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Baseball rebound velocities from wooden and aluminum bats

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BASEBALL REBOUND VELOCITIES FROM
WOODEN AND ALUMINUM BATS

A Thesis

Presented to

The Faculty of the Department of Physical Education
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By

Robert Diggle

December 1989

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ABSTRACT

BASEBALL REBOUND VELOCITIES FROM WOODEN AND ALUMINUM BATS

by Robert Diggle

The purpose of this study was to compare baseball rebound velocities from aluminum and wooden bats. Three aluminum and two wooden bats were used. All bats were matched for center-of-mass, circumference at the handle and COP, length, and weight. A pitching machine projected baseballs towards the stabilized bats. A vice attached to a sawhorse stabilized the bats. Baseballs impacting the bats inside the COP area and rebounding within 10° of the vertical plane of the bat were measured. A high speed LOCAM camera filmed the trials. A VCR filmed impact location which was also verified by chalking each ball so that it left an imprint upon the bats.

A one-factor analysis of variance for baseball rebound velocity among bats, significance level .05, was calculated. There were no significant differences among the bats. The results supported the research hypothesis.

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Chapter 1

INTRODUCTION

Wooden bats have been used in major league baseball since its inception almost 100 years ago. In 1974, the National Collegiate Athletic Association legalized the use of aluminum bats, with these now being the predominant bat used at the high school and college levels. Aluminum bats are not permitted for use in professional baseball (Bryant, Burkett, Chen, Krahenbuhl, & Lu, 1977a; Lloyd, 1980; M. Marquess, personal communication, May 16, 1985). During the time of the advent and acceptance of the aluminum bat into high school and college baseball, offensive production rose (Ricci, 1978). With this increase, questions about performance aspects of the aluminum bat arose. The most common questions related to rebound velocity and the reasons for differences between aluminum and wooden bats for post-impact velocity (Bryant et al., 1977a; Heald, 1985; Piziali, 1976).

Many college coaches, ex-college coaches, and researchers believe that baseballs rebound off the aluminum bat with greater velocity (Bryant et al., 1977a). Other investigators suggest there is no difference between wooden and aluminum bats (Heald, 1985; Lloyd, 1980; Mitchell, 1983; Piziali, 1976).

Statement of Problem

The reasons for differences between wooden and aluminum bats are clouded by controversy, particularly on performance characteristics. Several studies present conflicting evidence concerning performance characteristics of the two types of bats. Performance characteristics that have been reviewed for this study include rebound velocity, center of percussion (COP), hit distance, and offensive statistics (Bryant et al., 1977a; Heald, 1985; Lance, 1974; Mitchell, 1983; Piziali, 1976; Ricci, 1978).

Major university coaches from Stanford, Southern California, and Arizona State are at odds concerning the rebound velocities obtained from the two bat types. Mark Marquess (personal communication, May 16, 1985), head baseball coach at Stanford University, believes that no difference exists between wooden and aluminum bats for performance characteristics. His belief that balls do not have greater rebound velocity from either wooden or aluminum bats is supported by Piziali (1976). Rod Dedeaux, head baseball coach at the University of Southern California, and Jim Brock, head baseball coach at Arizona State University (Bryant, et al., 1977a), believe that rebound velocity is greater from an aluminum bat. They believe balls have more velocity coming off of an aluminum bat because the aluminum bat has a larger "sweet spot" or COP, as evidenced by the Bryant, Burkett, Chen, Krahenbuhl, and Lu study (1977b).

The COP is the critical area on a baseball bat for striking a ball. When a ball is struck at the COP minimal force is transmitted to the handle and rotation point of the bat. A ball struck away from the COP transmits forces to the handle. The further from the "sweet spot" a ball is struck the more force is transmitted into the handle. This leaves less force for driving the ball. The closer a ball is contacted to the COP, the greater the chance of a well-hit ball (Blanksby, Elliott, & Ellis, 1980; Bryant, et al., 1977a; Heald, 1985; Johnson, 1957).

The role of a coach is to assist players in selecting the best equipment for play. The issue at stake was which bat type would produce better results. Previous studies did not take into account bat speed and no performance measure was investigated for COP, although the COP and COP areas were measured (Bryant, et al., 1977a; Heald, 1985; Lance, 1974; Mitchell, 1983). Controlling for these variables, bat speed and measuring baseball rebound velocity impacting bats within the COP area, should help improve upon the past studies. The results of this study should assist in resolving the issue of which bat type, if either, will perform the best.

Purpose of Study

The purpose of this study was to determine which bat type was best for use in baseball games by comparing

baseball rebound velocities from stationary wooden and aluminum bats.

Research Hypothesis

No significant differences will exist among baseball rebound velocities from wooden and aluminum bats, when the bat is impacted by the baseball within the COP area.

Delimitations

This study was delimited to baseball rebound velocity within the COP area for one bat type from two wooden bat manufacturers and one bat type from three aluminum bat manufacturers. Baseballs were projected at 49 MPH. Diamond college approved baseballs were used in the testing.

Limitations

Baseball liveliness standards have not been established for amateur baseball (Baseball Liveliness Standards, 1978). This variable was not considered in this study. Only one bat from each manufacturer was used in this study. There is a possibility of variations in like models. Only 30 pitches were measured, pitch velocity may have varied across trials. Movement of the bat holding device limits this study.

Assumptions

Slight variations in pitch speeds were assumed to be randomly distributed across trials. Baseballs were assumed to be similar in liveliness. The bat holder was assumed to be displaced similarly across trials. Extra bats were

assumed to be manufactured the same as the tested models, and therefore performance characteristics were constant.

Definition of Terms

Center of Mass -- that point at which all the body's mass seems to be concentrated. The point of application of gravity's force on a mass (Kreighbaum & Barthels, 1985, p. 642).

Center of Percussion -- an exact point on the bat where reaction forces are the smallest and the greatest impact force is produced (Bryant et al., 1977a, p. 508).

Center of Percussion Area -- an area found on some aluminum bats where reaction forces are small and great impact force is produced.

Coefficient of Restitution -- relative bat-ball velocities before and after impact (Piziali, 1976, p. 4).

Impulse -- the force applied to the bat by the moving ball (Hay, 1978, p. 75).

Rebound Velocity -- post impact speed of the ball (Blanksby et al., 1980, p. 611).

Period--time elapsed for 50 complete swings of a bat freely suspended, divided by 50.

Pivot Point -- point around which the bat rotates.

Summary

Traditionally wooden bats have been used in professional baseball. College and high schools legalized the use of aluminum bats in the middle 1970's. Concern and

controversy exist relative to performance differences between the two bats. The controversy centers around the rebound velocity of baseballs off the aluminum and wooden bats. The purpose of this research project was to determine which bat would perform best by measuring baseball rebound velocity within the COP area of aluminum and wooden bats.

Chapter 2

REVIEW OF LITERATURE

Literature was examined for information on performance characteristics of aluminum and wooden bats. Topics reviewed included COP, hit distance, rebound velocity and offensive statistics for wooden and aluminum bats. These investigations have produced mixed results concerning the wooden versus aluminum bat controversy. The review of literature was organized into the aforementioned topics. The following is an overview and summary of related research for this study.

Rebound Velocity

Bryant, et al. (1977a) found mean rebound velocities of baseballs to be greater from aluminum bats than wooden bats. In the experiment six collegiate baseball players were tested during batting practice. Balls were thrown by a pitcher at an average speed of 56.6 mph. Rebound velocities were measured by electromagnetic radiation radar with only line drive hits used for measurement. Each subject batted until 30 timed line drives were recorded for both the wooden and aluminum bats. Each subject demonstrated a higher mean rebound velocity with the aluminum bat. The mean rebound velocities for the wooden and aluminum bats were 88.64 mph and 92.49 mph, respectively. The results of an analysis of variance indicated a significant ($p < .003$) difference

between rebound velocities of balls struck by wooden bats (88.64 mph) and aluminum bats (92.49 mph).

Another rebound velocity study was conducted by Baker and Wilson (1978) using cinematography to determine ball velocity after impact from tennis rackets of different string tensions. A Prince tennis ball machine projected tennis balls at vice held rackets at $100 \text{ mph} \pm 10 \text{ mph}$. Each ball/racket impact was photographed using a 35 mm camera with Tri-X film. The camera was triggered by a photoelectric relay. The relay was activated as the ball left the ball machine. Cinematography at 500 fps was used in a pilot study to determine the exposure rate to allow measurement of maximum racket head deflection from a stroboscopic film record.

Similar techniques have been used for post impact ball velocity measurements. Stroboscopic photography and accelerometry techniques were used to measure rebound velocities of tennis balls from various locations on conventional and oversized rackets in a study done by Blanksby et al. (1980). A ball machine projected balls at 21 meters per second towards hand held rackets. A photoelectric cell, positioned from the exit of the ball machine, activated the stroboscope lamp in time to record ball rebound images on a time-exposed single 35 mm negative. The stroboscope was preset at 100 flashes per second. A Nikon camera with the f-stop set at 1.2 and a 50 mm lens

were set on a tripod one meter from the path of the ball. The film was pushed to an ASA rating of 1600 during developing. Results of this study indicated a larger optimal impact area for the larger rackets. The authors concluded that a larger impact area results in higher rebound velocities for off-center hits.

A rebound velocity study conducted by Lloyd (1980) tested Easton aluminum bats for sound and playability with professional baseball players. Each player took batting practice with a wooden and an aluminum bat. After batting practice, Lloyd interviewed the players. The majority of players concluded that rebound velocity was the same for aluminum and wooden bats.

Rebound Velocity and Hit Distance

The Rawlings Sport Company Engineering Department (Mitchell, 1983) found no difference in the performance of wooden and aluminum bats. The variables measured in this study were the distance the baseball traveled in the air and the speed of the baseball after impact. A radar gun measured baseball velocity. Where the baseballs landed was marked and the distance from home plate measured in feet. There were 878 hits measured for distance and 457 hits measured for speed. Twenty-one college baseball players were used as subjects. Data were acquired during live batting practice with a radar gun recording rebound velocities. The distances each baseball traveled in the air

were measured in feet. This study found no significant difference in average rebound velocity, number of hits over 80 mph, or in hitting distance.

Hit Distance

Other investigations concerning hit distance have been conducted. The Stanford Hit Distance Test (Piziali, 1976) concluded that there was no difference in hit distance between aluminum and wooden bats. The parameters that affect hit distance and that were measured in this experiment were: (1) power of the player; (2) weight and balance of the bat; (3) relative speed of the bat and the ball, and the resultant speed of the ball off the bat; and (4) friction of the ball on the bat.

According to Piziali, the power of a player is constant and independent of the aluminum versus wood question. Length, weight, and balance points of aluminum bats have been found to be comparable to wooden bats and present no fundamental differences according to Piziali (1976). Friction characteristics can easily be varied for the two types of bats and present no fundamental differences.

The final variables, the relative speed of ball and bat before and after impact, were considered the significant variables in the Piziali (1976) study. The coefficient of restitution of the ball and bat was measured to determine if this variable was significant. Bats were placed in a clamp to a pivot point and were free to rotate. The balls were

projected from a pitching machine. A photo transistor array produced an impulse as the ball blocked some of the light hitting the array. Electronic timers measured the time between impulses. Speed of the ball before impact was calculated by determining the distance between the two arrays and the time it took the ball to travel between them. The rebounding ball was measured the same way. Photo transistors were located behind the bat with lights overhead. As the bat rotated backwards its shadow covered the transistors. Using the same process for ball speed, the speed of the rotating bat was calculated. From these data the coefficient of restitution was computed (Appendix A). The coefficient of restitution of wooden and aluminum bats showed only slight differences. The aluminum bat had a greater coefficient of restitution by .022, a very small difference says Piziali. Significance level was not indicated. Piziali suggests from the data that aluminum bats will not hit balls farther than wooden bats.

An investigation of the comparative effects of distance hitting of aluminum and wooden bats was also conducted at the University of Southern Mississippi (Lance, 1974). Three Youth League-approved wooden and aluminum bats of 28 in, 29 in, and 30 in lengths were tested for distance hitting. A springloaded bat swing machine, designed by Lance, and 45 volunteer Youth League baseball players (ages 8-9) were used to test the six bats. A batting tee was used for all

trials. Baseballs were hit off the batting tees and the distances to where the balls landed were measured. The three wooden bats had a significantly greater hitting distance than the three aluminum bats ($p < .01$). This is the only study to indicate a significant difference in hit distance.

Center of Percussion

The second Bryant et al. (1977b) study determined the COP of baseball bats. The COP was tested by a device built by the Arizona State University College of Engineering. The device consisted of four components: (1) a bat holder; (2) a load cell; (3) an impulse amplifier; and (4) an x-y recorder. The bat holder measured the COP. When a ball hit the COP the bat oscillated and did not activate the load cell plate. A ball missing the COP would force the bat to oscillate activating the load cell plate. This was detected by four sensor strain gauges. Center of percussion could be determined by watching the measured magnitudes of impulses at the bat handle. The amplifier displayed impulses on its own scale or on the external x-y recorder.

The same bats used in the first Bryant et al. (1977a) study were used in the second study. The bats used were: (1) a Slugger wood; (2) a Slugger aluminum; (3) a Worth aluminum; and (4) an Easton aluminum. The bats were placed in the bat holder. Center of percussion was determined by striking the bats with a ball every

centimeter, starting at the barrel. The impulse of the ball was kept constant by keeping the radius of rotation constant and the angle of release constant. A ball on a string delivered the impulse.

Results from this COP study showed distinct centers of percussion on the wooden and Easton aluminum bats. The other two aluminum bats had a large flat COP area.

Center of Percussion and Hit Distance

Heald (1985) found no difference in hit distance between wooden and aluminum bats. He measured bat weight, bat weight distribution, and pitch velocity. Heald had four collegiate baseball players hit baseballs with wooden and aluminum bats at speeds of 75 and 90 mph. Baseballs were marked where they landed and the distance was measured. This study used a method similar to Bryant et al. (1977b) for determining COP (exact schematics were unavailable). Although bat types were not indicated in this study, a larger COP area was found on the aluminum bat. However, no performance measure was conducted for the COP. Weight and weight distribution of the bats were not significantly different.

Comparison of Offensive Statistics for Bats

Offensive statistics of baseball teams using wooden and aluminum bats were studied by Ricci (1978). Colleges in the New England states provided the statistics for the study. Teams must have used wooden bats for a

minimum of three years during the 1966-73 seasons and aluminum bats for a minimum of three years during the 1973-77 seasons, in order to be included in this study. A t -test was used to compare batting averages and slugging averages of the two types of bats. The t -test showed both batting and slugging averages to be significantly higher ($p < .05$) when the teams used aluminum bats.

Summary

The findings of the literature concerning performance characteristics of wooden and aluminum bats are mixed. Two studies on rebound velocity indicated no difference exists (Lloyd, 1980; Mitchell, 1983). The study by Bryant et al. (1977a) found rebound velocity to be greater for aluminum bats. Three of four hit distance studies (Heald, 1985; Mitchell, 1983; Piziali, 1976) confirm the no difference conclusions between the bats. However, Lance's (1974) study confuses the research, indicating a significantly greater hit distance for wooden bats.

Some of the differences in performance characteristics of the two types of bats have been attributed to a larger "sweet spot" (Bryant et al., 1977a). This theory is supported by Blanksby et al. (1980) in a tennis racket study for COP. Blanksby concluded that a larger COP area would result in higher rebound velocity for off-center hits. Bryant et al. (1977b) found a distinct COP point on wooden and Easton aluminum bats. The COP for the Worth and

Louisville Slugger aluminum bats had larger COP areas. Another study for COP by Heald (1985) also found aluminum bats to have larger COP areas.

The final area studied that indicated differences between wooden and aluminum bats was in offensive statistics. Ricci (1978) found teams using aluminum bats had higher batting and slugging averages than teams using wooden bats.

The evidence on aluminum and wooden bats leads to no distinct conclusion. Some research points to possible differences due to a larger COP area on aluminum bats. However, none of the studies measured baseballs contacted just in the COP area. The review of available literature shows that continued research is warranted.

Chapter 3

METHODOLOGY

Introduction

This study was designed to improve upon previous baseball rebound velocity and bat investigations. Controlling for bat speed and doing a performance measure for COP assisted in improving upon past studies. The intent of the study was to find out which bat produced the greatest rebound velocity so that the players might be able to select the best equipment.

Pilot Study

A pilot study was conducted to determine film speed, impact location, expected rebound velocity, pitch speed, necessity of videography, distances for instrumentation placement, and acceptable range of angles for a measured rebound.

Instrumentation

Bats. Three aluminum and two wooden bats were utilized in this study. Extra bats of the same makes and models were available in the event of bats breaking and/or any other problems that would have affected the results and data collection. The aluminum bats were an Easton B-9, a Louisville Slugger, and a Worth. The wooden bats were a Louisville Slugger and a Worth. The bats were matched for length, weight, circumference at the handle, circumference

at the COP area, and center of mass (Table 1). The COP of each bat was determined using Johnson's formula (1957, Appendix B). One-half inch red tape was placed around the bats, 3 cm to each side of the COP. Thus, the COP area was 6 cm wide (Bryant et al., 1977b). Bat order of selection was counter-balanced. The counter balancing was accomplished by rotating bat #1 used in the first set of trials to bat #5 in the second set of trials. The #2 bat rotated to the #1 bat in the second set of trials, the #3 bat rotated to #2, etc. Each bat thus was in the #1 through #5 positions 3 times during the 15 sets of trials. Each trial consisted of five impacts. There were 15 sets of trials, for a total of 75 impacts per bat. Only impacts that occurred within the COP area and were within 5° in either direction of the vertical plane were included in the final analysis. The bats were stabilized to a saw horse, using a vice clamp, 1 m above the floor. The 4 inch vice clamped the bats starting 4 inches and ending 8 inches from the handle, or approximately where a hitter's top hand holds the bat. The legs of the saw horse were placed in 5 gallon buckets filled with sand to assist in stabilizing the bat holding device.

Balls. Diamond college-approved baseballs were used for this study. Each ball was used 25 times, 5 times for each bat type and trial (one set of trials). The balls were covered with a white chalk to leave an imprint on the bat.

Table 1

Bat PropertiesStandard Bat Dimensions: Length 34 inches; Weight 31 ounces

Bat Model	COP	Center of Mass	COP Circum- ference	Handle Circum- ference
Easton aluminum	26.00	18.75	8.00	3.25
Louisville aluminum	26.00	18.63	8.00	3.25
Worth aluminum	26.60	19.63	7.88	3.19
Louisville wood	25.30	19.70	8.00	3.25
Worth wood	24.70	19.63	7.75	3.25

*Bat properties are in inches. COP and center of mass are from bat handle end.

Subsequently, each trial was checked to determine if the ball contacted the bat within the COP area. If the rebound was not within 5° in either direction of the vertical plane of the bat, it was not measured. Trials continued until 75 bat/ball impacts occurred.

Pitching Machine. A Casey Pitching Machine projected balls at a velocity of 49 mph. Pitch velocity was determined by calculating an average of 30 consecutive pitch speeds (Appendix F). The dials on the pitching machine that controlled pitch velocity were set at 3-1/2 for the top wheel and 4-1/2 for the bottom wheel. These settings kept pitch velocity at 49 mph. The machine was directly in line

with the COP at a height of 1.5 m and a distance of 2.7 m from the bat (Appendix C).

Cinematography. A 16 mm LOCAM high speed camera, at a transport speed of 100 fps, recorded each trial. The camera speed was set at 100 fps to precisely record ball velocity prior to and just after impact. The LOCAM had a shutter factor of $1/3$, thus resulting in an exposure time of $1/300$ sec. The shutter factor and exposure time allowed enough light in for a clear picture. The camera was positioned perpendicular and to the right hand side of the bat. The camera was 1.06 m above the ground and 2.52 m from the bat. Distances for instrumentation placement are shown in Appendix C. The filming recorded the rebound angle. Only balls that were within 5° of vertical in either direction were measured, all other trials were stricken from the analysis. Speed of the pitched ball was controlled by the setting on the pitching machine and verified by high speed film analysis. A Bell-Howell 16 mm film analyzer projected film frames onto a screen. The rebound velocities were hand measured frame-by-frame using Dr. Ken Young's protocol, physics professor at the University of Washington (personal communication, December 27, 1988). From the images projected onto the wall screen and using a protractor, lines were drawn from the center of the bat at a 5° angle above and below the bat. Any part of the baseball that was inside the 10° angle two frames after impact, and that impacted the

bat within the COP area, was considered a valid impact. The average of 3 successive ball image tracings were used to calculate ball velocity for each trial. A tracing of the outer edge of the baseball furthest from the bat was made for each measured impact. The distances between the three successive tracings were measured and an average distance determined. Post impact baseball velocity was calculated by knowing the average distance the baseball traveled in one frame, the film speed, and by plugging these two known variables into Dr. Young's formula. The formula may be found with the raw data for 30 repeated measurements on Page 45 (Appendix F). The 30 pitch velocities were calculated the same way that rebound velocities were calculated (Appendix F). Investigator reliability in digitizing points was established prior to reduction of data by applying the Pearson Product Moment Correlation to a series of 30 repeated rebound velocity coordinate measurements.

Analysis of Data

A one factor analysis of variance for rebound velocity, significance level .05, was calculated to determine if there was a significant difference in rebound velocity between the bats. In addition, mean pitch velocities, range, and standard deviation, as well as mean rebound velocities, range, and standard deviation, were measured.

Summary

A pilot study was conducted to determine instrument reliability and placement. Three aluminum and two wooden bats from major bat manufacturers were used in this research project. Extra bats of the same makes and models were available in the event that something happened to the testing bats. The bats were matched for weight, length, COP, center of mass, and circumference at the COP and handle. The balls were projected at each bat 75 times. Baseballs rebounding within the COP area and within 5° in either direction of the vertical plane of the bats were counted in the statistical analysis. Digitizing the rebound velocities was accomplished by projecting film frames onto a screen. An ANOVA was calculated to determine any significant difference between bats.

Chapter 4

RESULTS AND DISCUSSION

The pilot study determined that film speed of 100 fps was sufficient to measure pitch and rebound velocities. Chalk was used to leave an imprint of the ball on the bats, showing the impact location of each trial. Also, a video tape recorder (VCR) filmed the testing to verify impact location. Pitch velocity was found to be most accurate at 49 mph. When pitch velocity increased or decreased from 49 mph, pitch accuracy was much less consistent.

The properties of the bats--length, weight, COP, center of mass, and circumferences at the handle and COP--are recorded in Table 1. From this table it was evident that there were only small variations between the bats.

Descriptive statistics for measuring pitch velocities of 30 pitches may be found in Table 2. A Pearson-Product Moment Reliability Correlation for 30 repeated rebound velocity measurements produced an r -value of 1 (Appendix D).

Table 2

Statistics for 30 Pitch Velocities (Hayslett, 1968)

Pitches	Mean Velocity	High	Low	Range	Standard Deviation
30	48.75	49.10	47.00	2.10	.51

*All numbers are in mph.

Mean baseball rebound velocities, ranges, and standard deviations may be found in Table 3. Although there was a large range in rebound velocities, there was little variation in the means. The Worth wood bat had a larger standard deviation. This may be attributed to the fact that it had less measurable impacts than the other bats. There were 375 impacts of which 104 were measurable. The other 271 impacts either didn't contact the bats within the COP area or rebounded outside the acceptable angles. Twenty-eight percent, an average of 21 per bat, were counted in the final analysis, a fairly small sample size. A small sample decreases the chance of finding a significant difference among bats (Appendix F).

Table 3

Range, Mean and Standard Deviation of Rebound Velocities
(Hayslett, 1968).

Bat	Range	High	Low	Mean	Standard Deviation
Easton aluminum	1.90	16.90	15.00	15.95	.88
Louisville aluminum	3.80	18.8	15.00	15.87	.97
Worth aluminum	3.95	16.90	12.95	15.67	1.20
Louisville wood	3.30	16.90	13.60	15.63	.74
Worth wood	3.95	16.90	12.95	15.36	1.97
All bats	5.85	18.80	12.95	15.69	1.11

*All numbers are in mph.

No significant difference in mean rebound velocity between bats existed according to the one-factor ANOVA statistical treatment ($p < .05$) (Appendix E). The statistical analysis supported the research hypothesis.

Discussion

Two important design aspects of this study were bat velocity control and impact around the COP of the bats. Given two bats of equal properties (length, weight, weight distribution, etc.), the bat that is swinging faster will theoretically generate more force (Piziali, 1976). By using a vice-clamp the bat velocity was controlled. Stabilizing the bat gave a constant bat velocity measurement. Knowing each bat velocity led to a strong conclusion for the resultant rebound measurement. The pitching machine controlled pitch velocity and thus bat and ball velocity measurements were simplified. This study differs from several other studies in regard to bat velocity measurements (Bryant et al., 1977a; Heald, 1985; Lance, 1974; Mitchell, 1983) by controlling for bat speed.

The Rawlings Sports Company study (Mitchell, 1983) supports the results of this study for rebound velocity, but it did not measure bat speed. Lance (1974) found wooden bats to be significantly different from aluminum bats in hit distance. Bryant et al. (1977a) found rebound velocity significantly higher for aluminum bats; however, neither Bryant et al. nor Lance measured bat velocity. The study

that controlled for bat-ball pre-impact velocity and most resembles this study was conducted by Piziali (1976). His conclusions were that aluminum bats do not hit baseballs further than wooden bats.

The COP area was the second important design aspect of this study. Performance measures were not conducted for COP in previous bat studies, despite researchers' citing a larger COP area as possibly having an effect on rebound velocity for aluminum bats. Blanksby et al. (1980) measured rebound velocity around the COP of tennis rackets. He found a larger COP area results in greater rebound velocity for off-center hits. The bat studies that did measure COP area (Bryant et al., 1977b; Heald, 1985) did not examine performance evaluations within the COP area. By measuring performance characteristics within the COP area, this study attempted to resolve the COP question.

Chapter 5

CONCLUSIONS, RECOMMENDATIONS, AND SUMMARY

The aluminum bat made its way into amateur baseball 15 years ago, and has found a home in high schools and colleges across America. The professional ranks have over 100 years of wooden bat tradition. Ever since the introduction and legalization of aluminum bats a controversy between the two bats has existed. Performance characteristics of the two bat types are at the heart of the controversy.

Research has been conducted in four areas of bat performance. The four areas are rebound velocity, hit distance, offensive statistics, and COP. Rebound velocity study results are mixed, ranging from no difference between the bats to aluminum bats having significantly greater velocities (Bryant, et al., 1977a; Lloyd, 1980; Mitchell, 1983). Hit distance research was similar to the rebound velocity findings with the exception of one study finding wooden bats to be significantly greater (Lance, 1974; Piziali, 1976). Offensive statistics were compared for batting and slugging averages of baseball teams using aluminum and wooden bats. Teams using aluminum bats had higher batting and slugging averages (Ricci, 1978). The fourth area of bat performance studied was COP. A larger COP on aluminum bats has been cited for the alleged difference in performance of the two bat types (Bryant, et

al., 1977b; Heald 1985). The theory that a larger COP area produces higher post-impact velocity for off-center hits was supported in tennis racket studies (Blanksby, et al., 1980). Bat performance in regard to COP had not been previously investigated for baseball bats.

The intent of this study was to investigate rebound velocity of aluminum and wooden bats. The uniqueness of the study was that it controlled for impacts within the theoretical COP area, as well as for bat velocity.

Conclusions

Findings of this study indicate there were no significant differences among the bats, although the aluminum bats had higher mean rebound velocities. Perhaps the alleged difference, as suggested by some researchers, of greater rebound velocity of baseballs being struck by aluminum bats can be found in the manufacturing of the bats. The advantage players have in using aluminum bats is in the controlled construction of the bats. The materials used for construction are the same for each aluminum bat. The wood bat may be only as good as the tree it was made from.

Recommendations

Several recommendations for future research are worth considering:

1. Amateur baseball should continue to use aluminum bats. Even though there were no significant differences

among bats, the mean rebound velocities of baseballs were higher from the aluminum bats.

2. Measure and compare all impacts of aluminum and wooden bats within 5 degrees of the vertical plane including those impacts outside the COP.

3. Stabilize the ball on a batting tee to control for pitch velocity and measure bat velocity as well as rebound velocity.

4. Use a bat swing machine with a stabilized ball to control for bat velocity.

5. Clamp bats to an immovable table.

6. Measure the coefficient of restitution of the bats under clamped conditions to determine if bat rigidity affects rebound velocity.

Summary

The invention and acceptance of aluminum bats in amateur baseball has created a controversy spanning the last 15 years. The question of which bat is best for performance is at the center of the controversy.

The research on the topics considered for this study leads to no clear cut conclusion. The conclusions from this investigation indicate neither bat performs better than the other. However, based on repeatability of design and manufacturing, it was recommended that amateur baseball continue to use aluminum bats.

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APPENDIXES

APPENDIX A
Coefficient of Restitution Equation

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APPENDIX B

Locating the Critical Hitting Zone in the Bat

APPENDIX C
Instrumentation Placement and Distances

Appendix C

Instrumentation Placement and Distances

Distances	To Bat Holder (COP)	Height Above _____
High speed camera	2.50 m	1.00 m
Pitching machine	3.00 m	1.60 m
VCR	4.70 m	1.37 m
Bat holder		1.30 m

APPENDIX D

Pearson Product Moment Reliability Correlation

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APPENDIX E
Analysis of Variance

Table 5

Analysis of Variance (Hayslett, 1968).

5 samples - 1 = 4; 104 observations - 4 = 100;

Fa (5-1, 104-4) = F_{.05} = 4,100

Fa = 2.53; F < 2.53

T₁ = 319.1

T₂ = 317.4

T₃ = 313.55

T₄ = 422

T₅ = 261.6

$$\frac{T^2}{n} = \frac{(1632.95)^2}{104} = \frac{2,666,525.7}{104} = 25,639.67$$

$$(16.9)^2 + (15)^2 + (16)^2 + (16)^2 = 25,746.18$$

$$SST = 25,746.18 - 25,639.67 = 106.51$$

$$SSC = \frac{(319.1)^2}{20} + \frac{(317.4)^2}{20} + \frac{(313.35)^2}{20} + \frac{(422)^2}{27} + \frac{(261.1)^2}{17} -$$

$$25,639.67$$

$$5091.24 + 5037.14 + 4909.41 + 6595.7 + 4010.19 = 25,643.68 -$$

$$25,639.67 = 4.01$$

$$SSE = 106.51 - 4.01 = 102.5$$

<u>Source</u>	<u>df</u>	<u>Sum of Squares</u>	<u>Mean sq.</u>
among	4	4.01	1.0025
within	100	102.5	1.025
Total	104	106.51	-

$$F = \frac{1.0025}{1.025} = .978$$

.978 < 2.53 accept Ho

APPENDIX F
Raw Data

Appendix F

Raw Data for 30 Repeated Digitizing Measurements
for Rebound Velocity

*2 inches = 1 foot. Film speed = 100 fps.

$$7/16 \text{ inch} = \frac{.22 \text{ ft}}{.01} = \frac{22 \text{ ft}}{1 \text{ sec}} = \frac{1320 \text{ ft}}{1 \text{ min}} = \frac{19200 \text{ ft}}{1 \text{ hour}} =$$

15 mph

$$13/32 \text{ inch} = \frac{.20 \text{ ft}}{.01} = \frac{20 \text{ ft}}{1 \text{ sec}} = \frac{1200 \text{ ft}}{1 \text{ min}} = \frac{72000 \text{ ft}}{1 \text{ hour}} =$$

136 mph

	<u>mph</u>		<u>mph</u>		<u>mph</u>
1.	7/16 = 15.00	11.	7/16 = 15.00	21.	7/16 = 15.00
2.	7/16 = 15.00	12.	7/16 = 15.00	22.	7/16 = 15.00
3.	7/16 = 15.00	13.	7/16 = 15.00	23.	13/32= 13.60
4.	7/16 = 15.00	14.	7/16 = 15.00	24.	7/16 = 15.00
5.	7/16 = 15.00	15.	7/16 = 15.00	25.	7/16 = 15.00
6.	13/32= 13.60	16.	7/16 = 15.00	26.	7/16 = 15.00
7.	7/16 = 15.00	17.	7/16 = 15.00	27.	7/16 = 15.00
8.	7/16 = 15.00	18.	7/16 = 15.00	28.	7/16 = 15.00
9.	7/16 = 15.00	19.	7/16 = 15.00	29.	7/16 = 15.00
10.	7/16 = 15.00	20.	7/16 = 15.00	30.	7/16 = 15.00
1.	7/16 = 15.00	11.	7/16 = 15.00	21.	7/16 = 15.00
2.	7/16 = 15.00	12.	7/16 = 15.00	22.	7/16 = 15.00
3.	7/16 = 15.00	13.	7/16 = 15.00	23.	13/32= 13.60
4.	7/16 = 15.00	14.	7/16 = 15.00	24.	7/16 = 15.00
5.	7/16 = 15.00	15.	7/16 = 15.00	25.	7/16 = 15.00

<u>mph</u>		<u>mph</u>		<u>mph</u>	
6.	$13/32 = 13.60$	16.	$7/16 = 15.00$	26.	$7/16 = 15.00$
7.	$7/16 = 15.00$	17.	$7/16 = 15.00$	27.	$7/16 = 15.00$
8.	$7/16 = 15.00$	18.	$7/16 = 15.00$	28.	$7/16 = 15.00$
9.	$7/16 = 15.00$	19.	$7/16 = 15.00$	29.	$7/16 = 15.00$
10.	$7/16 = 15.00$	20.	$7/16 = 15.00$	30.	$7/16 = 15.00$

Raw Data for 30 Repeated Digitizing Measurements

	X mph	Y mph	x^2	y^2	XY
1.	15.00	15.00	225	225	225
2.	15.00	15.00	225	225	225
3.	15.00	15.00	225	225	225
4.	15.00	15.00	225	225	225
5.	15.00	15.00	225	225	225
6.	13.60	13.60	185	185	185
7.	15.00	15.00	225	225	225
8.	15.00	15.00	225	225	225
9.	15.00	15.00	225	225	225
10.	15.00	15.00	225	225	225
11.	15.00	15.00	225	225	225
12.	15.00	15.00	225	225	225
13.	15.00	15.00	225	225	225
14.	15.00	15.00	225	225	225
15.	15.00	15.00	225	225	225
16.	15.00	15.00	225	225	225
17.	15.00	15.00	225	225	225
18.	15.00	15.00	225	225	225
19.	15.00	15.00	225	225	225
20.	15.00	15.00	225	225	225
21.	15.00	15.00	225	225	225
22.	15.00	15.00	225	225	225
23.	13.60	13.60	185	185	185
24.	15.00	15.00	225	225	225

	X mph	Y mph	x^2	y^2	XY
25.	15.00	15.00	225	225	225
26.	15.00	15.00	225	225	225
27.	15.00	15.00	225	225	225
28.	15.00	15.00	225	225	225
29.	15.00	15.00	225	225	225
30.	15.00	15.00	225	225	225
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
E	447.20	447.20	6670	6670	6670

Raw Data Rebound Velocity for Measurable Impacts

	Easton	Lou Alum.	Worth Alum.	Lou Wood	Worth Wood
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
	<u>mph</u>	<u>mph</u>	<u>mph</u>	<u>mph</u>	<u>mph</u>
1.	16.90	16.90	16.00	15.00	16.00
2.	15.00	16.90	16.90	16.90	16.90
3.	15.00	16.90	16.90	15.00	15.00
4.	16.90	15.00	16.90	16.90	12.95
5.	16.90	16.00	16.90	16.90	12.95
6.	16.00	16.00	15.00	16.00	16.90
7.	15.00	15.00	12.95	15.00	16.90
8.	16.90	15.00	15.00	16.90	16.90
9.	15.00	16.00	15.00	13.60	16.00
10.	16.90	15.00	16.00	15.00	16.00
11.	16.90	15.00	15.00	16.00	15.00
12.	15.00	16.00	15.00	15.00	14.30
13.	15.00	15.00	15.00	15.00	15.00
14.	15.00	16.90	15.00	15.00	15.00
15.	15.00	16.00	16.90	15.00	14.30
16.	16.90	15.00	15.00	15.00	16.00
17.	16.00	15.00	16.00	16.00	15.00
18.	15.00	18.80	16.90	16.00	M=15.36
19.	16.90	15.00	16.00	15.00	Range = 3.95
20.	16.90	16.00	15.00	15.00	
21.	M=15.95	M=15.87	M=15.67	16.90	
22.				16.00	

	Easton <u>1</u>	Lou Alum. <u>2</u>	Worth Alum. <u>3</u>	Lou Wood <u>4</u>	Worth Wood <u>5</u>
	<u>mph</u>	<u>mph</u>	<u>mph</u>	<u>mph</u>	<u>mph</u>
23.				16.00	
24.	Range 1.9	Range 3.8	Range 3.95	15.00	
25.				16.90	
26.				16.00	
27.				15.00	
				M=15.63	
				Range 3.30	

30 Pitches Mean Pitch Velocity

2 inches = 1 foot

1 6/16 inches = .69 ft = 47 mph

1 13/32 inches = .71 ft = 48.41 mph

1 7/16 inches = .72 ft = 49.1 mph

	mph		mph
1. 1 6/16 = 47.00		16. 1 13/32 = 48.41	
2. 1 7/16 = 49.10		17. 1 7/16 = 48.41	
3. 1 7/16 = 49.10		18. 1 6/16 = 47.00	
4. 1 7/16 = 49.10		19. 1 6/16 = 47.00	
5. 1 6/16 = 47.00		20. 1 7/16 = 49.10	
6. 1 7/16 = 49.10		21. 1 13/32 = 48.41	
7. 1 7/16 = 49.10		22. 1 7/16 = 49.10	
8. 1 7/16 = 49.10		23. 1 7/16 = 49.10	
9. 1 7/16 = 49.10		24. 1 7/16 = 49.10	
10. 1 13/32 = 47.41		25. 1 7/16 = 49.10	
11. 1 7/16 = 49.10		26. 1 7/16 = 49.10	
12. 1 7/16 = 49.10		27. 1 7/16 = 49.10	
13. 1 7/16 = 49.10		28. 1 7/16 = 49.10	
14. 1 7/16 = 49.10		29. 1 7/16 = 49.10	
15. 1 7/16 = 49.10		30. 1 7/16 = 49.10	

M = 48.75 mph