Theory of the human operator in control systems: 1. The operator as an engineering system. British Journal of Psuchology, 38, 56-61.

Devore, J. (1987) Probability and Statistics for Engineering and the Sciences. Brooks/Cole Publishing Co. Monterey CA.

Devore, J. & Peck, R. (1987) Statistics. West Publishing Co. St. Paul MN.

Deregowski, J. (1968) Difficulties in Pictorial Depth Perception in Africa. The British Journal of Psychology, 59, 195-204.

de Weert, C. (1979) Colour Contours and Stereopsis. Vision Research, 22, 531-544.

Edlund L. (1972) The Relationship of Hitting Abilities in Baseball to Selected Anatomical Measurements and Motor Responses. Master's Thesis. South Dakota State University.

Eyzaguirre,C. & Fidone,S. (1984) The Physiology of the Nervous System. Year Book Medical Publishers, Chicago Ill.

Falkowitz, C & Mendel, H. (1977) The role of visual skills in batting averages. Optometric Weekly, 557, 33-36.

Fuchs,A. (1971) The Saccadic System. In P. Bach-y-Rita & C. Collins(eds.) The Control of Eye Movements. Academic Press:New York, 343-362.

Gould, S.J. (1981) The Mismeasure of Man. W.W. Norton and Company, New York.

Hoffman,J. (1986) The Psychology of Perception. In J. LeDoux & W. Hirst (Eds), Mind and Brain : Dialogues in Cognitive Neuroscience. Cambridge University Press, Cambridge.

Hubbard, A. & Seng, C. (1965) Visual movements of batters. Research Quarterly, 25, 42-57 .

Imada, T. & Yodogawa, E. (1985) Feature Extraction Processing Time in the Human Visual System. Japanese Psychological Research, 27(1), 11-20.

Intraub, H. (1981) Rapid Conceptual Identification of Sequentially Presented Pictures. Journal of Experimental Psychology: Human Perception and Performance. 7(3), 604-610

Johansson, G. (1973) Visual Percetion of Biological Motion and a Model for its Analysis Perception & Psychophysics, 14, 201-211.

Jones, C. & Mills,T. (1987) Use of Advanced Cues in Predicting the Flight of a Lawn Tennis Ball. Journal of Human Movement Studies, 4, 231-235.

Kandel E. (1985) Processing of Form and Movement in the Visual System. In Kandel, E. & Schwartz, J. (eds.) Principles of Neural Science. 2nd. Elsevier : New York. 366-383.

Keele,S. & Posner,M. (1968) Processing of Visual Feedback in Rapid Movements. Journal of Experimental Psychology. 77, 155-158.

Kitzman, E. (1962) Baeaball: Electromyographic Study of Batting Swings. Doctoral Dissertation, State University Iowa.

Lappin,J., Bell, H., Harm, J. & Kottas,B. (1975) On the Relation Between Time and Space in the Visual Discrimination of Velocity. Journal of Experimental Psychology: Human Perception and Performance. 1(4), 383-394.

LaRitz, T., Hall,D., & Bahill, A. (1983) Modleing head and Eye Coordination of Baseball Players. In Modeling and Simulation: Proceedings of the 14th Annual Pittsburg Conference, ed. W. Vogt & M.Mickle, Pittsburg: Instrument Soc. Am. 1059-1063.

Lau, C. & Glossbrenner, A. (1984a) The Art of Hitting 300., Hawthorne/Dutton, New York .

Lau, C. & Glossbrenner, A. (1984b) The Winning Hitter., Hearst Books, New York.

Lee, D.N., Young, D.S., Reddish, P.E., Lough, S. & Clayton, T.M.H. 1(1983) Visual timing in hitting an accelerating ball. Quarterly Journal of Experimental Psychology, 35A , 333-346.

Logan, G., Cowam,W., & Davis, K. (1984) On the Ability to Inhibit Simple and Choice Reaction Time Responses: A Model and a Method. Journal of Experimental Psychology: Human Perception and Performance. 10(2), 267-291

Luttgens, K & Wells, K. (1982) Kinesiology. Saunders College Publishing. New York. 336-339.

Mack, A. (1970) An Investigation of the Relationship Between Eye and Reinal Image Movements in the Perception of Movement. Perception and Psychophysics, 8, 291-298

Marascuilo,L. & McSweeney, M. (1977) Nonparametric and Distribution-Free Methods for the Social Sciences. Brook/Cole Publishing Co. Monterey CA.

Marrocco,R. (1986) The Neurobiology of Perception. In J. LeDoux & W. Hirst (Eds), Mind and Brain : Dialogues in Cognitive Neuroscience. Cambridge University Press, Cambridge.

Mateeff, S. (1978) Saccadic Eye Movements and Localization of Visual Stimuli. Perception and Psychophysiscs, 24, 215-24.

Mather, J. & Putchat, C. (1983) Parallel Ocular and Manual Tracking Responses to a Continuously Moving Visual Target. Journal of Motor Behavior, 15, 29-38.

McLeod, Peter, McLaughlin, C, & Smith, I. (1985) Information Encapsulaation and Automaticity : Evidence from the visual control of finely timed actions. In Posner,M.I. & Marin,o. (Eds) Attention and Performance XI: Mechanism of Attention. Hillsdale, N.J. Lawrence Erlbaum.

Meyer, C., Lasker, A. & Robinson, D.(1985) The Upper Limit of Human Smooth Pursuit Velocity. Vision Research, 25, 561-563.

Mikle, R. (1984) The Relationship of Specific Variables to Successful Batting in Selected Varsity College Baseball Players. Unpublished Master of Arts Thesis. Northeast Missouri State University.

Moltler, C, & Wurtz, R. (1976) Organization of Monkey Superior Colliculus : Intermediate Layers Discharge before Eye Movements. Journal of Neurophysiology, 40, 74-94.

Moore, S. (1984) Systematic Removal of Visual Feedback. Journal of Human Movement Studies, 10, 165-173.

Navon,D.(1984) Resourses-A theoretical Soup Stone? Psychological Review, 91(2), 216-234.

Nielsen, D. & McGowm, C. (1985) Information Processing as a Predictor of Offensive Ability in Baseball. Perceptual and Motor Skills, 60, 775-781.

Norman, D. (1975) On Data-limited and Resourse-limited Processes. Cognitive Psychology, 7, 44-64.

Noton, D, & Stark, L. (1971) Scanpaths in Eye Movements During Pattern Recognition. Science, 171, 308-311.

Olson, L. (1974) A Study to Determine if Hitting Can Be Improved through Use of Motion Pictures. Master's Thesis, Western Illinois University.

Osman, A., Kornblum,S., & Meyer, D. (1986) The Point of No Return in Choice Reaction Time: Controlled and Ballistic Stages of Response Preparation. Journal of

Experimental Psychology: Human Perception and Performance. *12(3)*, 243-258.

Potter, M. (1974) Meaning in Visual Search. *Science*, *187*, 965-966.

Potter, M. (1976) Short-Term Conceptual Memory for Pictures. *Journal of Experimental Psychology: Human Learning and Memory*, *5(2)*, 509-522.

Puck, P.(1964) *Cinematographical Analysis of Effective Batting Performance*. Master's Thesis. Illinois State University.

Quinn, J. & Sherwood, D. (1983) Time Requirements of Changes in Program and Parameter Variables in Rapid Ongoing Movements. *Journal of Motor Behavior*, *15-2*, 163-178 .

Race, D. (1961) A Cinematographic and Mechanical Analysis of the External Movements Involved in Hitting a Baseball Effectively. *Research Quarterly*, *32*, 394-404.

Ramachandran,V. & Gregory, R. (1978) Does Color Provide an Input to Human Motion Perception? *Nature(London)*, *275*, 55-56.

Robinson, D. (1981) Control of Eye Movements. In V. B. Brooks (ed) *Handbook of Physiology - Nervous System II*. Baltimore: Williams & Wilkins, 1275-1334.

Robinson, D. (1964) The Mechanics of Human Saccadic Eye Movement. *Journal of Physiology*, *174*, 245-264.

Robinson, D. (1965) The Mechanics of Human Smooth Pursuit Eye Movement. *Journal of Physiology*, *180*, 569-591.

Rose, P. & Golenbock P. (1985) *Pete Rose on Hitting*, Perigee Books, New York.

Rosenbaum,D. (1975) Perception and Extrapolation of Velocity and Acceleration. *Journal of Experimental Psychology: Human Perception and Performance*. *1(4)*, 395-403.

Sage, G.H. (1984) *Motor Learning - a neurophysiological approach.* Dubuque, IA. W. Brown

Sakitt,B. (1975) Locus of Short-Term Visual Storage. *Science*, 1318-1319.

Salthouse,T., Ellis,C., Diener,D. & Somberg,B. (1981)

Stimulus Processing During Eye Fixations. Journal of Experimental Psychology: Human Perception and Performance. 7(3), 611-623.

Schalen,L. (1980) Quantification of tracking eye movements in normal subjects. Acta Otolaryngol, 90, 404-413.

Schmidt, R. A. (1976) Control Processes in Motor Skills. Exercise and Sports Sciences Reviews. 4, 229-261.

Schneider, D. (1969) A Mechanical Analysis of Baseball Batting. Master's Thesis. Chico State College.

Schneider, W. & Shiffrin R. (1977) Controlled and Automatic Information Processing : I Detection Search and Attention. Psychological Review, 84, 1-66.

Shank,M & Haywood,K. (1987) Eye Movements while Viewing a Baseball Pitch. Perceptual and Motor Skills, 64, 1191-1197.

Shiffrin,R. & Schneider,W. (1977) Controlled and Automatic Information Processing : II Perceptual Learning, automatic attending, and a general theory.. Psychological Review, 84, 127-190.

Selin, C. (1954) An analysis of the aerodynamics of pitched baseballs. Reasearch Quarterly, 30, 232-240.

Slater-Hammel, A.T. & Andreas, E. (1950) Velocity measurements of fastballs and curve balls, Motor Skills Research Exchange, 3, 54.

Slater-Hammel, A.T. & Stumpner, R. (1950) Batting reaction time. Research Quarterly, 21, 353-356.

Smith, M. (1982) The Effect of Roughness Elements on the Magnus Characteristics of Rotating Sherical Projections. Unpublished Master of Science Thesis. North Texas State Unversity.

Smith,W., & Bowen, K. (1980) The Efects of Delayed and Displaced Visual Feedback on Motor Control. Journal of Motor Behavior, 12, 91-101.

Thorn, J. & Palmer, P. (1985) The Hidden Game of Baseball. Doubleday & Co. Garden City, NY.

Treisman, A., & Gelade G. (1980) A Feature Integration Theory of Attention. Cognitive Psychology, 12, 97-136.

Treisman, A., & Schmidt, H. (1982) Illusory Conjuctions in the Perception of Objects. Cognitive Psychology, 14, 107-141.

Treisman, A. (1986) Features and Objects in Visual Processing. Scientific American, 255, 114b-125.

Turvey, M. (1977) Contrasting Orientations to the Theory of Visual Information Processing. Psychological Review, 84, 67-88.

Van Essen,D. (1979) Visual areas of the Mammalian Cerebral Cortex. Annual Review of Neuroscience, 2, 227-263.

Verwiebe, F. (1942) Does a baseball curve? American Journal of Physics, 10, 119-120.

Watts, R. & Sawyer, E. (1975) Aerodynamics of a knuckleball. American Journal of Physics, 43, 960-963.

Williams, T.S. & Underwood, J. (1982) The Science of Hitting Simon and Schuster. New York.

Winograd, S. (1942) The relationship of timing and vision to baseball performance, Research Quarterly, 13, 481-493,

Yonas,A., & Pittenger,J. (1973) Searching for Many Targets: An Analysis of Speed and Accuracy. Perception and Psychophysics, 13, 513-516.

Zelaznik, H., Hawkins, B., & Kisselburg, L., (1983) Rapid Visual Feedback Processing in Single-Aiming Movements. Journal of Motor Behavior, 15, 217-236.

APPENDICES

APPENDIX A
SURVEY QUESTIONNAIRE

Batting Questionnaire

Name (optional)____________________

School____________________

Number of Years as a Baseball Coach__________.

Rate the questions based on your own experience and opinions. The main question is which cues are useful to the batter and which are not in making a swing/no swing decision.

1. Which cues are batters most able to use during the first half of the flight of the pitch to determine which type of pitch has been thrown. Rate on a 1 to 4 scale, with 1 as least useful and 4 most useful.

		lst	sm	mr	mst
a.	The pitchers' motion or release.	1	2	3	4
b.	The velocity of the pitch.	1	2	3	4
c.	The spin of the ball.	1	2	3	4
d.	The initial location of the pitch.	1	2	3	4
e.	The flight trajectory of the pitch.	1	2	3	4

f. Other. Describe any other cues that you feel are useful to batters:____

2. Rate the following factors as to their importance to the batter in making a swing/no swing decision.

	lst	sm	mr	mst
a. The pitchers motion and release.	1	2	3	4
b. Looking for a certain pitch.	1	2	3	4
c. The spin of the ball.	1	2	3	4
d. The count.	1	2	3	4
e. The location of the ball.	1	2	3	4
f. The game situation.	1	2	3	4
g. The flight trajectory of the ball.	1	2	3	4
h. Knowledge of the particular pitcher.	1	2	3	4
i. The velocity of the ball.	1	2	3	4

k.Other (optional) ______________________________________

____

APPENDIX B
COACHES COMMENTS

The following are the optional comments that the surveyed batting coaches made in response to the batting questionnaire. The first number is the number of the individual survey that they returned, the second number is/are the question(s) they responded to, and the third number is the number of reported years of coaching experience.

103. 1-F. 12. "I teach our hitters to stride prior to the pitcher releasing the ball and then determine which pitch is thrown before swinging."

109. 1-F. 17. "Accurate and immediate fine focus on ball fron release point."

115. 2-J. 17. "So many variables and interrelated options?! One pitch, one spot; 1/9 zone; 1/4 zone; whole zone; widen zone."

116. 2-J. 9. " Knowing the pitcher, watching/learning from previous hitters or previous times at bat."

2-J. " Batter's individual strike zone window and is the pitch in it according to b,c,e,g,i."

117. 1-F. "Catcher's stance/position"

119. 1-F. 16. "Obviously you are aware different batters are and can be equally effective using different cues. Spin, trajectory and velocity being the ones most used. I

believe good hitters most often anticipate and visualize a certain pitch in a certain area and picture hitting that ball when it happens. The only decision at the plate then being a <u>no swing</u> decision when a different pitch is thrown."

124. 1-F. 32. "Position of ball as it leaves pitchers hand. A lot of white breaking ball, flat ball - fast ball."

127. 1-F. 18. "Find center on specific area of pitcher, hat (letter) etc - before delivery."

129. 1-F. 30. "Grips."

2-J. "Movement."

APPENDIX C

SCHOOLS SURVEYED

Washington State University

University of Washington

University of Utah

California State University Hayward

California State University Long Beach

California State University Northridge

New Mexico State University

Portland State University

University of California Davis

Arizona State University

University of Puget Sound

University of Arizona

University of Portland

Sonoma State University

Western New Mexico University

University of Northern Colorado

University of Nevada Reno

Fresno State University

Willamette University

Lewis and Clark College

Pacific University

Seattle University

APPENDIX D

SURVEY QUESTION # 1 - ITEM ANALYSIS

Survey 1a

Mean	Std.Dev	Std. Error	Variance	Count
2.773	1.02	.218	1.041	22
Minimum	Maximum	Range	Sum	Sum2
1	4	3	61	191

Survey 1b

Mean	Std.Dev	Std. Error	Variance	Count
2.636	.79	.168	.623	22
Minimum	Maximum	Range	Sum	Sum2
1	4	3	58	166

Survey 1c

Mean	Std.Dev	Std. Error	Variance	Count
2.909	.921	.196	.848	22
Minimum	Maximum	Range	Sum	Sum2
1	4	3	64	204

Survey 1d

Mean	Std.Dev	Std. Error	Variance	Count
2.682	1.041	.222	1.084	22
Minimum	Maximum	Range	Sum	Sum2
1	4	3	59	181

Survey 1e

Mean	Std.Dev	Std. Error	Variance	Count
2.818	.958	.204	.918	22
Minimum	Maximum	Range	Sum	Sum2
1	4	3	59	181

APPENDIX E

SURVEY QUESTION # 2 ITEM ANALYSIS

Survey 2a

Mean	Std.Dev	Std. Error	Variance	Count
2.091	.921	.196	.848	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	46	114

Survey 2b

Mean	Std.Dev	Std. Error	Variance	Count
2.864	.834	.178	.695	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	63	195

Survey 2c

Mean	Std.Dev	Std. Error	Variance	Count
2.773	.752	.16	.565	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	61	181

Survey 2d

Mean	Std.Dev	Std. Error	Variance	Count
3.136	.64	.136	.409	22
Minimum	Maximum	Range	Sum	Sum^2
2	4	2	69	225

Survey 2e

Mean	Std.Dev	Std. Error	Variance	Count
3.455	.912	.194	.831	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	76	280

Survey 2f

Mean	Std.Dev	Std. Error	Variance	Count
2.227	.685	.146	.47	22
Minimum	Maximum	Range	Sum	Sum^2
1	3	2	49	119

Survey 2g

Mean	Std.Dev	Std. Error	Variance	Count
3	.69	.147	.476	22
Minimum	Maximum	Range	Sum	Sum^2
2	4	2	66	208

Survey 2h

Mean	Std.Dev	Std. Error	Variance	Count
2.682	.839	.179	.703	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	59	173

Survey 2i

Mean	Std.Dev	Std. Error	Variance	Count
2.636	1.049	.224	1.1	22
Minimum	Maximum	Range	Sum	Sum^2
1	4	3	58	176

APPENDIX F

PERCEPTUAL VERSUS CONCEPTUAL ITEM ANALYSIS

perceptual factors

Mean	Std.Dev	Std. Error	Variance	Count
2.755	.365	.078	.133	22
Minimum	**Maximum**	**Range**	**Sum**	**Sum^2**
2	3.6	1.6	60.6	169.72

conceptual factors

Mean	Std.Dev	Std. Error	Variance	Count
2.705	.51	.109	.26	22
Minimum	**Maximum**	**Range**	**Sum**	**Sum^2**
1.5	3.5	2	59.5	166.375

APPENDIX G

ANALYSIS OF PITCHES

Pitch Condition	Mean # of Frames	s	Mean Velocity
Pitcher-underspin	11.75	.71	76 mph
Pitcher-overspin	12	.52	75 mph
Machine-underspin	11	.52	82 mph
Machine-overspin	11.25	.46	80 mph

Pitch Condition	Mean # of Revolutions	s	R/sec
Pitcher-underspin	13.8	.64	27.6
Pitcher-overspin	14.8	.57	29.6
Machine-underspin	13.6	.50	27.2
Machine-overspin	15.12	.52	30.2

APPENDIX H

SUBJECT INSTRUCTIONS

1. The purpose of these trials is to see how well you can read the direction of rotation of an approaching baseball.
2. You will be looking at film of baseballs being thrown in different conditions.
3. Sometimes a human will be thowing the ball, sometimes the ball will be thrown by a pitching machine.
4. During some of the trials you will see the full flight of the ball, during other trials you will see the first half of the flight of the ball.
5. Your task is to carefully watch the ball and try to read it's direction of rotation.
6. You will see one of two possible direction of rotation in each trial, either overspin, as with a curveball, or underspin, as with a fastball.
7. After each trial you will circle on your score sheet which direction you thought the ball was rotating, either overspin or underspin.
8. You must record a response for every trial.
9. Do not try to second guess what you think a trial might be in advance. Respond individually to each trial without regard for previous trials.

APPENDIX I

SUBJECTS

Subject Group	Mean Age	s	Mean Baseball Years	s
Non-baseball	20.9	2.5	2.2	2.45
Baseball	20.3	1.4	11.9	1.91

ANOVA : baseball subjects age versus non-baseball subjects age : $f = 1.6$, .10 , $p \leq .25$

ANOVA : baseball subjects years baseball experience versus non-baseball subjects years baseball experience : $f = 322.265$, $p \leq .0001$.

N - Baseball = 30

N - Non-baseball = 30

APPENDIX J

SUBJECT DATA SHEET

Name_______________________________

Age________

Class Standing____________________

S#_________

===

BASEBALL PLAYERS

Numbers of years playing experience in organized baseball:

Professional major league ______

Professional minor league ______

College ______

High School ______

Babe Ruth ______

American Legion ______

Little League ______

Other :________________________ ______

Position/s _________________________________

Batting Average Last Season ___________

Bat: Right-handed______ Left-handed______

Switch_______

Handwriting: Right hand_____ Left hand_____

===

NON BASEBALL PLAYERS

Number of years playing experience in organized baseball

Professional major league ______

Professional minor league ______

College ______

High School ______

Babe Ruth ______

American Legion ______

Little League ______

Other :________________________ ______

Position/s_____________________________________

Batting Average Last Season ______

Bat: Right-handed_____ Left-handed_____

Switch_____

Handwriting: Right hand_____ Left hand_____

APPENDIX K

VISION SCREEN FORM

VISION CHECK

Corrective lenses worn. yes_____ no_____

If yes, which type: Contacts_____ Glasses_____ Bifocals_____

Do you have them with you currently? ______

Correction required for: near-sightedness______ far-sightedness______ astigmatism______ eye movement problems______

Describe any visual conditions requiring medical attention; congenital, acquired, injury induced or any other situation. None______

Describe____

____

____

____

____

==

Office use only

Subject Status: accept/reject ______