A KINEMATIC ANALYSIS OF THE BASEBALL BATTING SWINGS INVOLVED IN OPPOSITE-FIELD AND SAME-FIELD HITTING

THESIS

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By

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The purpose of the study was to examine selected mechanical factors involved in hitting a baseball to the same and opposite fields. Special emphasis was placed on an identification of those factors which distinguish players of different hitting abilities. Twenty male college level baseball players, ten in each of two groups, hit six pitched baseballs, three each to two assigned areas of the playing field. The movement patterns for the opposite field and same field batting swings appeared to be similar in form with differences between the two swings due to (a) differences in the angular displacements at the left wrist and left elbow joints and (b) differences in the temporal characteristics.

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CHAPTER I

INTRODUCTION

Hitting a baseball is a unique skill in that the performer attempts to hit a round ball with the curved surface of a bat. The nature of the contact surfaces and the rapid speed of the pitched ball increase the difficulties encountered in projecting the ball with the desired velocity.

Williams (1971) stated that one of the factors which distinguishes highly skilled batters from less skilled batters is an ability to hit the ball to all areas of the playing field. If the playing field were divided into two equal areas by a line extending from home plate through second base, the more highly skilled batters hit equally well to both areas. These two field areas are named according to the side of home plate at which a batter positions himself to receive the pitched ball, that is, the "opposite field" and the "same field".

The mechanical factors which contribute toward an ability to hit a ball to the opposite field have not as yet been clearly defined. Most of the documented explanations have been concerned with the point of contact between the bat and ball in relation to home plate. For example, Hay (1978) explained that a ball that is hit to the same field, or a "pulled" hit, is accomplished by initiating the swing of the bat early and contacting the ball in front of home plate. For an opposite field hit, the swing of the bat is initiated relatively late and contact is made with the ball as it passes over home plate. Williams (1971) stated that the primary differences between the two batting swings concern the location of the hands relative to the area of the bat where ball contact is to be made and the degree of extension at the lead elbow joint. For an opposite field hit the hands should precede the hitting area on the bat as contact is made with the ball, and for a pulled hit the hands should be behind the hitting area. The lead elbow joint should not be fully extended during the opposite field swing whereas for a pulled swing full extension should occur.

Considering the acknowledged importance of an ability to hit the ball to all areas of the playing field, it is somewhat surprising that little attention has been directed toward a scientific understanding of the differences in the batting swings involved in hitting the ball to the same field and to the opposite field. In addition, the characteristics of players of different hitting abilities with regard to these two swings have received little scientific study.

Purpose of the Study

The purpose of this study was to examine selected mechanical factors involved in hitting a baseball either to the same field or to the opposite field. Consideration was given to (a) kinematic parameters selected to describe the motion of the ball, the bat, and the performer, and (b) an identification of those factors which distinguish players of different hitting abilities.

Delimitations of the Study

The delimitations in the analysis of the baseball batting swing performances included the following:

1. Only young adult males with college baseball playing experience were used as subjects.
2. All subjects were right-handed batters.
3. The batting swing performances of each subject were evaluated on the basis of three performances for each condition.

Limitations of the Study

The limitations in the analysis of the baseball batting swing performances included the following:

1. Normal cinematographical analysis limitations were recognized.

2. The anatomical reference points necessary to make various computations were estimates for approximating the actual locations of these points on each subject.
3. The assumption was made that the subject movements occurred in a single plane perpendicular to the optical axis of a single camera.

Definition of Terms

The following definitions are presented to clarify terms that appear in the text and might be ambiguous:

Lead arm. The arm of the batter that is closer to the pitcher when a normal batting stance is assumed.

Tip of the bat. The end of the bat that is further from the hands when the bat is normally held.

Handle of the bat. The narrow portion of the bat that is gripped by the batter.

Angle of the bat and lead forearm. The angle formed by the intersection of the line joining the midpoints of each end of the bat and the line joining the styloid process of the left ulna and the lateral epicondyle of the left humerus.

Angle of the lead forearm and lead arm. The angle formed by the intersection of the line joining the styloid process of the left ulna and the lateral epicondyle of the left humerus and the line joining the lateral epicondyle and greater tubercle of the left humerus.

Angle of incidence. The angle that the direction of the velocity of the ball before impact makes with a line perpendicular to the surface of the bat at the instant of impact.

Angle of reflection. The angle that the direction of the velocity of the ball after impact makes with a line perpendicular to the surface of the bat at the instant of impact.

Inside pitch. A pitched ball which passes over that half of home plate which is nearest to the batter.

Outside pitch. A pitched ball which passes over that half of home plate which is furthest from the batter.

Opposite field. The area of a baseball field, for right-handed batters, bounded by lines extending from home plate through second base and first base.

Same field. The area of a baseball field, for right-handed batters, bounded by lines extending from home plate through second base and third base.

Opposite field hitting. Hitting the ball to the opposite field.

Pull hitting. Hitting the ball to the same field.

Power hitting. Hitting or attempting to hit the ball with great force.

Batting average. A numerical value which is determined by dividing the total number of base hits by the total number of at-bats.

Slugging percentage. A numerical value which is determined by dividing the total number of bases advanced by a batter on that batter's base hits by the total number of at-bats accumulated by the batter.

CHAPTER II

REVIEW OF LITERATURE

A review of related literature revealed that many books and articles have been written on the "art" of hitting a baseball. However, very few scientific studies have been conducted to identify or compare the mechanical factors involved in opposite field and same field hitting.

Hitting a baseball, without concern for the direction the ball travels after impact, has been studied by several investigators. Breen (1967) conducted a cinematographical analysis of major league batters and found that highly-skilled batters had the following characteristics:

1. The path of travel of the total body center of gravity was approximately level throughout the swing.
2. The batter adjusted his head during each pitch to obtain the best possible location from which to view the flight of the ball.
3. The lead elbow joint tended to extend fully at the beginning of the swing, which resulted in a greater linear velocity of the bat.
4. The length of the stride was approximately the same for all types of pitches.

5. After contact between the bat and ball, the weight of the body shifted to the front foot and the upper body moved in the same direction as the flight of the hit ball.

The velocity with which the bat is swung is apparently one of the most important factors in the swing. Hay (1978) explained that the linear velocity of the point on the bat with which the ball makes contact is the primary means by which the batter controls the force imparted to the ball. With all else being equal, the greater the linear velocity of this part of the bat, the greater the force imparted to the ball and the greater the resultant velocity of the ball after impact. Supportive evidence for the importance of the linear velocity of the bat at the instant of impact has been provided by Vaughn (1969).

Race (1961) found that the starting body position, or the stance, of a batter was not significantly related to batting average or slugging percentage. Breen (1967) found that the direction and length of the stride of the batter was approximately the same for all types of pitches. Based on these results it is reasonable to assume that differences in the motion of the bat cause the ball to travel in different directions.

An indication of the differences in the swings is provided by Swimley (1964) and Vaughn (1969). Swimley compared a power hitter with a hitter who attempted to hit to all fields. Vaughn compared the power swing with a swing used to obtain a high batting average. This latter swing generally produces hits consistently to all fields. Although both of these authors examined the power swing and a swing used to hit to all fields, similarities between these two swings and the swings involved in hitting a ball to the same and opposite fields, respectively, give an indication that mechanical differences may exist between the latter two swings. Swimley found that the power hitter had a greater angular velocity of the hips during the performance of the swing than the hitter who attempted to hit to all fields. Vaughn correlated the bat velocity, length of lever arm, which was defined as the distance from the tip of the bat to the axis of rotation through the left hand (for right-handed batters), and the angular displacement of the bat during the time intervals 0.01 and 0.03 seconds prior to ball contact with: (a) batting average, (b) slugging percentage, and (c) percentage of extra base hits. Vaughn concluded that a short swing, with a shorter range of motion of the bat, emphasizing the wrist action just prior to impact was more likely to yield a high batting average, whereas a longer swing with the elbows extended and emphasis on hip and arm rotation was more indicative of power hitting.

Several authors have discussed the factors relevant to hitting a baseball to different areas of the playing field. Williams (1971) termed the swing used when hitting to the opposite field the "inside-out swing". According to Williams, the mechanical factors of the opposite field swing that differ from the same field swing are that when hitting to the opposite field the elbow joints do not fully extend and the hands are ahead of the point on the bat where ball contact is made. Williams stated that the opposite field swing is "a panacea for pull-hitters who want to go to the opposite field, even on inside pitches. . . . also a remedy for big swingers who strike out often and the ideal protective swing on a two-strike pitch" (p. 42). Scott (1963) was of the opinion that directing the ball to the opposite field is determined by timing the wrist action so that the point on the bat where ball contact is made is behind the hands. Hay (1978) explained that the angle of incidence is the factor that a batter uses to direct the ball to the opposite field. That is, by swinging late and contacting the ball when it is over the plate, the batter obtains the angle of incidence necessary to accomplish an opposite field hit. Bunn (1972) noted that timing the swing to obtain the proper angle of incidence is the correct method for hitting to the opposite field. Bunn stated that

> To bat the ball in a given direction, the bat should be held so that, when it meets the ball, it makes an angle with the front edge of the plate which is equal to one-half the angle formed by the line made by the thrown ball with the line of the intended direction of

> flight. In order to allow for the movement of the bat and the spin of the ball, the bat should be held at a little less than one-half this angle. (p. 177)

In summary, a review of the literature related to the mechanics of hitting a baseball to the same and opposite fields revealed that while the mechanics of the two swings involve some similarities, adjustments apparently have to be made in the swing to direct the ball toward the opposite field. In addition, it would appear that the correct angle of incidence between the bat and path of the pitched ball is the primary means by which the ball is hit to different field areas. The literature indicates that the appropriate angle of incidence for an opposite field hit is obtained by timing the swing so that the hands are ahead of the point on the bat where contact with the ball is made and by keeping the elbow joints less than fully extended.

CHAPTER III

PROCEDURES

The purpose of this study was to examine selected mechanical factors involved in hitting a baseball to the same field and to the opposite field with special emphasis placed on an identification of those factors which distinguished players of different hitting abilities.

Subjects

The subjects used in this study were 20 adult males. Eighteen of the subjects were on the roster of a college or university baseball team during the 1980 playing season and two were former college players. The only requirement for subject selection was that they were right-handed batters. Each subject was assigned to one of two groups based on recommendations by their respective college coaches regarding their ability to hit effectively to the opposite field. Group one consisted of those subjects who were judged to be above average hitters but more effective when hitting the ball to the same field. Group two consisted of those subjects who were judged to be above average hitters and equally capable of hitting the ball to the same and opposite fields. Corroboration of the selection of each subject was provided by an analysis of individual playing statistics from the 1980 college baseball season. The statistics analyzed were the Scoring Index (Cook, 1966), batting average, and the ratio of number of base hits to the opposite field to the number of base hits to the same field.

Instrumentation

Cinematographical Instrumentation

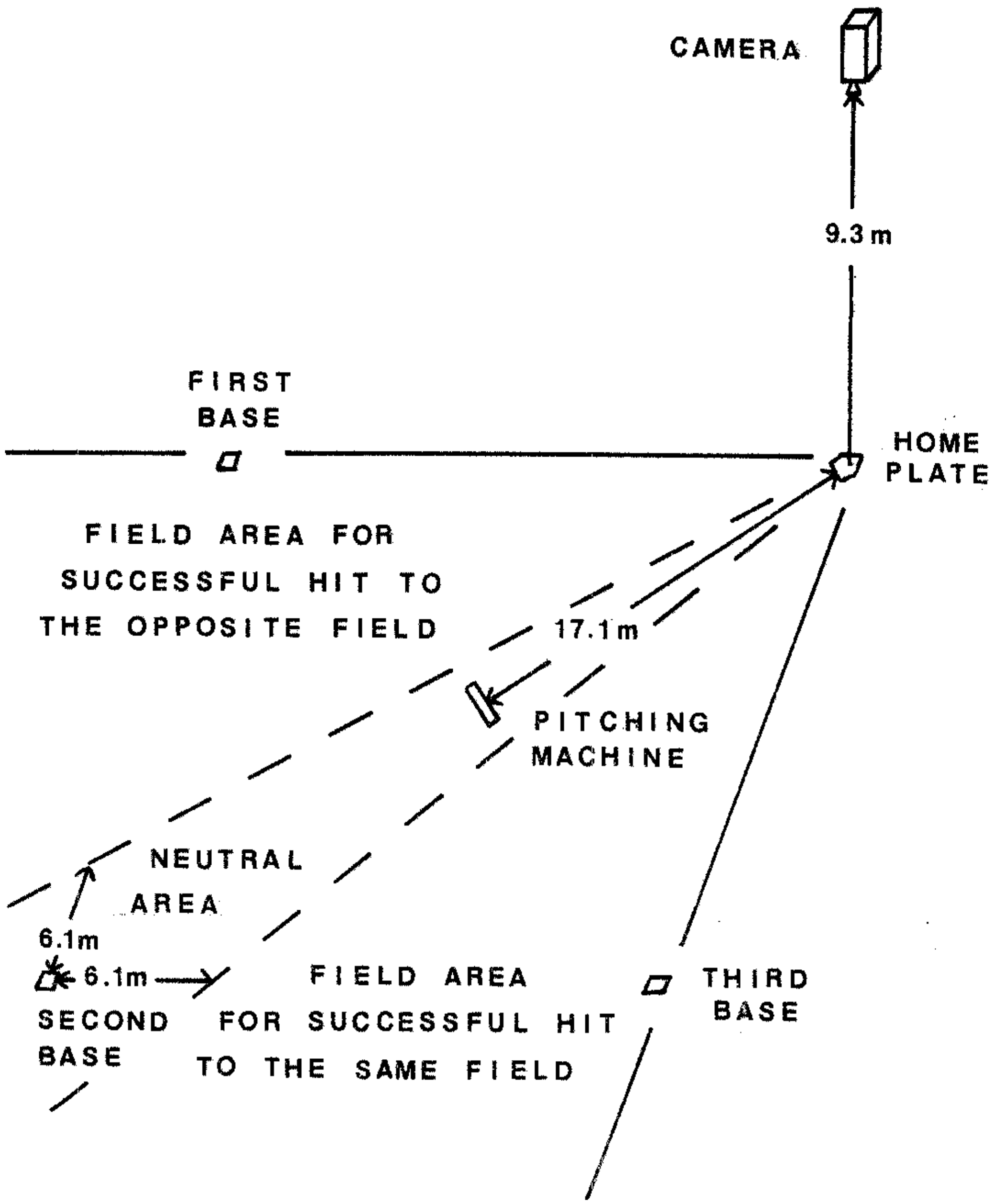
The batting performances of each subject were filmed using a high-speed 16-mm motion picture camera (Teledyne Camera Systems, Model DBM-54) operating at 200 frames per second. The camera was positioned 9.3 meters above ground level. Appropriate levelling techniques were used to ensure that the optical axis of the camera was directed along a vertical axis. The camera was aligned so that the range of motion under study of the subjects, the bat, and the ball were recorded on film. The location of the camera was as shown in Figure 1.

Three sets of number coded cards were included within the field of view of the camera and recorded on film for each trial. The three sets of numbers were used to identify the assigned subject number, treatment number, and trial number, respectively. A temporal scale was provided by a timing light system built into the camera.

Figure 1

Location of Testing Instruments and

Designated Field Areas



Pitching Machine

An automatic pitching machine (Curveball Model, JoPaul Industries, Inc.) was used to pitch balls to the subjects. The machine was positioned 17.1 meters from the front edge of home plate. It was adjusted so that the balls were pitched at a speed of approximately 33.5 meters per second, which corresponded to the average speed of a college pitcher's fastball (Scott, 1963). The height of release of the ball relative to ground level was approximately 1.4 meters. Due to the terrain of the experimental location, this height of release was lower than the normal range of 1.7 to 2.0 meters reported by Williams (1971). The location of the pitching machine was as shown in Figure 1.

Baseball Bat

One metal baseball bat of standard weight and dimension was used throughout the study. The bat was 0.86 meters in length and weighed 0.90 kilograms. A strip of white adhesive tape was placed around the tip of the bat to facilitate subsequent identification of this point from the processed film records.

Testing Procedures

All of the trials for the study were conducted on a field adjacent to the Physical Education Building at North Texas State University (Denton, Texas). Prior to the filming sessions, each subject was familiarized with the testing procedure and asked to sign a consent form for participation (Appendix A). Each subject was permitted to perform their preferred "warm-up" prior to the performance of their trials.

Each subject performed as many trials as were necessary to successfully hit the ball six times, three times to each of the two assigned areas of the field. The assigned areas corresponded to experimenter imposed limits for either an opposite field hit or a same field hit. The designated areas of the field were as shown in Figure 1. A neutral area between the two assigned areas was established to identify those hits which may have involved characteristics of both opposite field and same field hitting. The field area to which attempts were first made to hit the ball was randomly assigned to each subject. After the completion of three successful hits to the first assigned area, each subject then attempted to hit the ball on three occasions to the second field area. Each trial by each subject was recorded on film.

Data Acquisition Procedures

For each successful trial, each of the film frames which showed the motion of the subject and the bat from the initial movement of the bat to the frame in which the ball was last visible were analyzed with the aid of a Lafayette 16-mm Analyzer (Lafayette Instrument Co., Lafayette, Indiana) in conjunction with a Numonics Electronic Graphics Digitizer

(Model 1200, Numonics Corp., North Wales, Pennsylvania), which was interfaced to Tektronix 4052 Graphics Calculator (Tektronix Inc., Beaverton, Oregon). The motion of the ball for all frames in which it was visible was also analyzed. The x- and y-coordinates of the following landmarks were digitized and recorded for each of the selected film frames:

1. Tip of the bat,
2. Midpoint of the handle of the bat immediately adjacent to the right hand,
3. Distal end of the third metacarpal of the right hand,
4. Distal end of the third metacarpal of the left hand,
5. Styloid process of the left ulna,
6. Lateral epicondyle of the left humerus,
7. Greater tubercle of the left humerus,
8. Center of the ball,
9. Rear corner of home plate.

The extracted displacement data were "smoothed" using cubic spline curve-fitting techniques, and average values were found for each subject for each type of field hit. The data thus obtained were used in conjunction with a computer program to compute the following variables:

1. Component linear x- and y-displacements from an origin at the rear corner of home plate to the tip of the bat,

2. Component linear x- and y-displacements from an origin at the rear corner of home plate to the midpoint of the handle of the bat immediately adjacent to the right hand,
3. Component linear x- and y-displacements from an origin at the rear corner of home plate to the distal end of the third metacarpal of the left hand,
4. Component linear x- and y-displacements from an origin at the rear corner of home plate to the left wrist joint,
5. Component linear x- and y-displacements from an origin at the rear corner of home plate to the left elbow joint,
6. Component linear x- and y-displacements from an origin at the rear corner of home plate to the left shoulder joint,
7. Angular displacement of the bat relative to the positive x-axis,
8. Angular displacement of the left hand relative to the positive x-axis,
9. Angular displacement of the left forearm relative to the positive x-axis,
10. Angular displacement of the left arm relative to the positive x-axis,
11. Angle between the bat and the left forearm,
12. Angle at the left wrist joint,

13. Angle at the left elbow joint,
14. Component linear x- and y-velocities of the tip of the bat,
15. Component linear x- and y-velocities of the distal end of the third metacarpal of the left hand,
16. Component linear x- and y-velocities of the left wrist joint,
17. Component linear x- and y-velocities of the left elbow joint,
18. Component linear x- and y-velocities of the left shoulder joint,
19. Angular velocity of the bat,
20. Angular velocity of the left hand,
21. Angular velocity of the left forearm,
22. Angular velocity of the left arm,
23. Angular velocity of the projected joint between the bat and the left forearm,
24. Angular velocity of the left wrist joint,
25. Angular velocity of the left elbow joint,
26. Angle of incidence between the bat and the ball,
27. Angle of reflection between the bat and the ball.

All displacement and velocity measures which occurred in a projected horizontal plane were measured relative to an origin established at the rear corner of home plate. Component displacements to the right and above the established origin, as depicted in the projected film frames, were defined as positive x- and positive y-displacements respectively.

The values of these variables at the instant prior to initial ball contact with the bat were recorded for subsequent analysis. In addition, all of the displacement and velocity variables were averaged by condition.

Statistical Analysis

A statistical analysis utilizing mixed design repeated measures analysis of variance procedures, $p \leq 0.05$, with subject groups serving as the non-repeating factor was conducted to determine whether or not interactions existed between subject groups and the two types of baseball batting swings. The displacement and velocity values of the computed variables at the instant prior to contact between the bat and the ball served as dependent variables.

CHAPTER IV

RESULTS

The purpose of this study was to examine selected mechanical factors involved in hitting a baseball either to the same field or to the opposite field. Consideration was given to (a) kinematic parameters selected to describe the motion of the ball, the bat, and the performer and (b) an identification of those factors which distinguish players of different hitting abilities.

Subjects

The subjects used in this study ranged in age from 18 to 30 years ($\bar{x}$ = 21.1, SD = 3.3 years), in height from 1.73 to 1.91 meters ($\bar{x}$ = 1.807, SD = 0.057 meters), and in weight from 65.0 to 91.8 kilograms ($\bar{x}$ = 75.57, SD = 6.10 kilograms). Selected anthropometric characteristics and batting statistics of each subject appear in Appendix B.

Results

Times from the initial batting position to the instant prior to the first angular displacement of the bat and the times from the initial movement of the bat until ball contact are shown in Table 1.

TABLE 1

Temporal Characteristics of the Batting Swing[a]

Subject Group	T1[b]	T2
1		
Same field condition	0.020	0.139
Opposite field condition	0.019	0.124
2		
Same field condition	0.021	0.144
Opposite field condition	0.020	0.125

[a] Time measured in seconds.

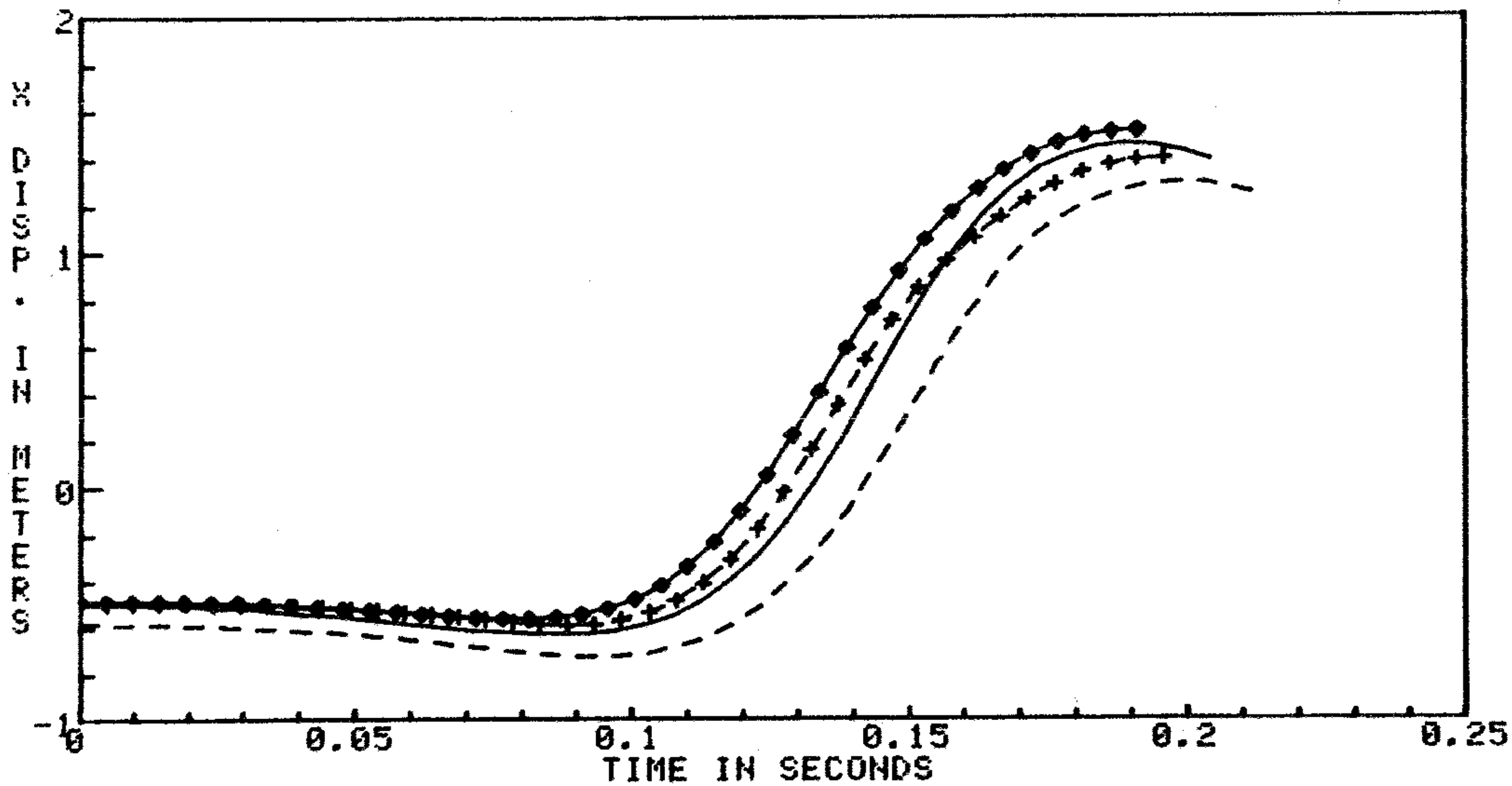
[b] T1 = Time from initial position to initial movement of the bat.
T2 = Time from initial movement of the bat to the instant prior to contact.

A statistical analysis revealed that the latter times for the opposite field conditions were significantly less than those for the same field conditions. No differences were found between the subject groups. A summary table of the statistical analysis appears in Appendix C.

The mean x- and y-displacements of the tip of the bat for all conditions are shown in Figure 2 and Figure 3 respectively. All of the curves for each component displacement display similarities in form with apparent differences in the y-displacement values being accounted for by differences in the initial locations. The mean component displacements of the tip of the bat at the instant prior to

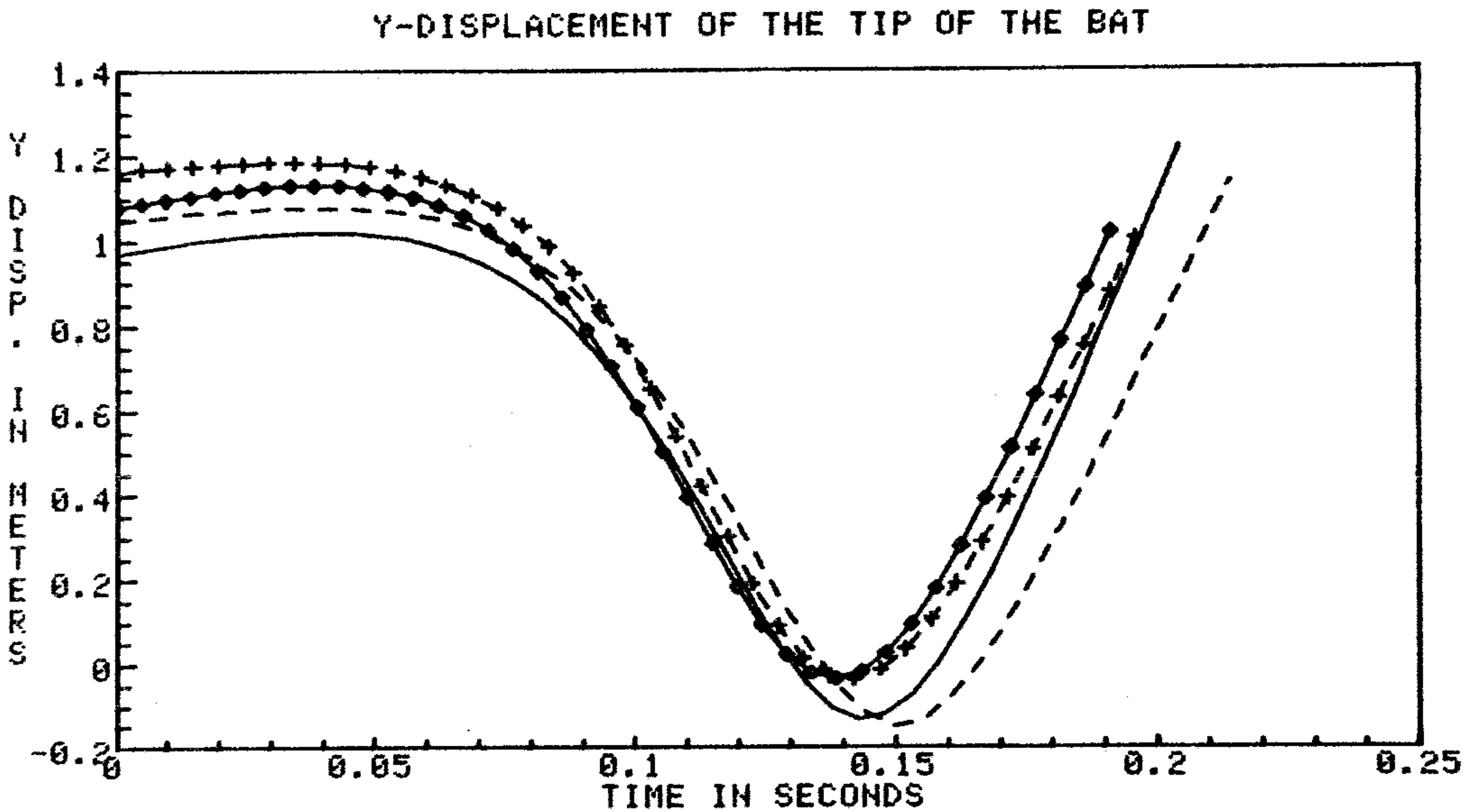
FIGURE 2

X-DISPLACEMENT OF THE TIP OF THE BAT



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 3



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

contact are shown in Table 2. A statistical analysis of the component displacements at the instant prior to contact of the bat and ball revealed that for the opposite field conditions the x-component was significantly less than that for the same field conditions. A summary table of the statistical analysis appears in Appendix D.

The x- and y-component linear velocities of the tip of the bat are shown in Figure 4 and Figure 5 respectively. The shape of the component linear velocity curves appears to be the same for all conditions. The mean component velocities of the tip of the bat at the instant prior to contact are shown in Table 3. A statistical analysis of the velocities of the instant prior to contact revealed that for the opposite field swing the x-component of velocity was significantly greater than that found for the same field swing. Moreover, the y-component for the opposite field swing was found to be significantly less than that for the same field swing. A summary table for the statistical analysis appears in Appendix E.

The computed maximum resultant linear speeds of the tip of the bat and the time at which these speeds occurred are shown in Table 4. For all conditions, it appears as though the maximum speed of the tip of the bat occurred prior to the instant contact was made with the ball. These results do not support the contention that in order for the

TABLE 2

Mean X- and Y-Displacements at the Instant Prior to Contact

Subject Group	Linear Displacement[a]	
	X	Y
Tip of the Bat		
1		
Same field condition	1.105	0.021
Opposite field condition	0.760	-0.032
2		
Same field condition	0.948	-0.008
Opposite field condition	0.673	-0.034
Handle of the Bat		
1		
Same field condition	0.748	0.572
Opposite field condition	0.708	0.540
2		
Same field condition	0.581	0.540
Opposite field condition	0.597	0.586
Distal End of the Third Metacarpal of the Left Hand		
1		
Same field condition	0.700	0.712
Opposite field condition	0.729	0.677
2		
Same field condition	0.536	0.680
Opposite field condition	0.622	0.728

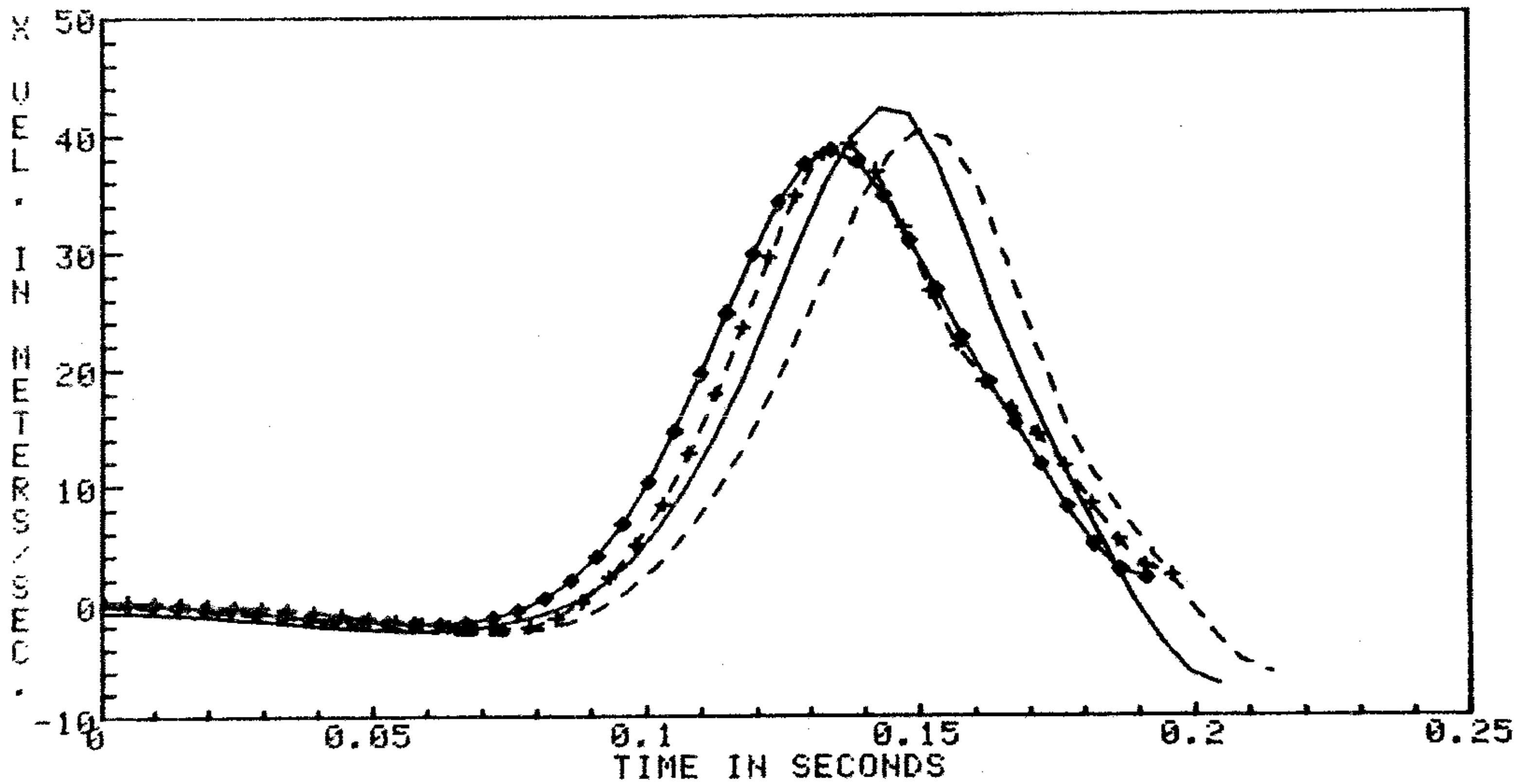
TABLE 2 (continued)

Subject Group	Linear Displacement[a] X	Y
Left Wrist		
1		
Same field condition	0.618	0.723
Opposite field condition	0.659	0.716
2		
Same field condition	0.449	0.691
Opposite field condition	0.544	0.766
Left Elbow		
1		
Same field condition	0.378	0.889
Opposite field condition	0.462	0.902
2		
Same field condition	0.218	0.861
Opposite field condition	0.326	0.960
Left Shoulder		
1		
Same field condition	0.103	0.945
Opposite field condition	0.178	0.965
2		
Same field condition	-0.049	0.965
Opposite field condition	0.051	1.014

[a]Displacement measured in meters from an origin at the rear corner of home plate.

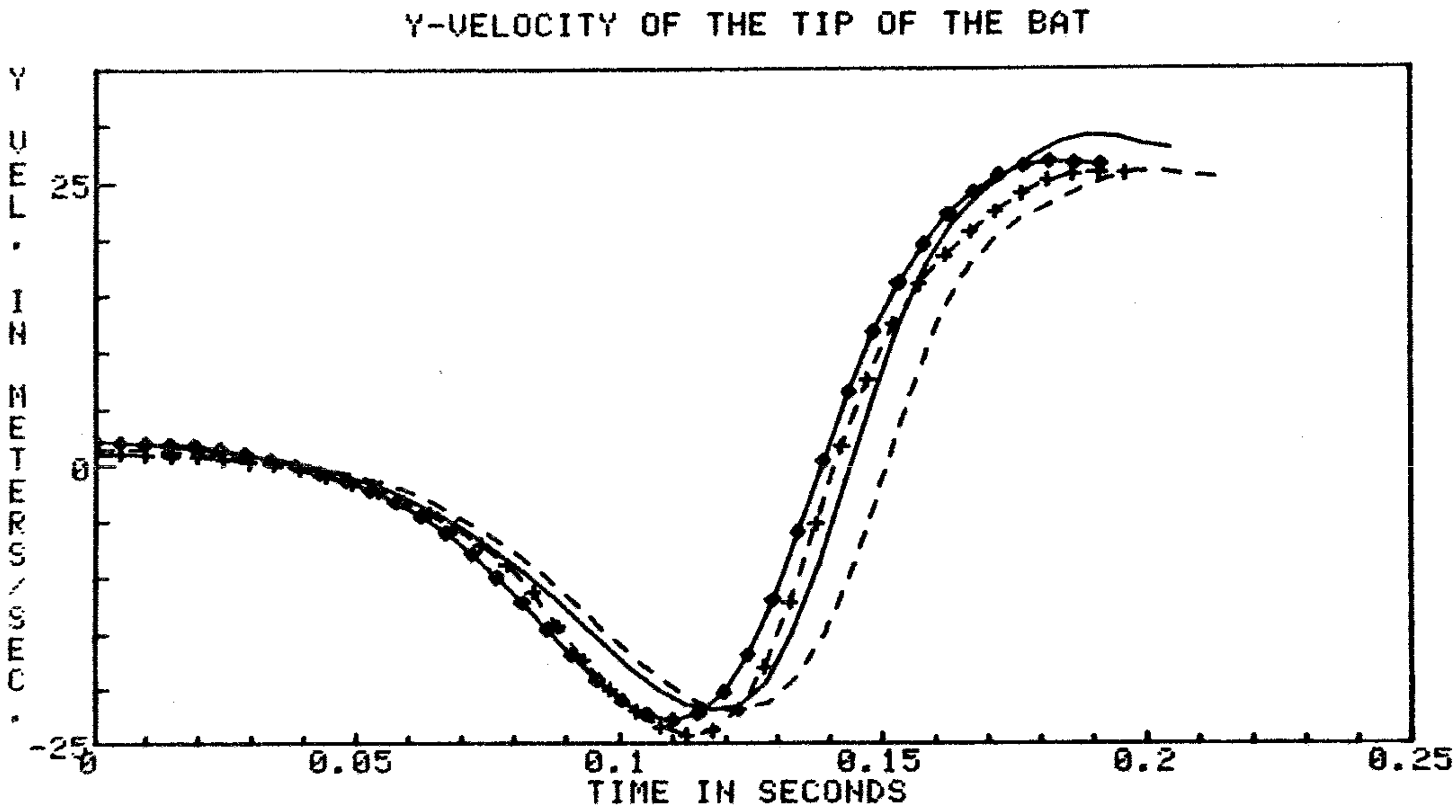
FIGURE 4

X-VELOCITY OF THE TIP OF THE BAT



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 5



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

TABLE 3

Mean X- and Y-Components of Velocity at the Instant Prior to Contact

Subject Group	Linear Velocity[a] X	Y
Tip of the Bat		
1		
Same field condition	32.86	21.42
Opposite field condition	37.03	8.17
2		
Same field condition	29.39	20.08
Opposite field condition	35.64	7.01
Distal End of the Third Metacarpal of the Left Hand		
1		
Same field condition	1.20	8.92
Opposite field condition	3.82	9.34
2		
Same field condition	1.70	8.54
Opposite field condition	3.74	9.12
Left Wrist		
1		
Same field condition	0.45	6.51
Opposite field condition	2.24	6.45
2		
Same field condition	0.96	5.76
Opposite field condition	2.29	5.88

TABLE 3 (continued)

Subject Group	Linear Velocity[a] X	Y
Left Elbow		
1		
Same field condition	-1.48	1.92
Opposite field condition	-0.54	3.08
2		
Same field condition	-1.23	1.48
Opposite field condition	-1.16	2.42
Left Shoulder		
1		
Same field condition	-1.76	-1.11
Opposite field condition	-1.67	-0.50
2		
Same field condition	-1.74	-0.90
Opposite field condition	-1.75	-0.41

[a]Velocity measured in meters per second.

TABLE 4

Maximum Values and Temporal Characteristics of the Resultant Linear Speeds

Subject Group	Max. Speed[a]	Time[b]
Tip of the Bat		
1		
Same field condition	42.2	0.123
Opposite field condition	39.3	0.110
2		
Same field condition	40.3	0.129
Opposite field condition	40.2	0.112
Distal End of the Third Metacarpal of the Left Hand		
1		
Same field condition	14.1	0.103
Opposite field condition	14.9	0.086
2		
Same field condition	13.3	0.097
Opposite field condition	14.5	0.085
Left Wrist		
1		
Same field condition	11.9	0.093
Opposite field condition	12.8	0.081
2		
Same field condition	11.0	0.091
Opposite field condition	12.2	0.083

TABLE 4 (continued)

Subject Group	Max. Speed[a]	Time[b]
Left Elbow		
1		
Same field condition	6.7	0.082
Opposite field condition	7.1	0.067
2		
Same field condition	6.1	0.081
Opposite field condition	6.9	0.073
Left Shoulder		
1		
Same field condition	3.5	0.072
Opposite field condition	2.8	0.058
2		
Same field condition	3.3	0.086
Opposite field condition	3.3	0.073

[a]Speed measured in meters per second.

[b]Time measured in seconds from the initial angular displacement of the bat until the maximum resultant linear speed was reached.

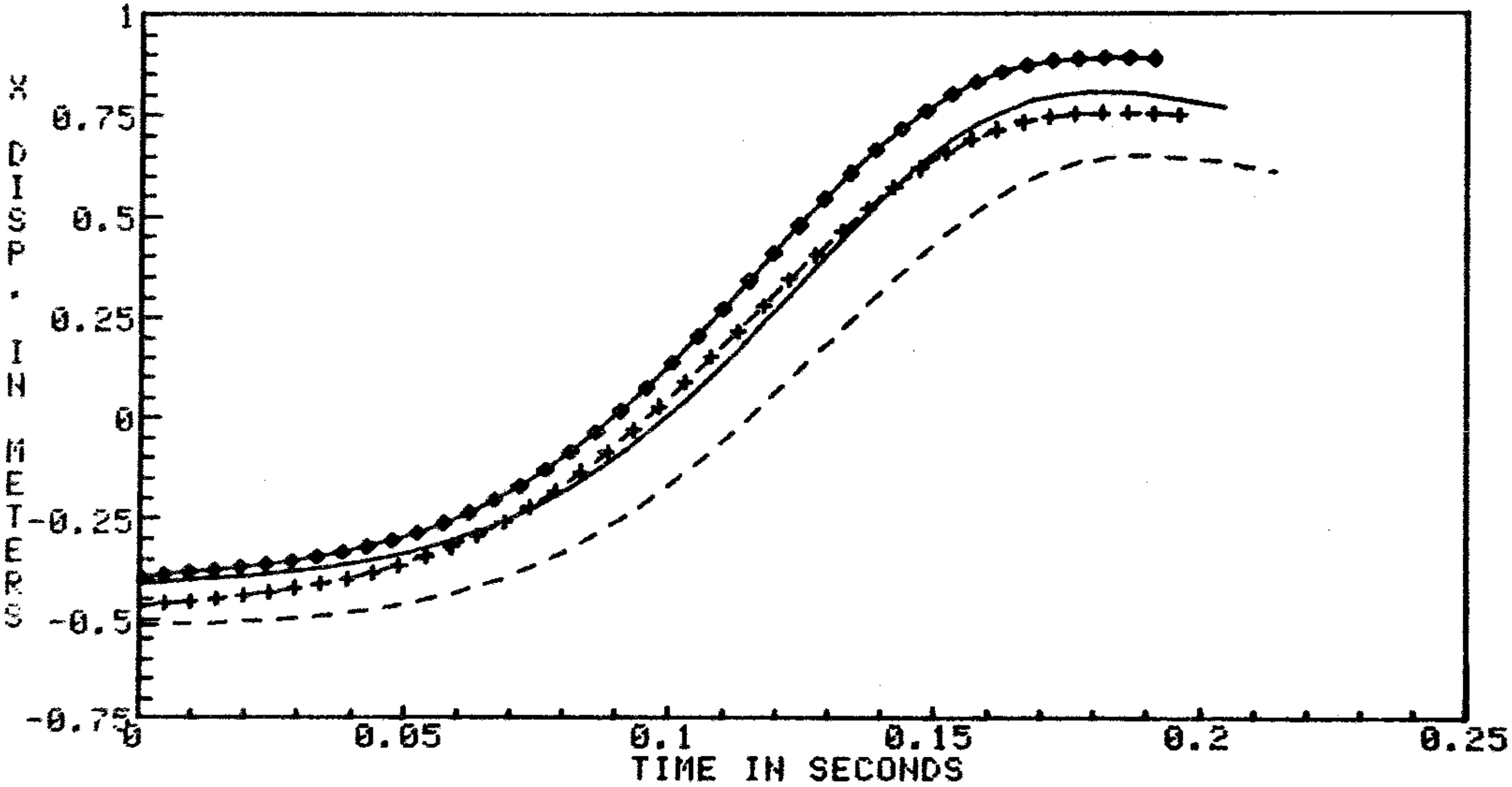
ball to be projected with the greatest speed, the maximum speed of the bat should occur just prior to ball contact. One possible explanation of these results may be the difficulties encountered by the subjects in accurately timing the instant the ball was released from the pitching machine, although it would also seem reasonable to assume that these errors would be randomly distributed.

The x- and y-displacements for the handle of the bat, the distal end of the third metacarpal of the left hand, and the left wrist joint are illustrated in Figures 6 through 11. The movement patterns of the component displacements are similar for all conditions for each landmark. Apparent differences in the locations of the curves may be accounted for by differences in the initial positions. The summary tables for the statistical analysis appear in Appendices F through H.

The x- and y-component velocities of the distal end of the third metacarpal of the left hand and the left wrist joint appear in Figures 12 through 15. A statistical analysis revealed that the x-component of velocity at the instant prior to contact for both the third metacarpal and the left wrist joint were significantly greater for the opposite field swing. In addition, the maximum resultant speed of these segment endpoints occurred earlier than the

FIGURE 6

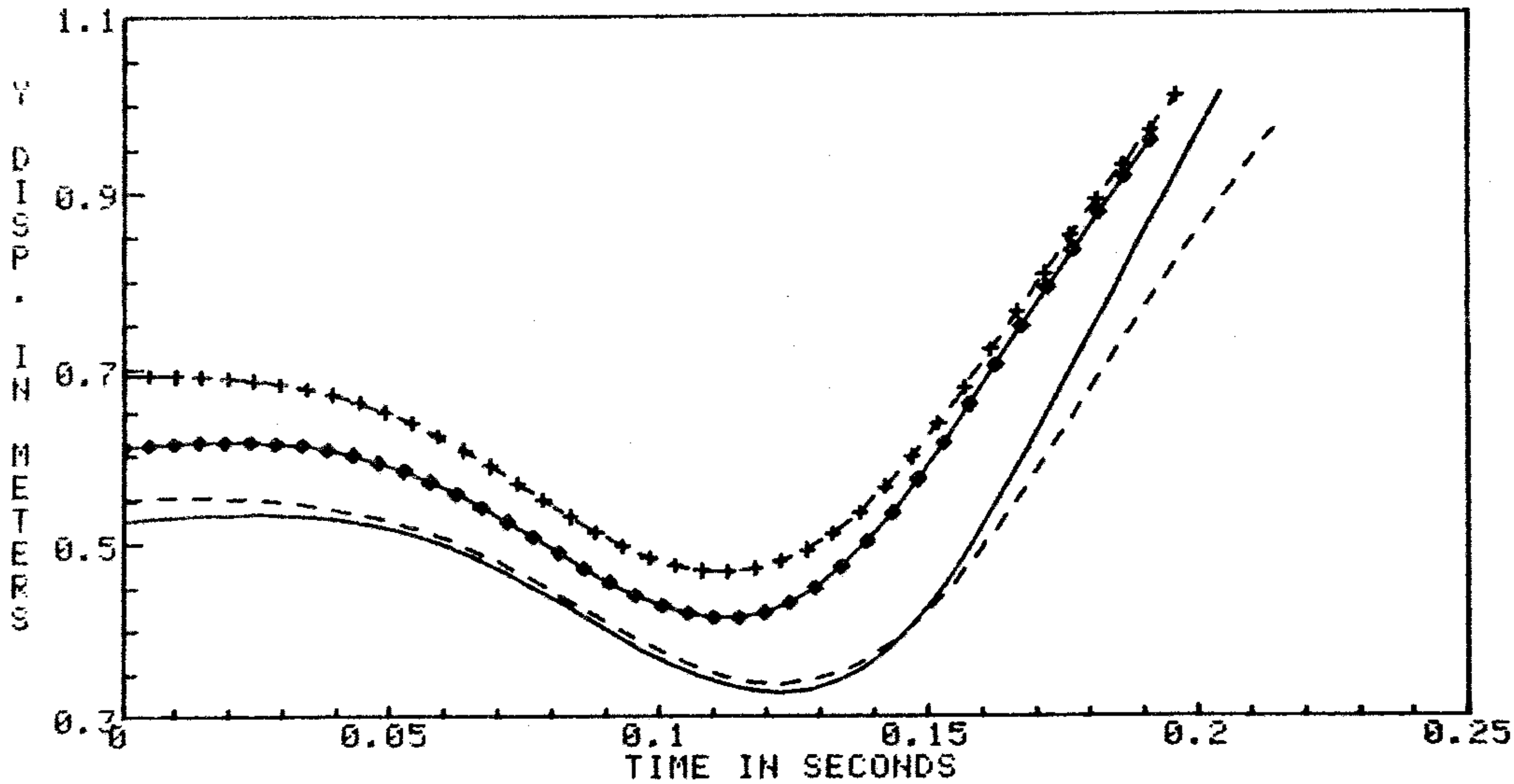
X-DISPLACEMENT OF THE HANDLE OF THE BAT



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

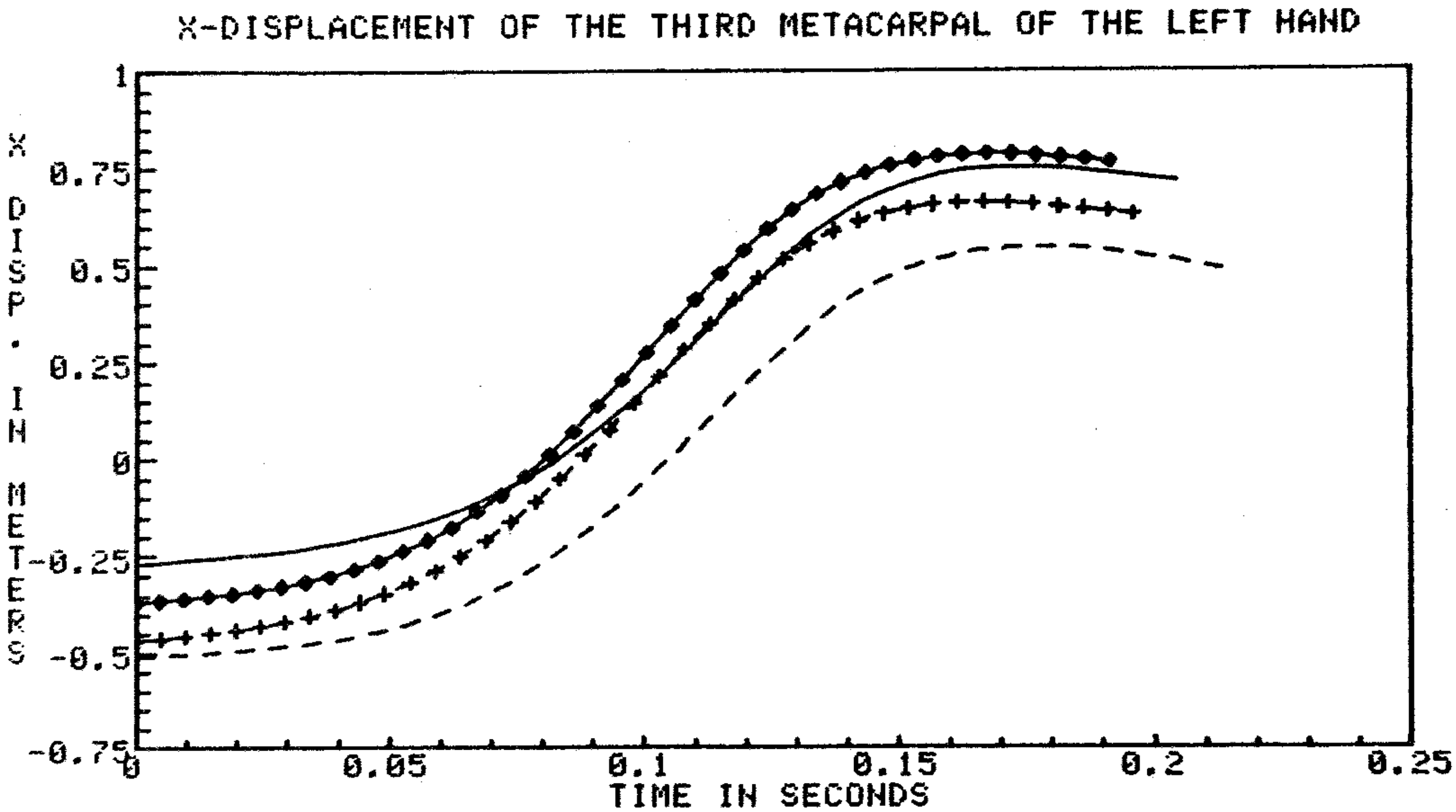
FIGURE 7

Y-DISPLACEMENT OF THE HANDLE OF THE BAT



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

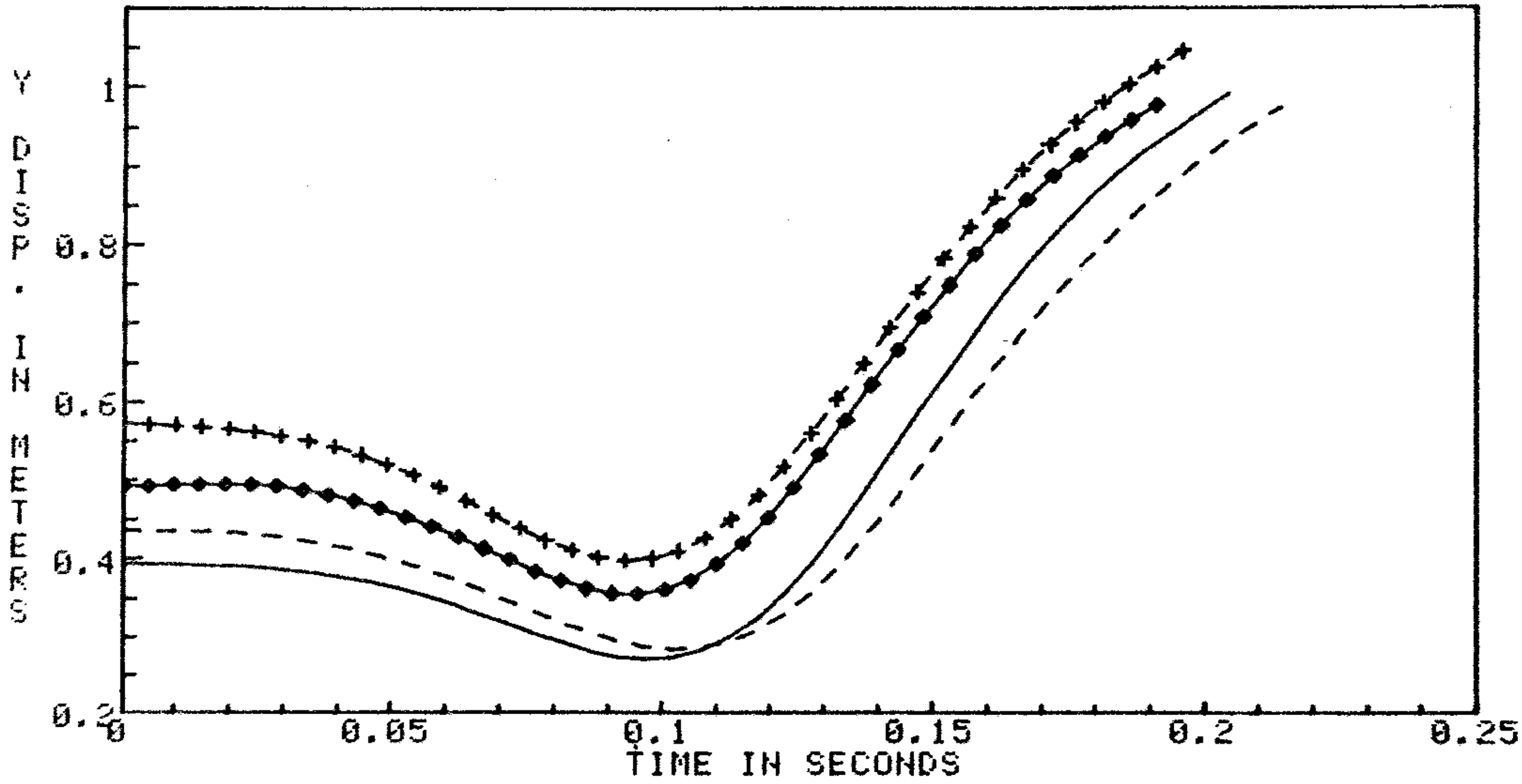
FIGURE 8



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 9

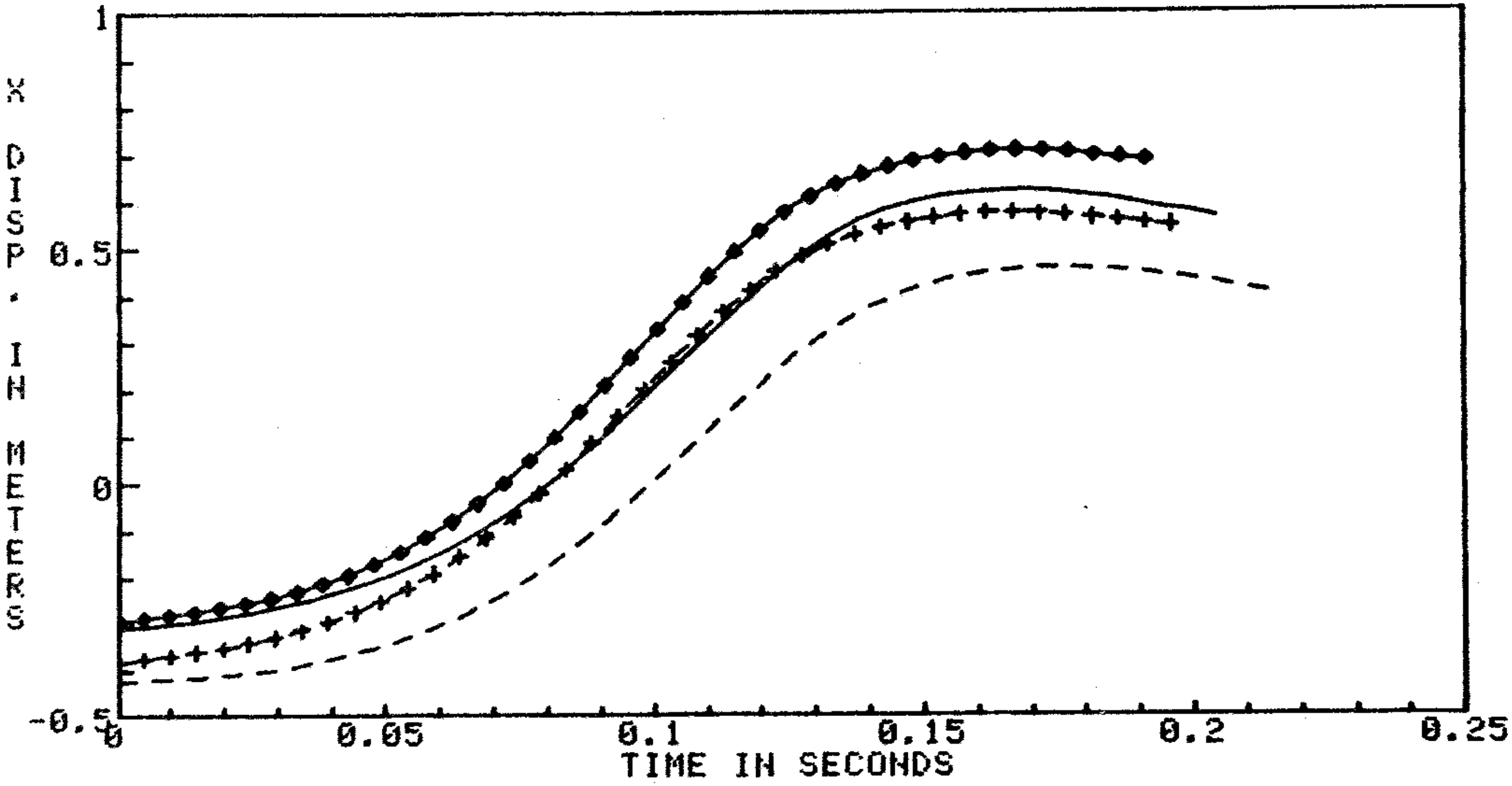
Y-DISPLACEMENT OF THE THIRD METACARPAL OF THE LEFT HAND



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 10

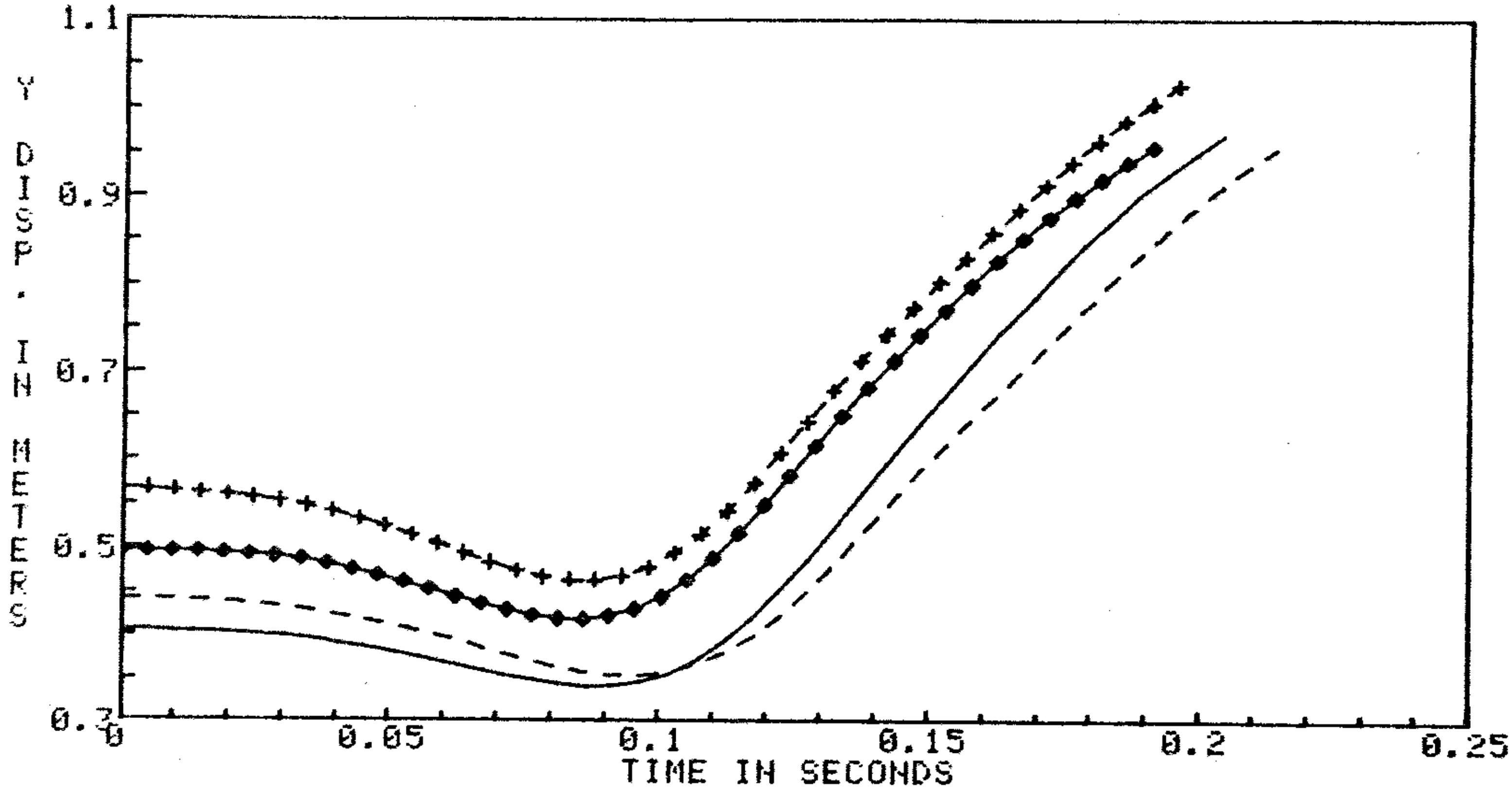
X-DISPLACEMENT OF THE LEFT WRIST



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

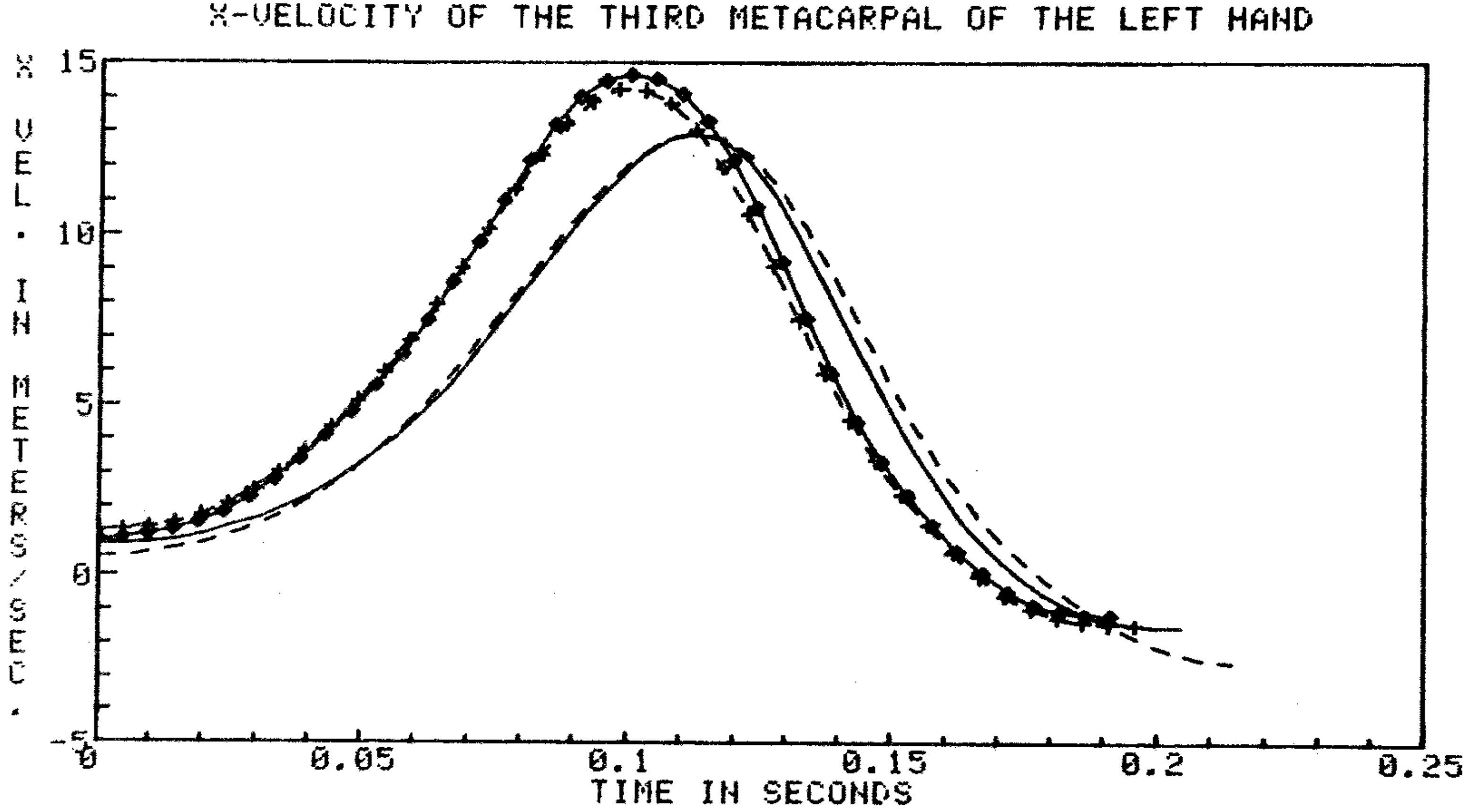
FIGURE 11

Y-DISPLACEMENT OF THE LEFT WRIST



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

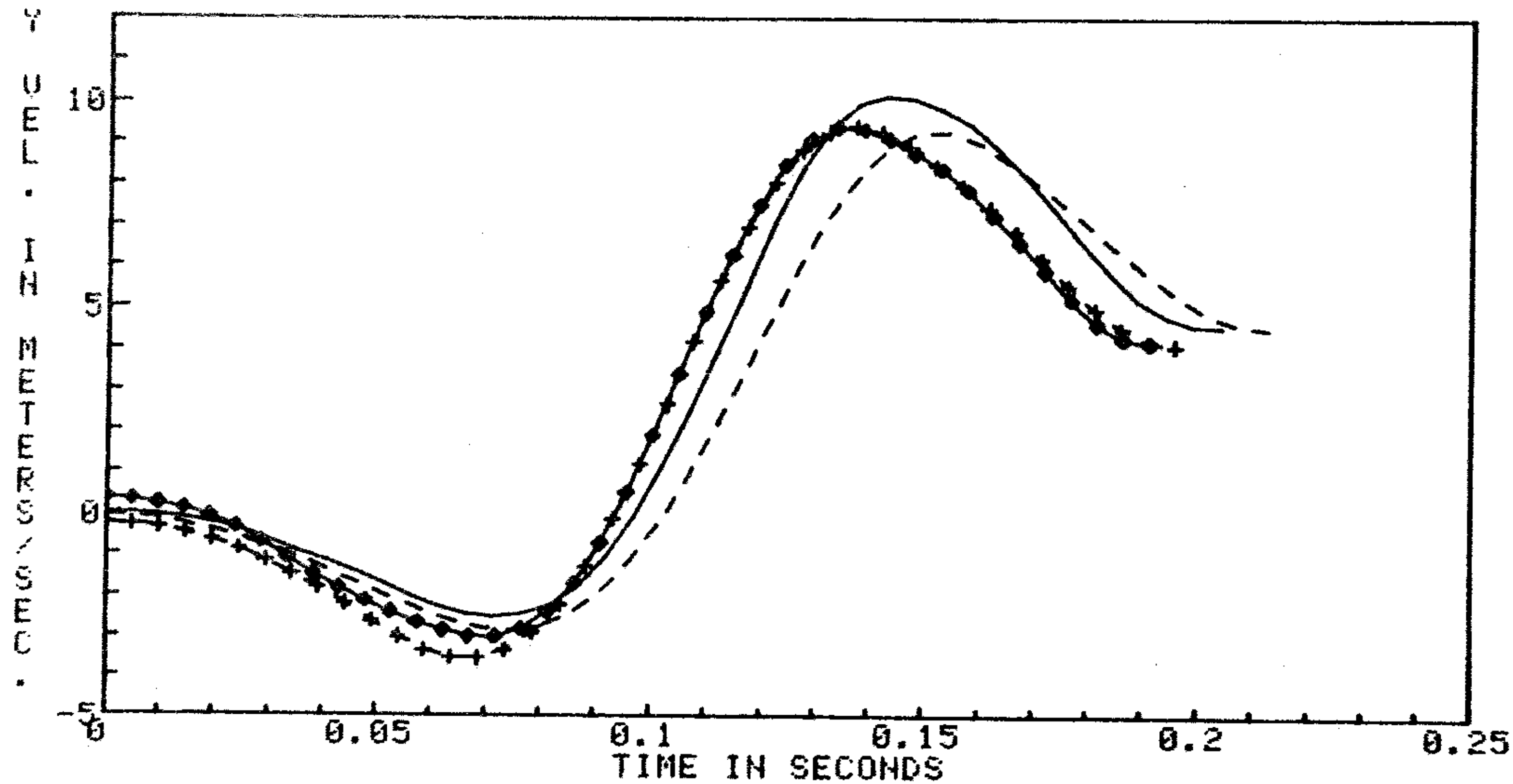
FIGURE 12



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 13

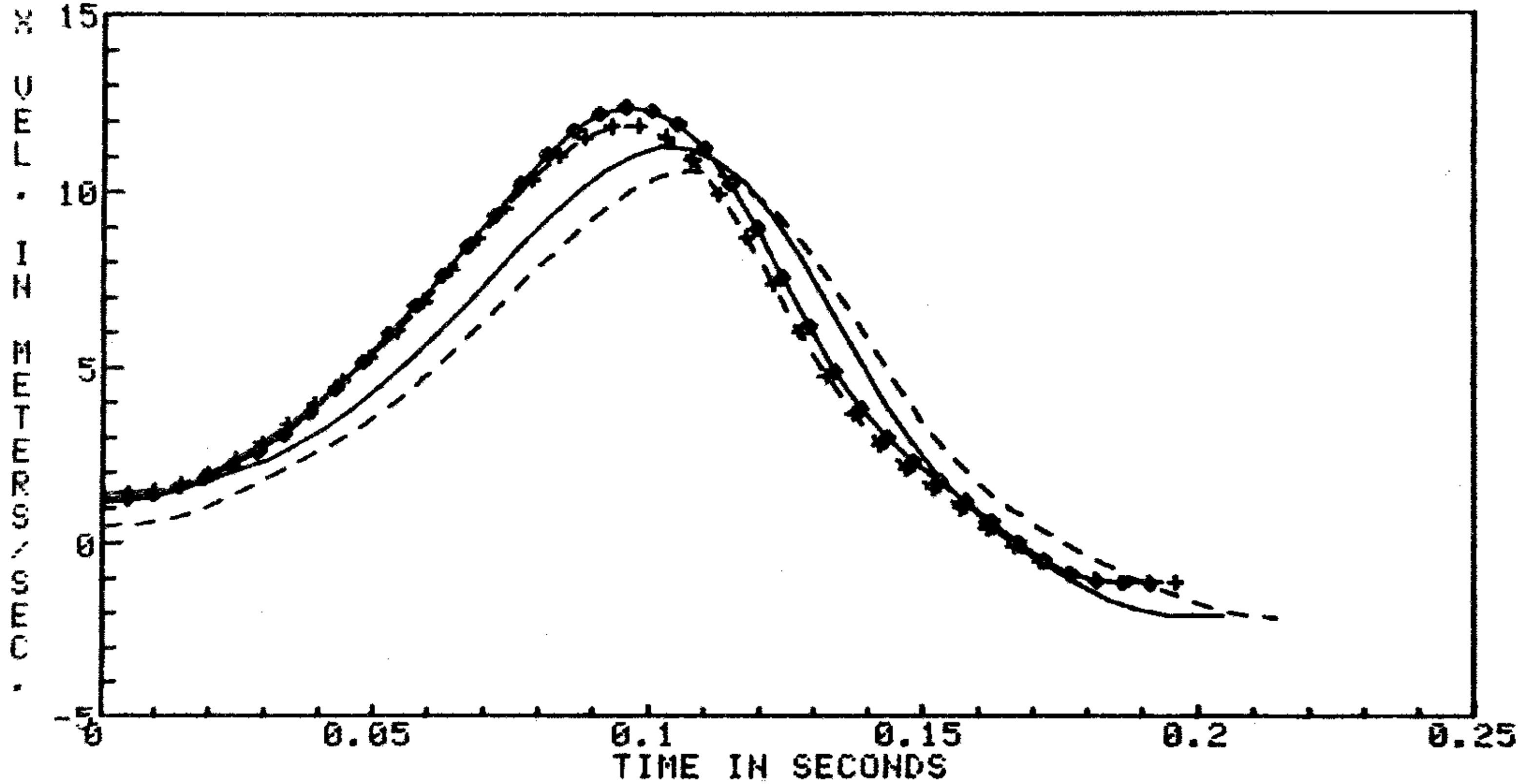
Y-VELOCITY OF THE THIRD METACARPAL OF THE LEFT HAND



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 14

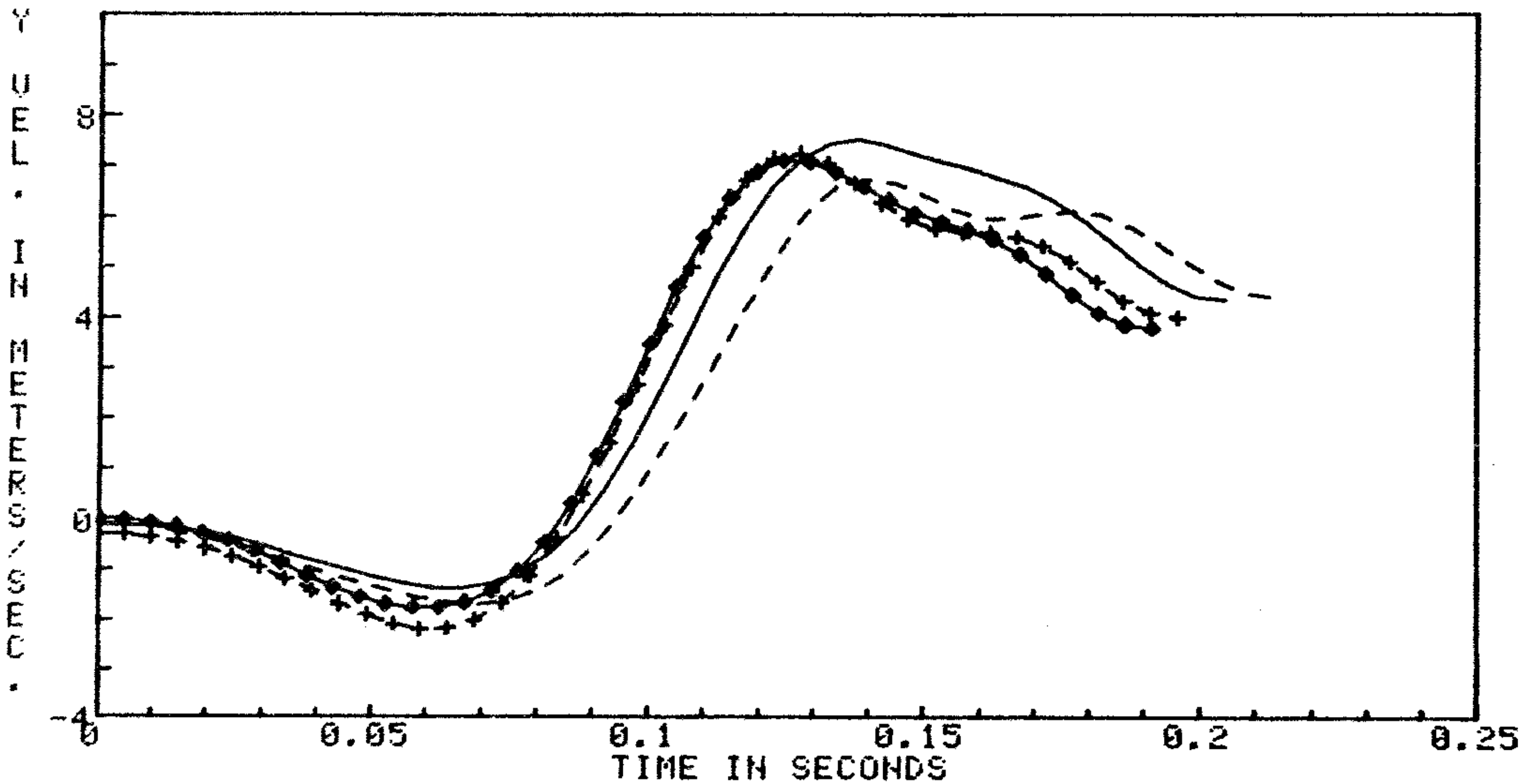
X-VELOCITY OF THE LEFT WRIST



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 15

Y-VELOCITY OF THE LEFT WRIST



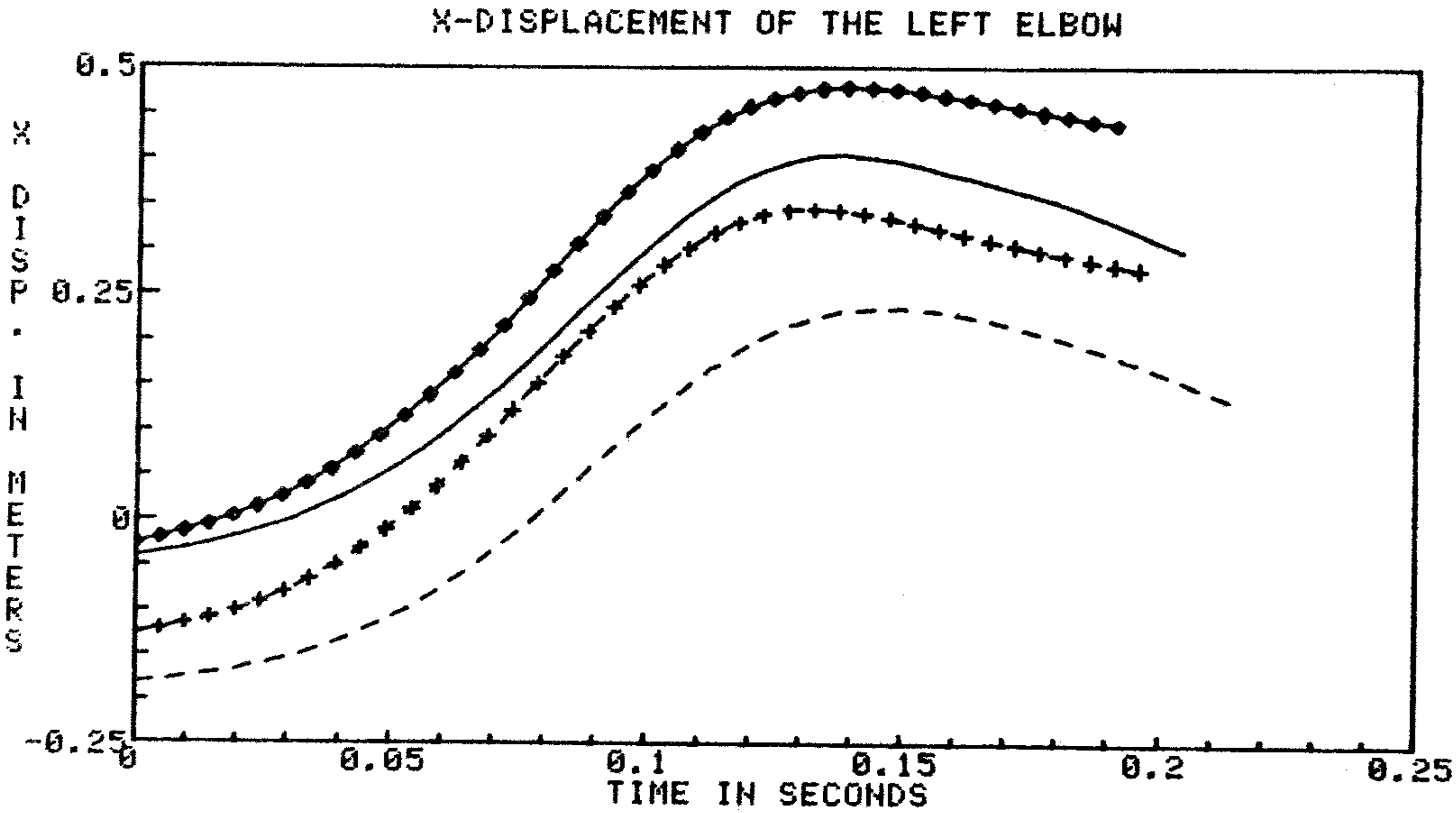
Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

time of ball contact. The summary tables of the statistical analysis appear in Appendix I and Appendix J.

The x- and y-displacements of the left elbow joint and left shoulder joint are shown in Figures 16 through 19. As was found with the more distal segments and the tip of the bat, all of the component curves are similar in form. Any apparent differences in the locations of the y-displacement curves may be accounted for by differences in the initial positions. Statistically significant differences were found in the x-displacement for both joints with the opposite field conditions showing greater displacement than the same field conditions. The summary tables for the statistical analysis appear in Appendix K and Appendix L.

The component velocity curves for the above mentioned segment endpoints are shown in Figures 20 through 23. Similarities between the shapes of the curves for each condition are evident. In contrast to the results found for the more distal segment endpoints, the y-component of velocity for the left elbow joint and left shoulder joint just prior to ball contact were found to be significantly greater for the opposite field swing. Summary tables for these results appear in Appendix M and Appendix N. The maximum linear speeds of both of these segment endpoints were found to occur prior to the time of bat-ball contact. Further examination of the results, illustrated in Table 4, revealed a tendency for the time to reach maximum speed to increase

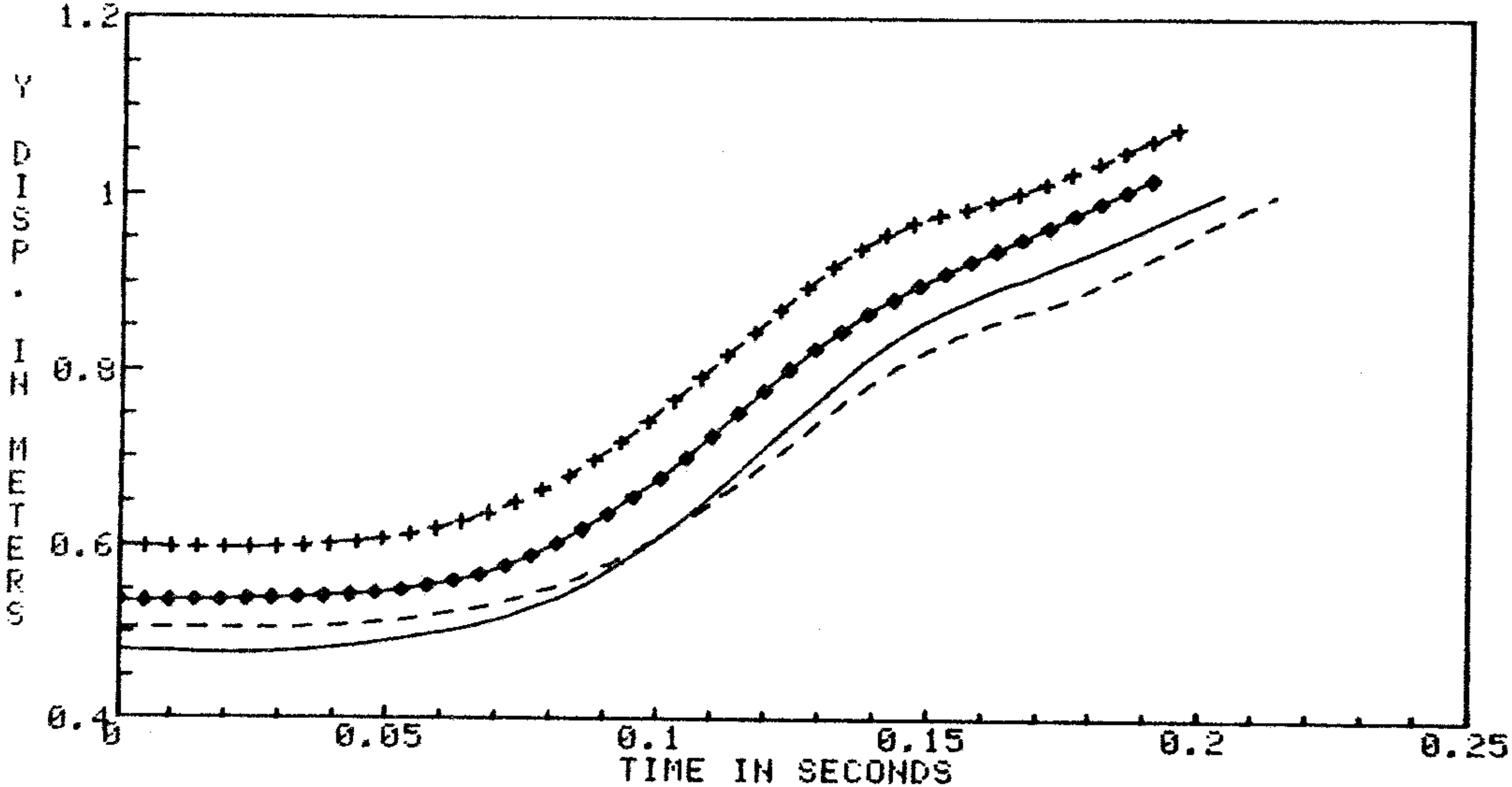
FIGURE 16



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

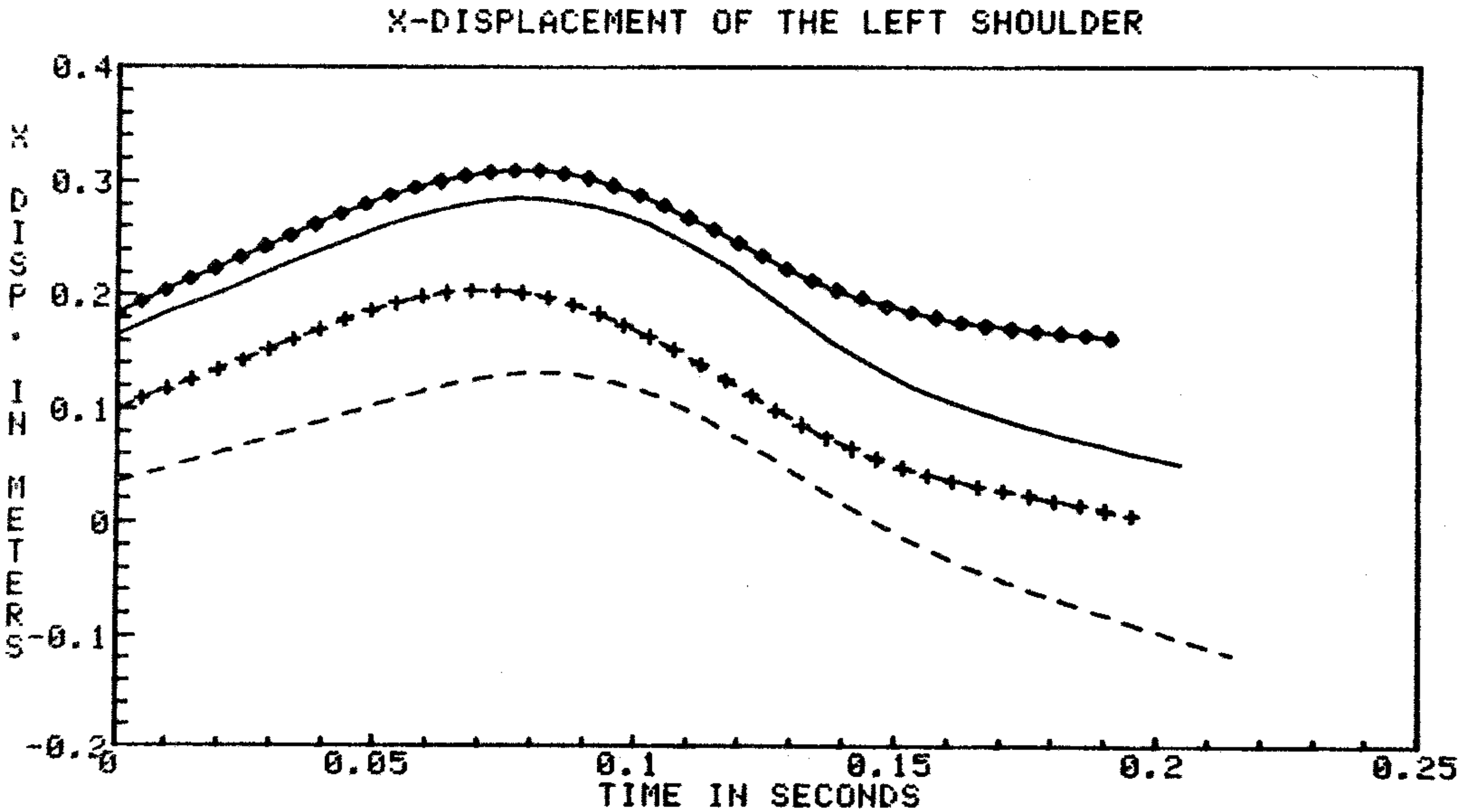
FIGURE 17

Y-DISPLACEMENT OF THE LEFT ELBOW



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

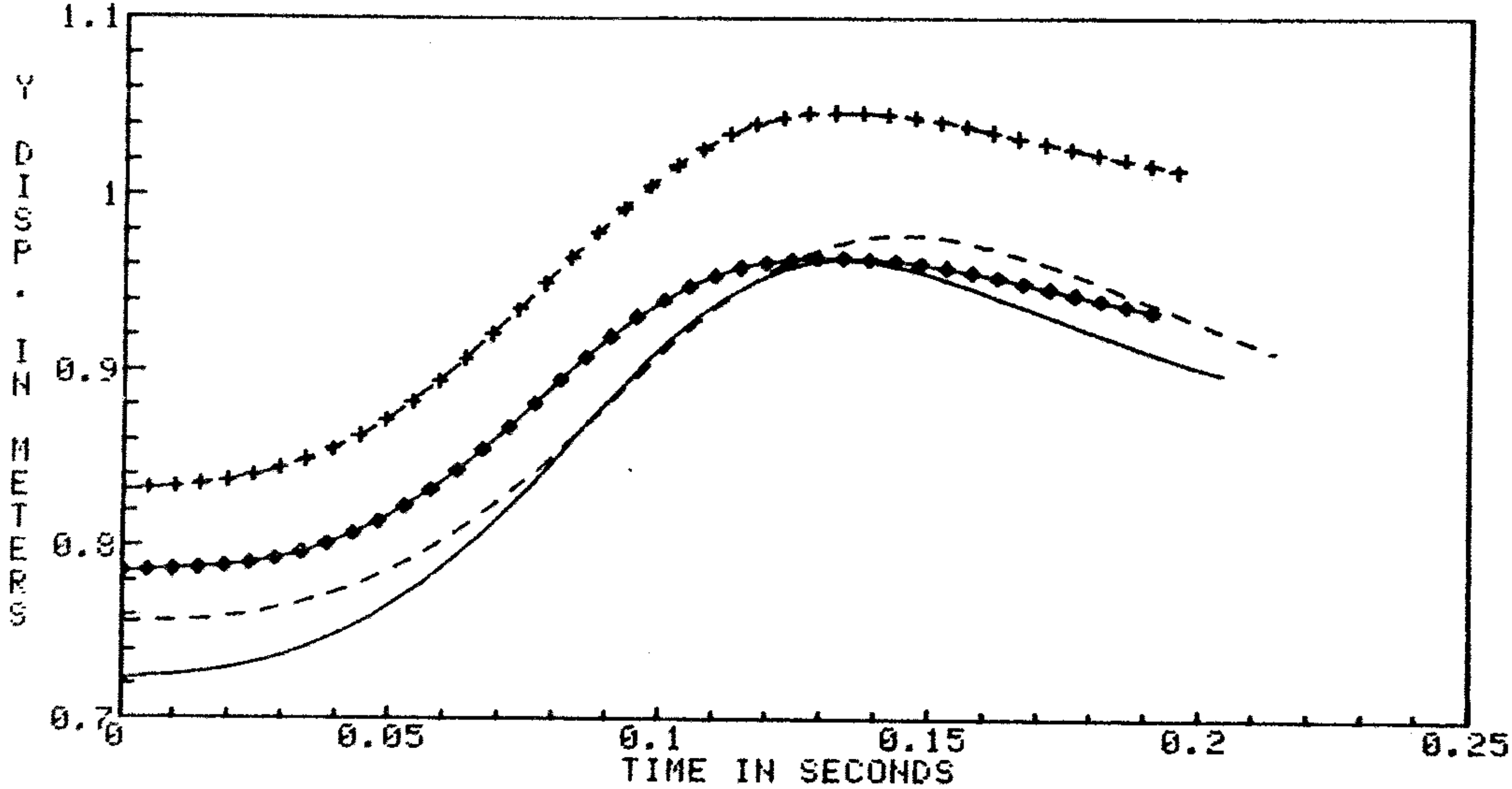
FIGURE 18



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 19

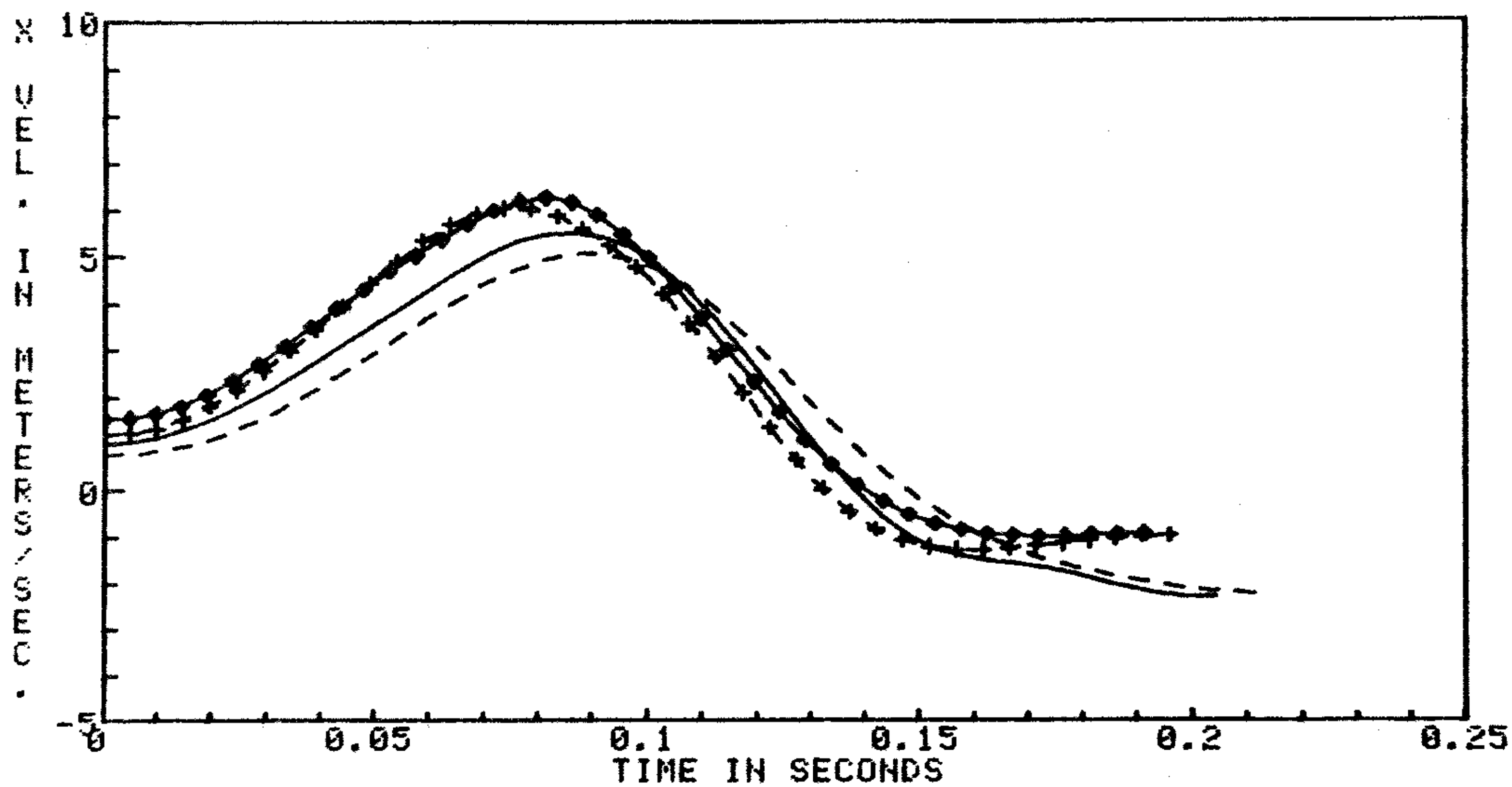
Y-DISPLACEMENT OF THE LEFT SHOULDER



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 20

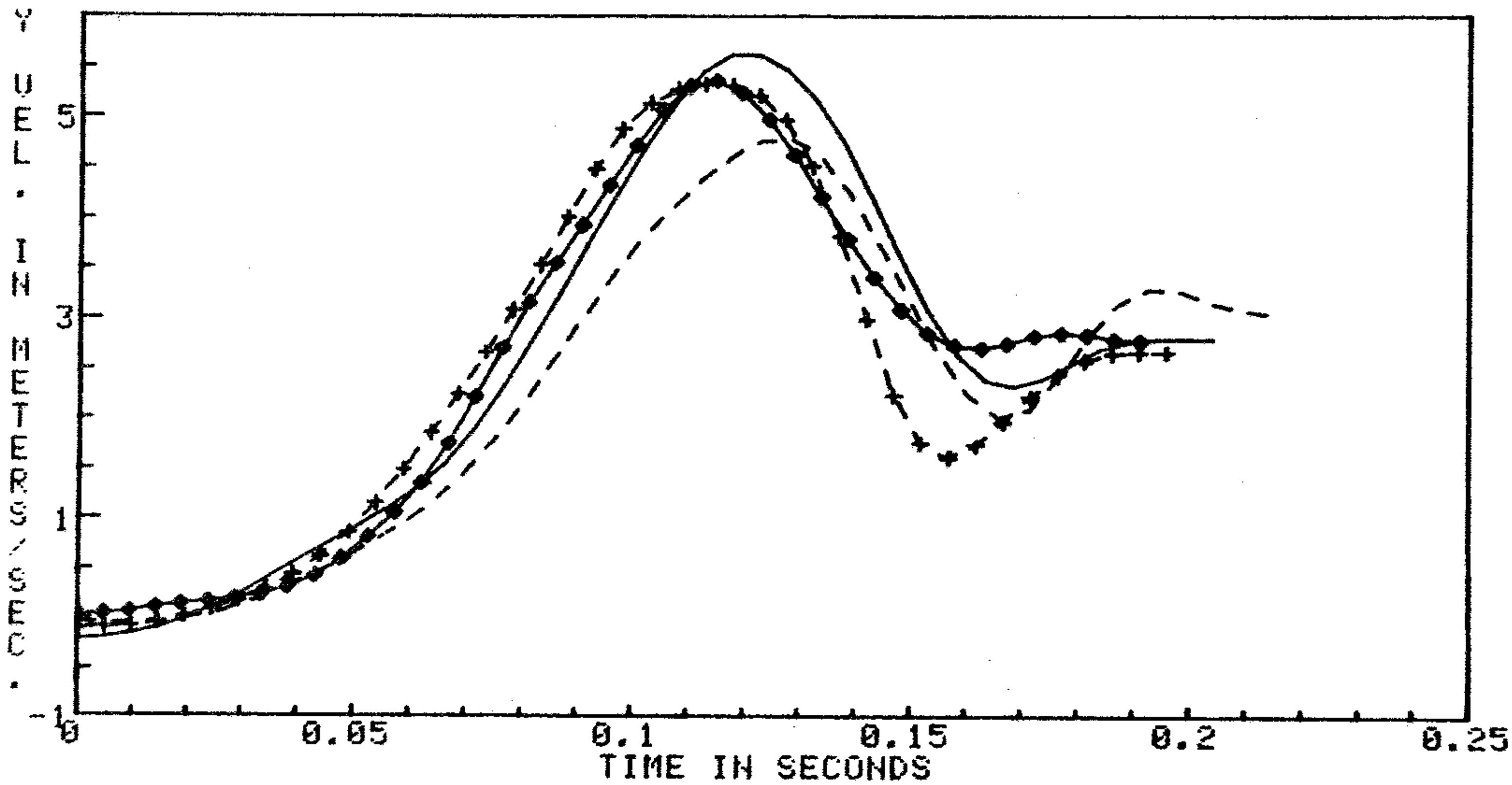
X-VELOCITY OF THE LEFT ELBOW



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 21

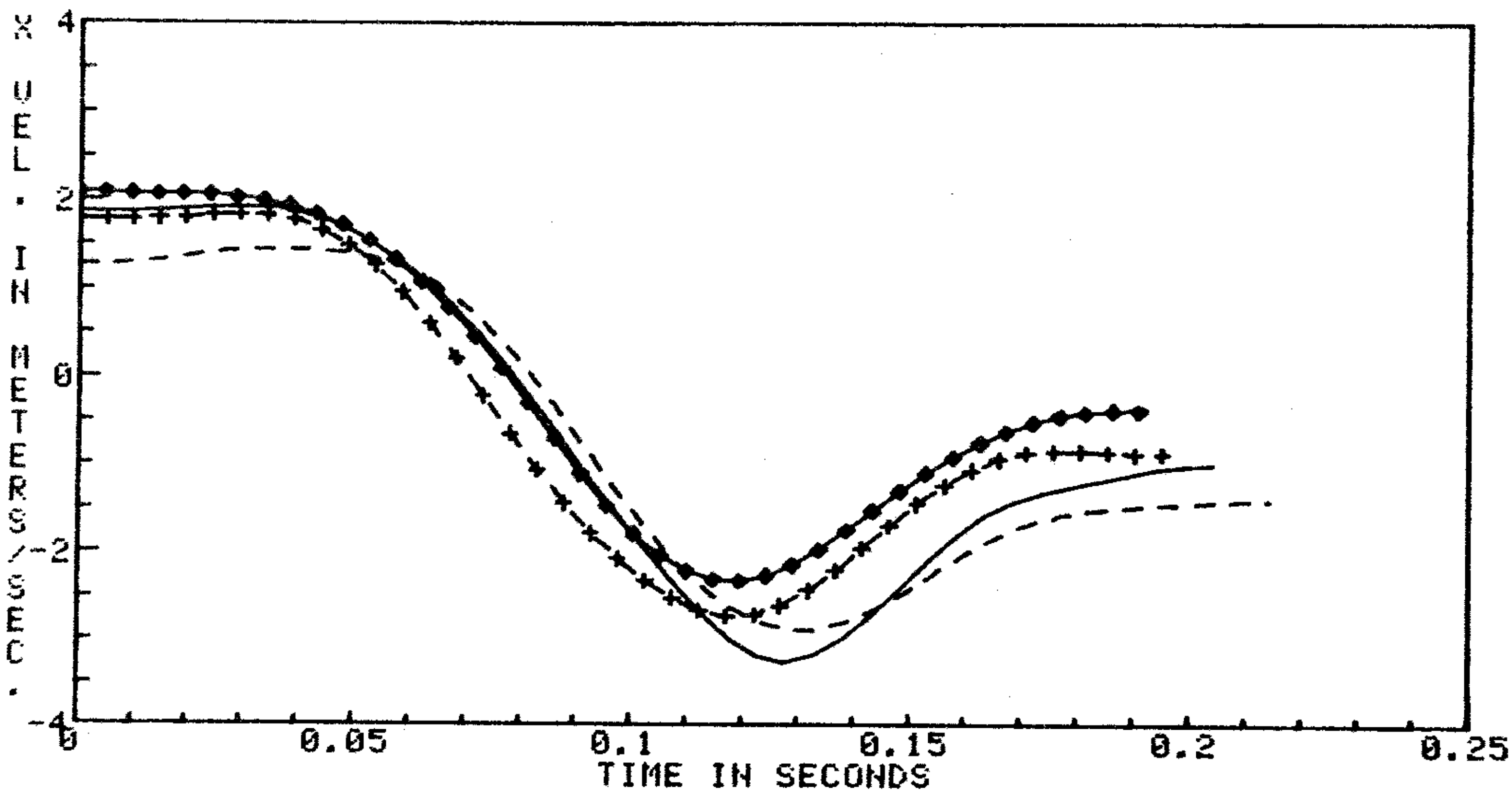
Y-VELOCITY OF THE LEFT ELBOW



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

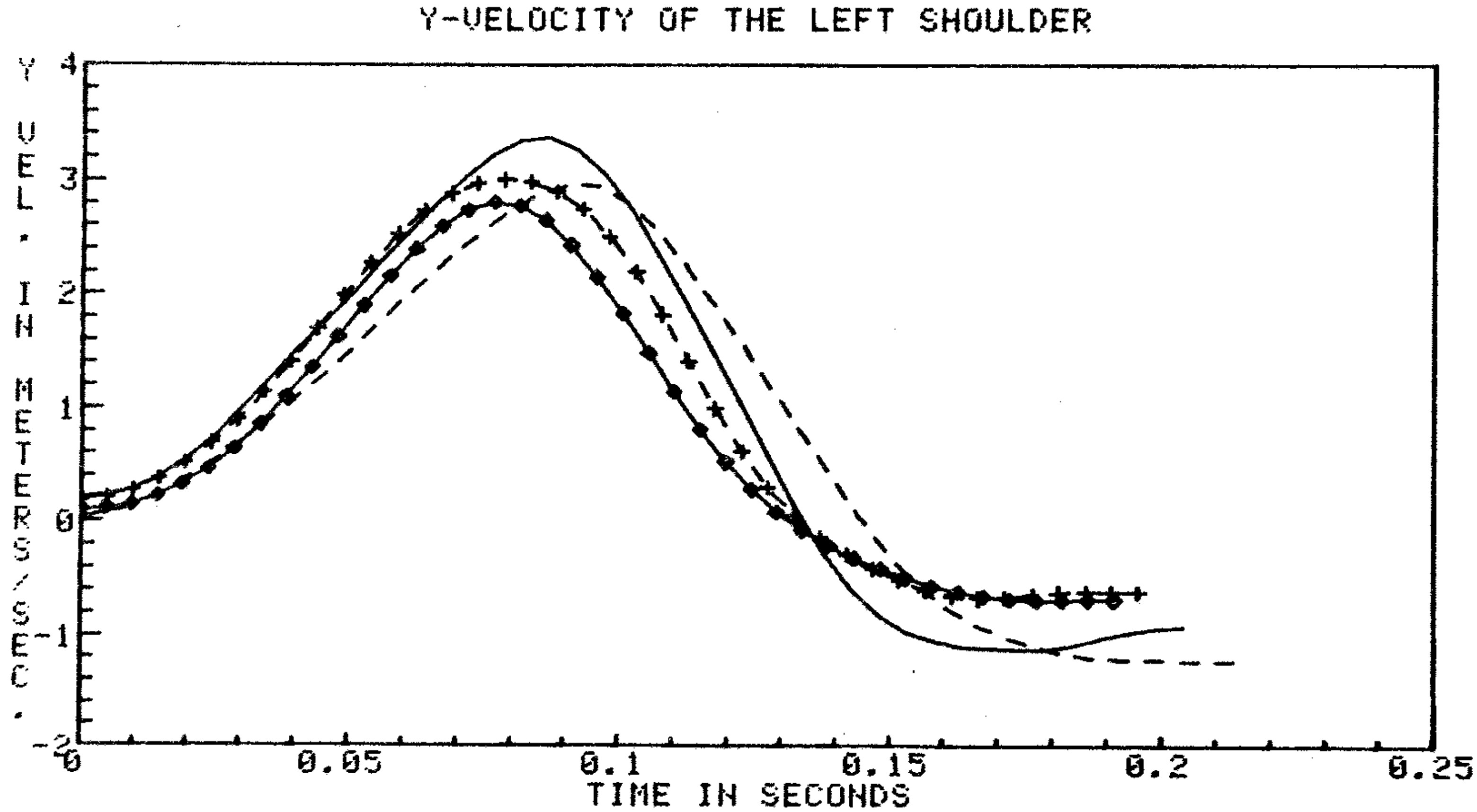
FIGURE 22

X-VELOCITY OF THE LEFT SHOULDER



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 23



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

for the more distal segment endpoints. This result would support a contention for a summated contribution of the upper limb segments.

If the axes are rotated such that the x-axis is colinear with a line from the rear corner of home plate to the point at which the ball was released, the x-coordinates of the tip of the bat, handle of the bat, and third metacarpal of the left hand at the instant prior to contact are adjusted to yield the results shown in Table 5.

TABLE 5

Adjusted X-Displacements at the Instant Prior to Contact[a]

	Landmark[b]		
Subject Group	A	B	C
1			
Same field condition	1.085	0.851	0.833
Opposite field condition	0.737	0.805	0.854
2			
Same field condition	0.926	0.681	0.666
Opposite field condition	0.651	0.706	0.760

[a]Displacement measured in meters from an origin at the rear corner of home plate.

[b]A = Tip of the bat
B = Handle of the bat
C = Third metacarpal of the left hand

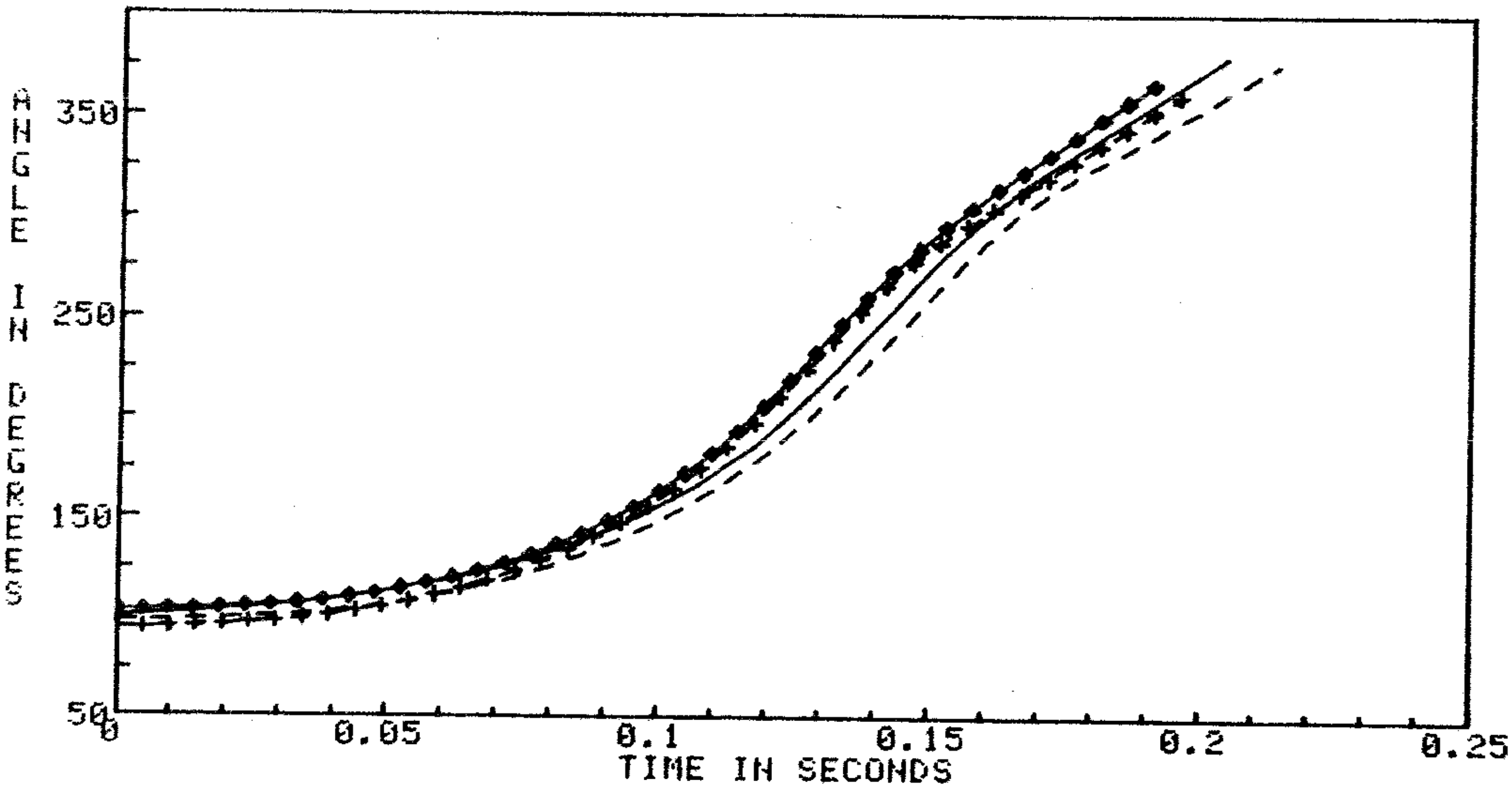
An examination of the x-displacements of the tip and handle of the bat show that for all conditions the ball was contacted before it reached home plate. This is in contrast to Hay (1978) who stated that to hit the ball to the opposite field the ball should be contacted when it is over the plate. (Note: The smallest x-displacements for the tip and handle of the bat were 0.651 meters and 0.681 meters respectively.) It was also found that the third metacarpal of the left hand preceded the tip of the bat at contact for the opposite field swing, whereas for the same field swing it was behind the tip of the bat.

The angular displacements of the bat, left hand, left forearm, and left arm are shown in Figures 24 through 27. All of the angles were measured relative to the positive x-axis. All of the curves are similar in form with no apparent differences existing between the conditions. The mean angles for each of the segments at the instant prior to contact are shown in Table 6. A statistical analysis revealed that the bat, hand, and forearm angles were significantly less for the opposite field conditions than for the same field conditions. No significant difference was found for the left arm. The summary tables for the statistical analysis appear in Appendices O through R.

The angular velocities of the bat, left hand, left forearm, and left arm for all conditions (Figures 28 through 31) reveal that the maximum angular velocities

FIGURE 24

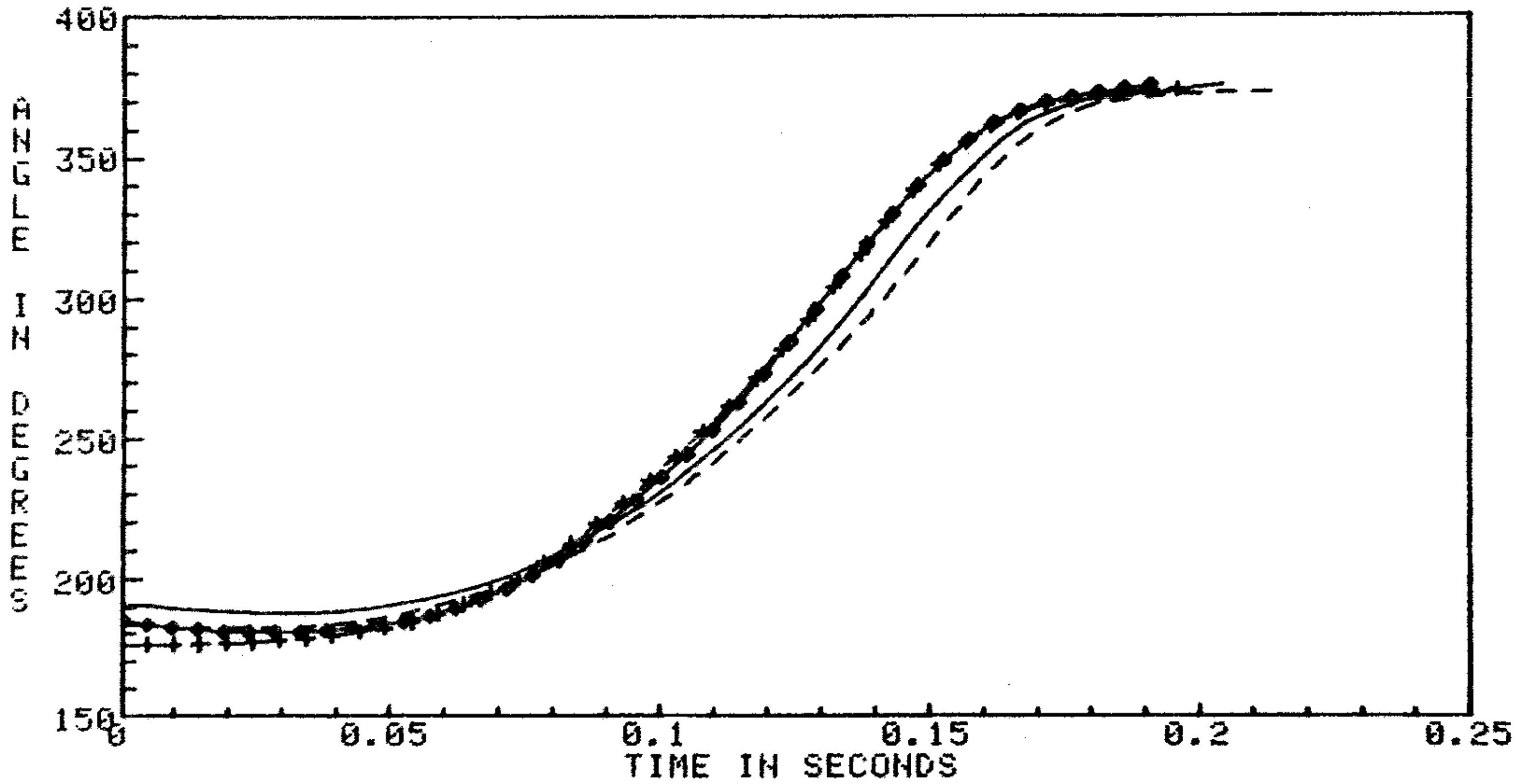
ANGLE OF THE BAT DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 25

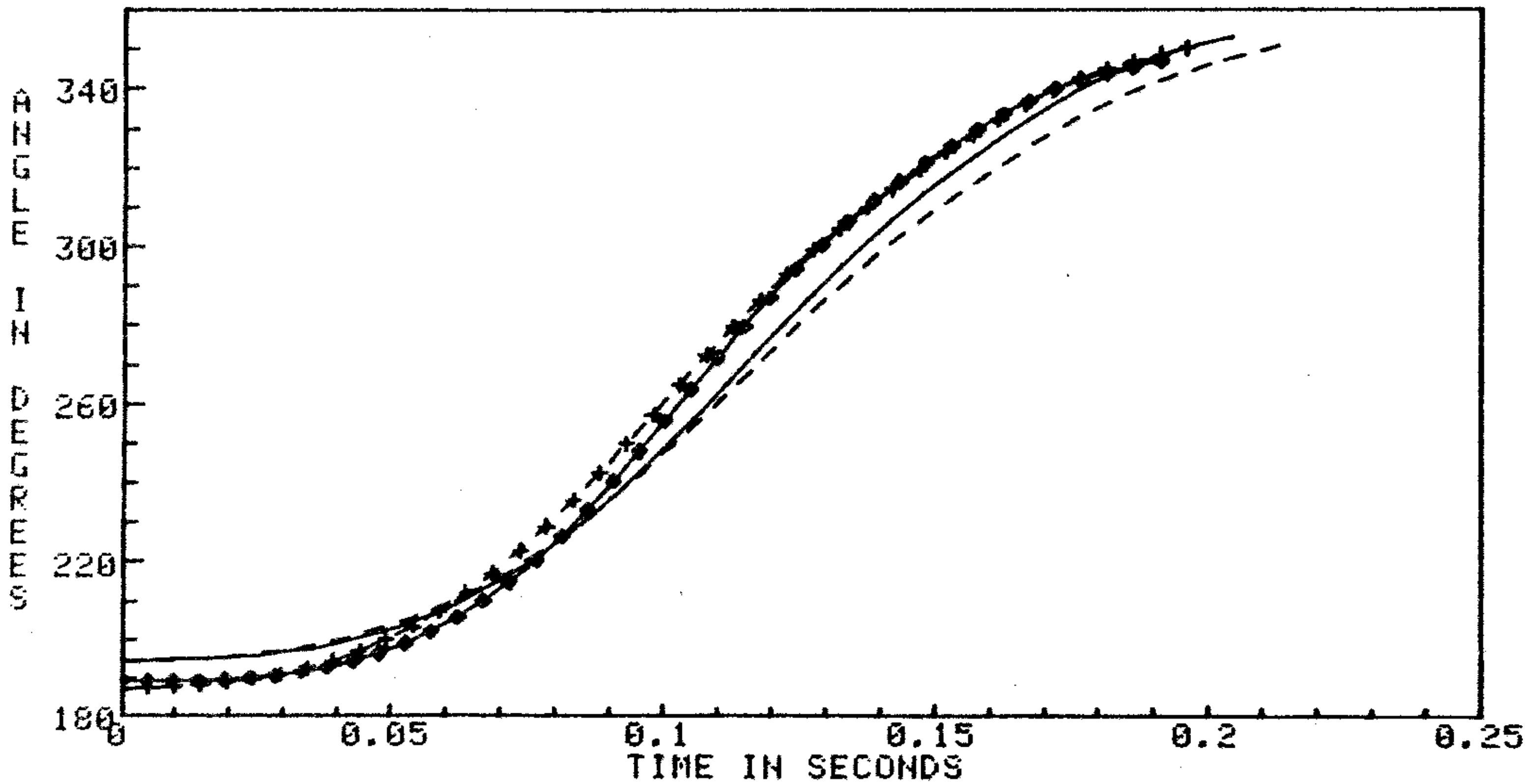
ANGLE OF THE LEFT HAND DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 26

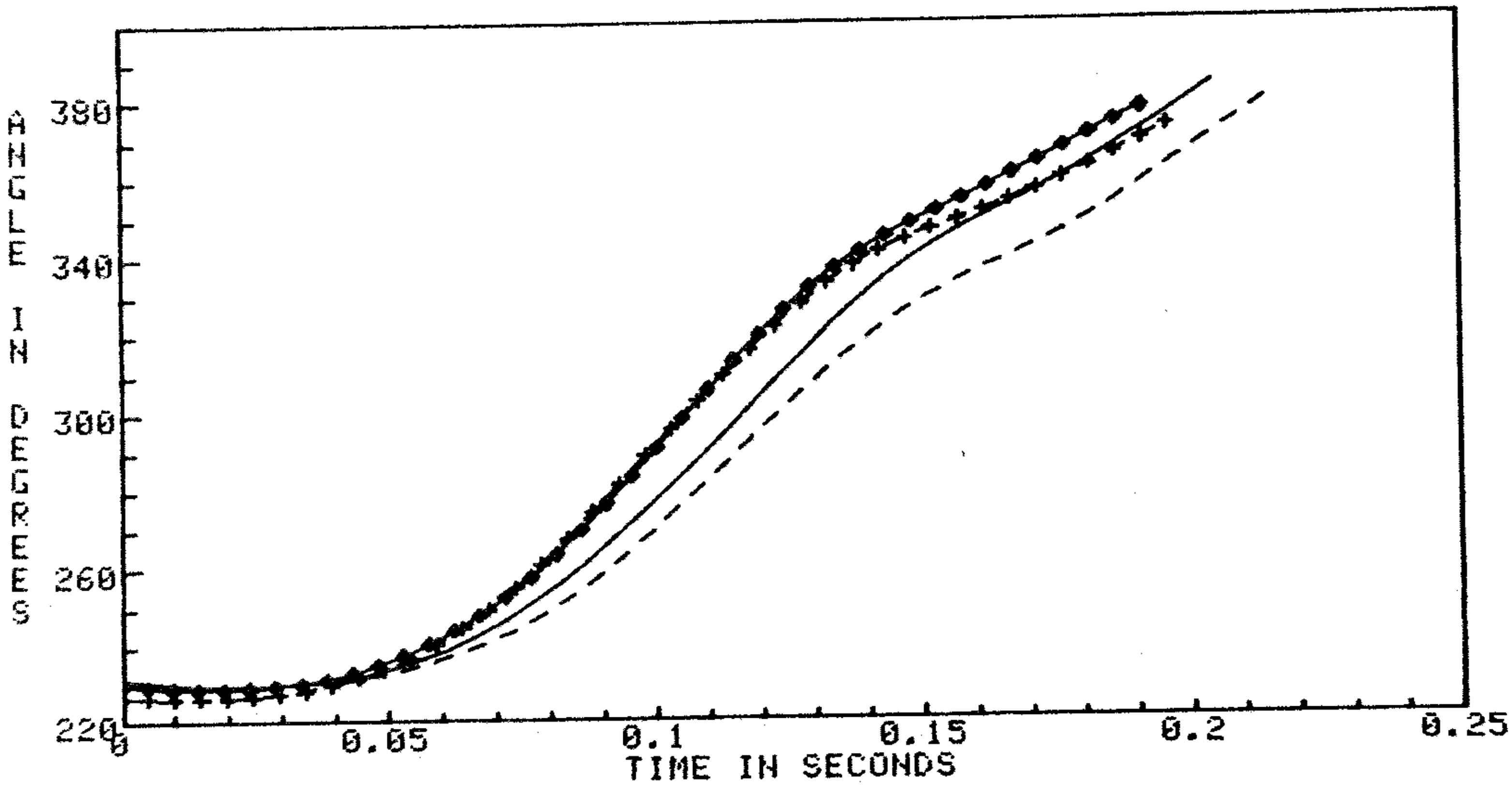
ANGLE OF THE LEFT FOREARM DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

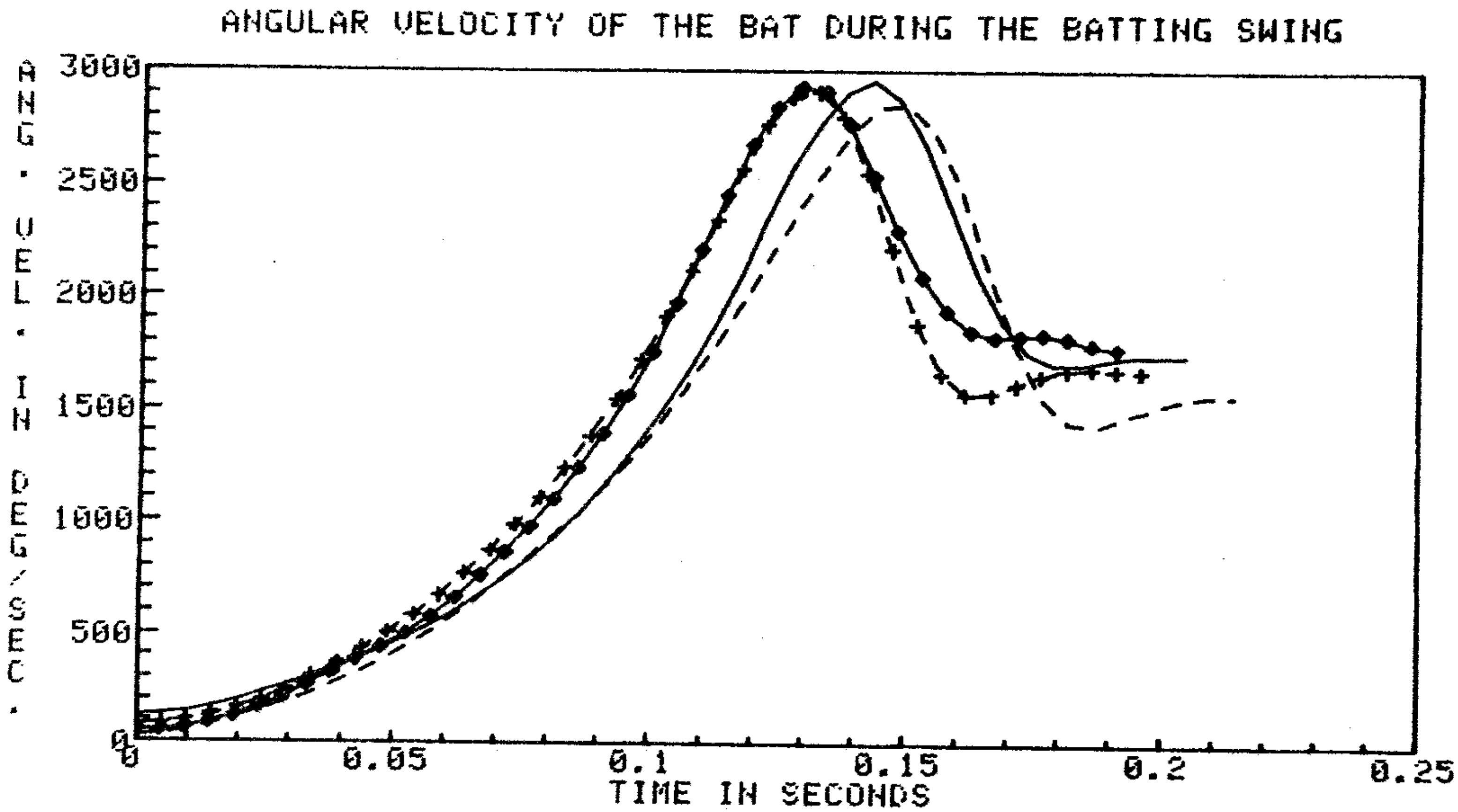
FIGURE 27

ANGLE OF THE LEFT ARM DURING THE BATTING SWING



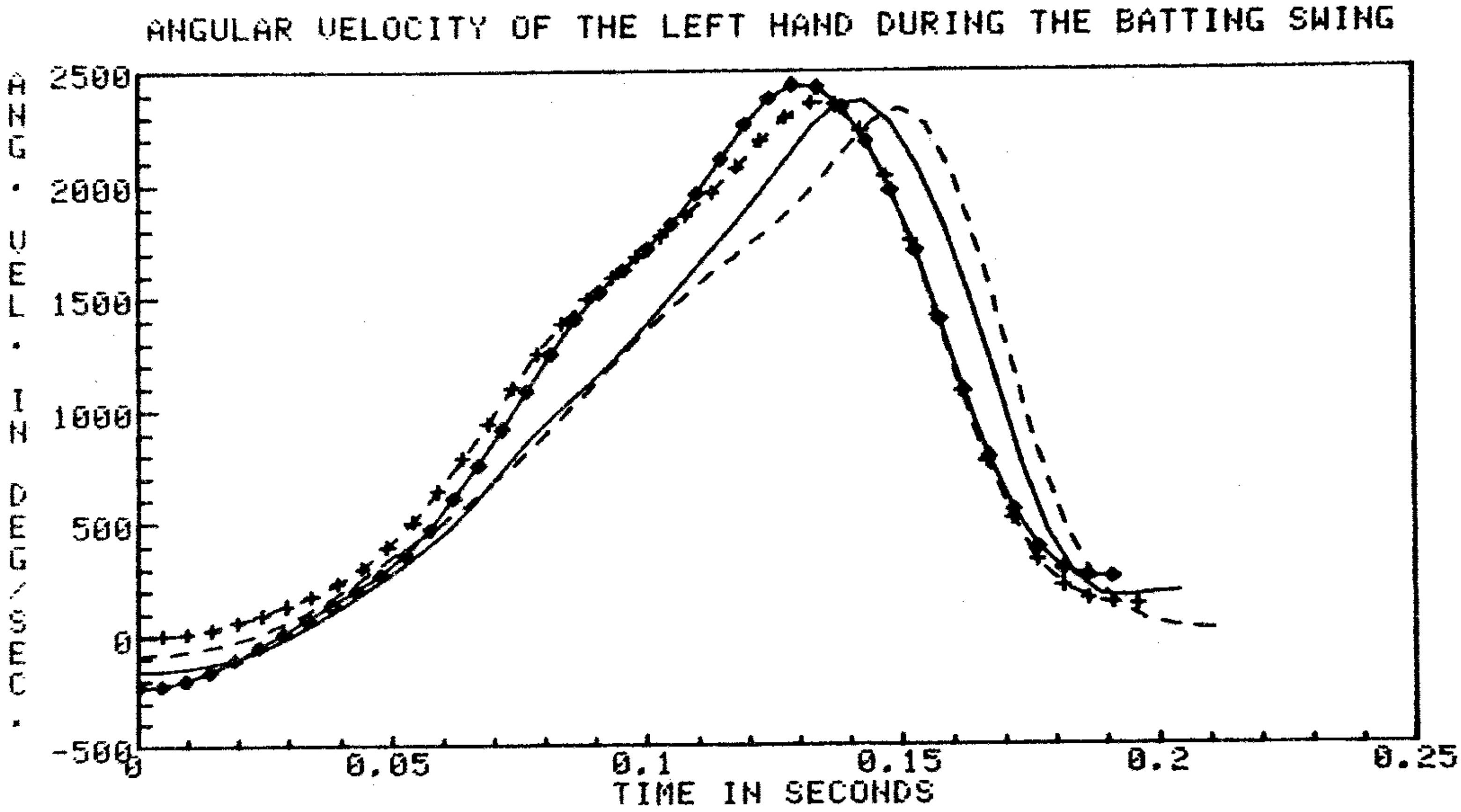
Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 28



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

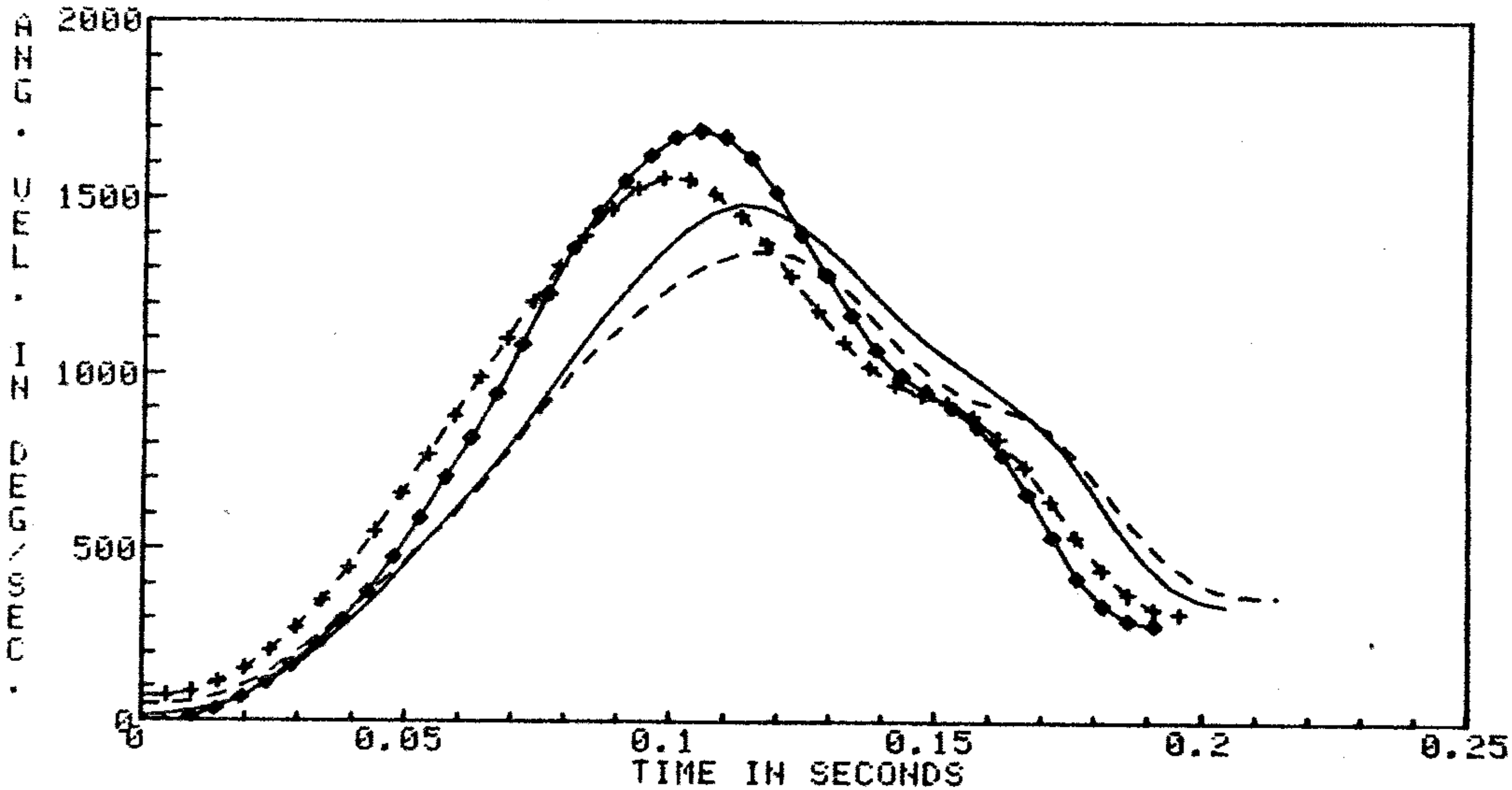
FIGURE 29



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 30

ANGULAR VELOCITY OF THE LEFT FOREARM DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 31

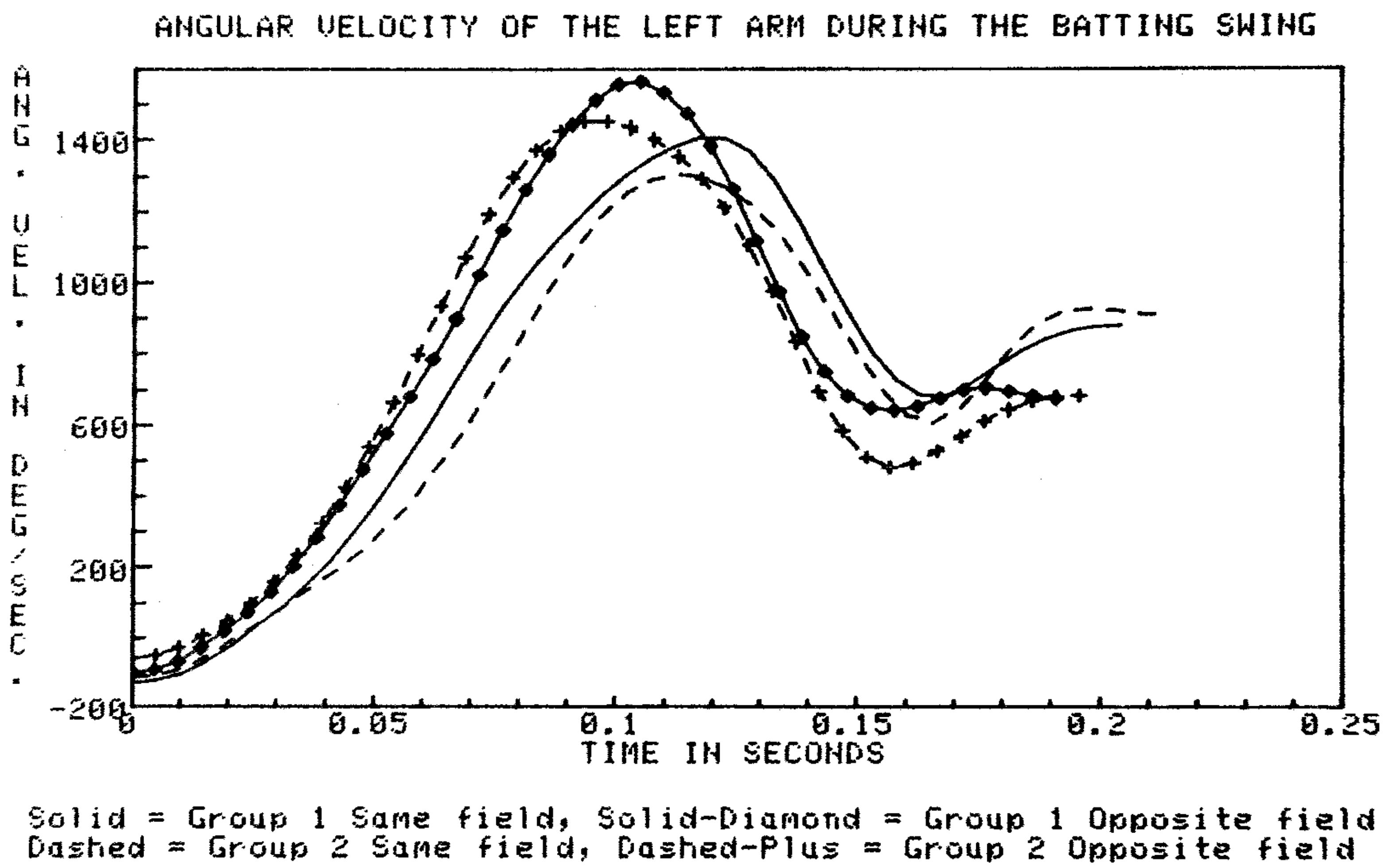

ANGULAR VELOCITY OF THE LEFT ARM DURING THE BATTING SWING
ANG. VEL. IN DEG/SEC.
1400
1000
600
200
-200
0
0.05
0.1
0.15
0.2
0.25
TIME IN SECONDS
Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

TABLE 6

Segment Angles at the Instant Prior to Contact[a]

	Segment[b]			
Subject Group	A	B	C	D
1				
Same field condition	295.0	347.0	323.6	347.0
Opposite field condition	268.1	324.8	314.5	345.3
2				
Same field condition	294.8	349.0	321.2	336.1
Opposite field condition	269.2	330.1	316.3	342.7

[a]Angles measured in degrees relative to the x-axis.

[b]A = Bat
B = Left hand
C = Left forearm
D = Left arm

occurred before contact. These results are supportive of the reported occurrences of the maximum linear speeds. The angular velocities of these four segments at the instant prior to contact are shown in Table 7. The angular velocities for the bat, left hand, and left arm were found to be significantly greater for the opposite field swing. For this to have occurred, the average time from the initiation of movement to contact with the ball for the same field swing must have increased at a proportionately greater rate than the angular displacement of the bat. The temporal and angular displacement data in Table 1 and Table 6 respectively

TABLE 7

Segment Angular Velocities at the

Instant Prior to Contact[a]

Subject Group	Landmark[b]			
	A	B	C	D
1				
Same field condition	2701.2	2027.2	984.6	619.7
Opposite field condition	2908.1	2603.1	969.0	789.9
2				
Same field condition	2414.0	2025.0	915.5	533.7
Opposite field condition	2607.6	2351.8	955.5	625.5

[a]Angular velocities measured in degrees per second.

[b]A = Bat
B = Left Hand
C = Left forearm
D = Left arm

would lend support to such an occurrence. With these results, the linear speed of the tip of the bat, as illustrated in Table 8, would be expected to decrease with decreases in the angular velocity. However, no statistical differences were found between the linear speeds of the tip of the bat between field hit conditions. This apparent discrepancy in the results could only be explained if the radius of rotation of the bat changed according to the type of field hit. An indication of changes in the radius of rotation is the linear distance between the tip of the bat

TABLE 8

Linear Velocity of the Tip of the Bat at the Instant Prior to Contact[a]

	Field Hit Condition	
Subject Group	Same field	Opposite field
1	39.495	35.721
2	39.303	36.443

[a]Linear velocity measured in meters per second.

and the third metacarpal of the left hand. These distances, shown in Table 9, illustrate that for the opposite field conditions the "radius of rotation" was less than that for the same field conditions.

TABLE 9

Distance from the Tip of the Bat to the Third Metacarpal of the Left Hand[a]

	Field Hit Condition	
Subject Group	Same field	Opposite field
1	0.801	0.710
2	0.802	0.764

[a]Distance measured in meters.

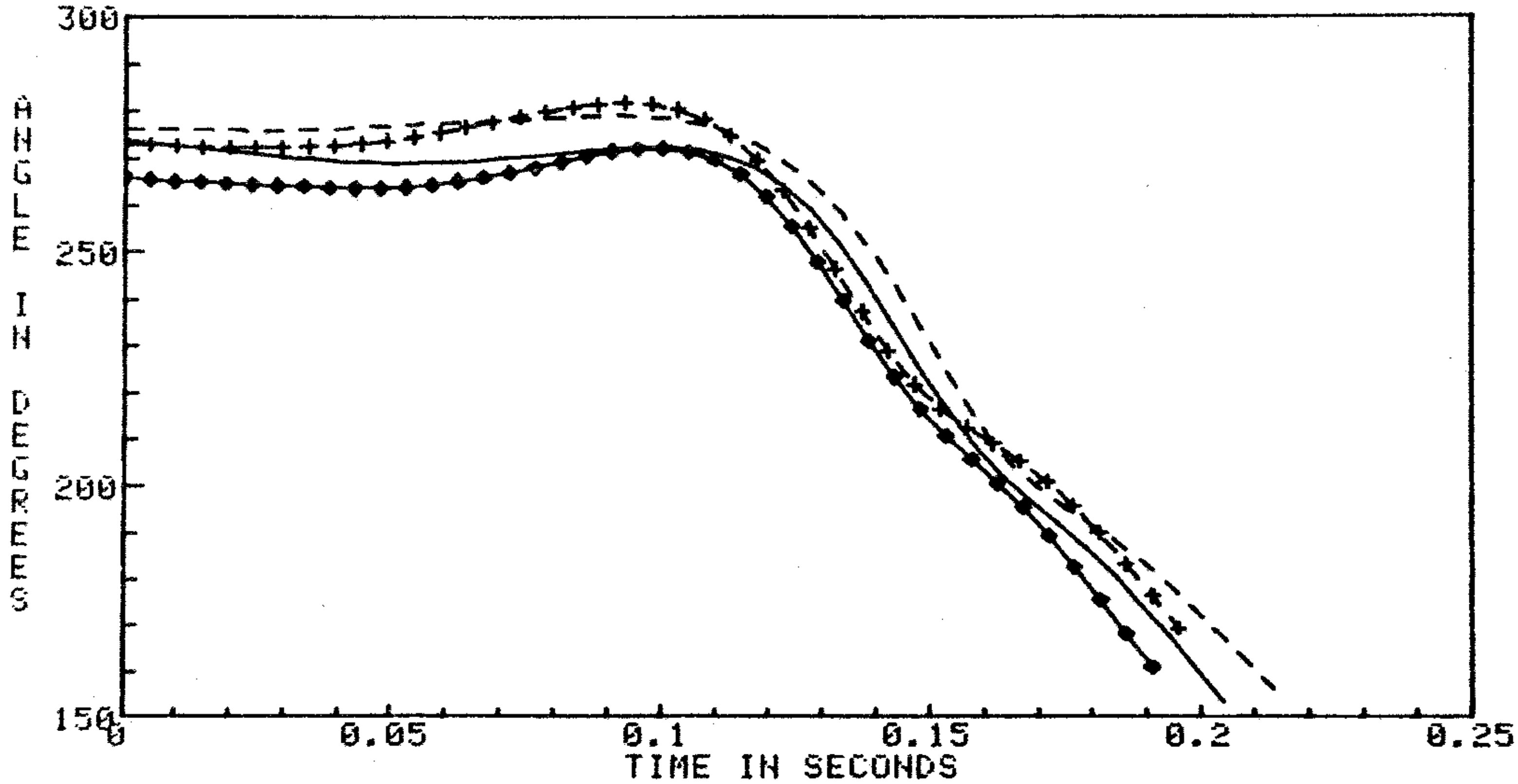
The radial changes occurred as a result of the subjects being aware of the type of field hit to be performed and by making appropriate adjustments in the hand-grip locations.

Figure 32 and Figure 33 show the angle between the bat and left forearm and the angular changes occurring at the left wrist joint. The initial increases in the angles are indicative of an abduction, or "cocking" action, at the wrist joint. Maximum adduction occurred approximately at the time of contact. It would appear from the results shown in Figure 34 that there is no motion of the bat relative to the hands. The angle between the bat and left forearm continued to decrease after ball-bat contact. Both of these angles at the instant prior to contact, as illustrated in Table 10, were found to be significantly greater for the opposite field swing, which indicates that the required directional characteristics of the bat are partially brought about by differences in the angular displacements at the wrist joint. The summary tables for the statistical analysis appear in Appendix S and Appendix T.

The angular velocities of the projected joint between the bat and left forearm, and the left wrist joint are shown in Figure 35 and Figure 36 respectively. The angular velocities at the instant prior to contact are illustrated in Table 11. Statistically significant differences were found between the field hit conditions for the angular velocity of the left wrist joint, with the opposite field

FIGURE 32

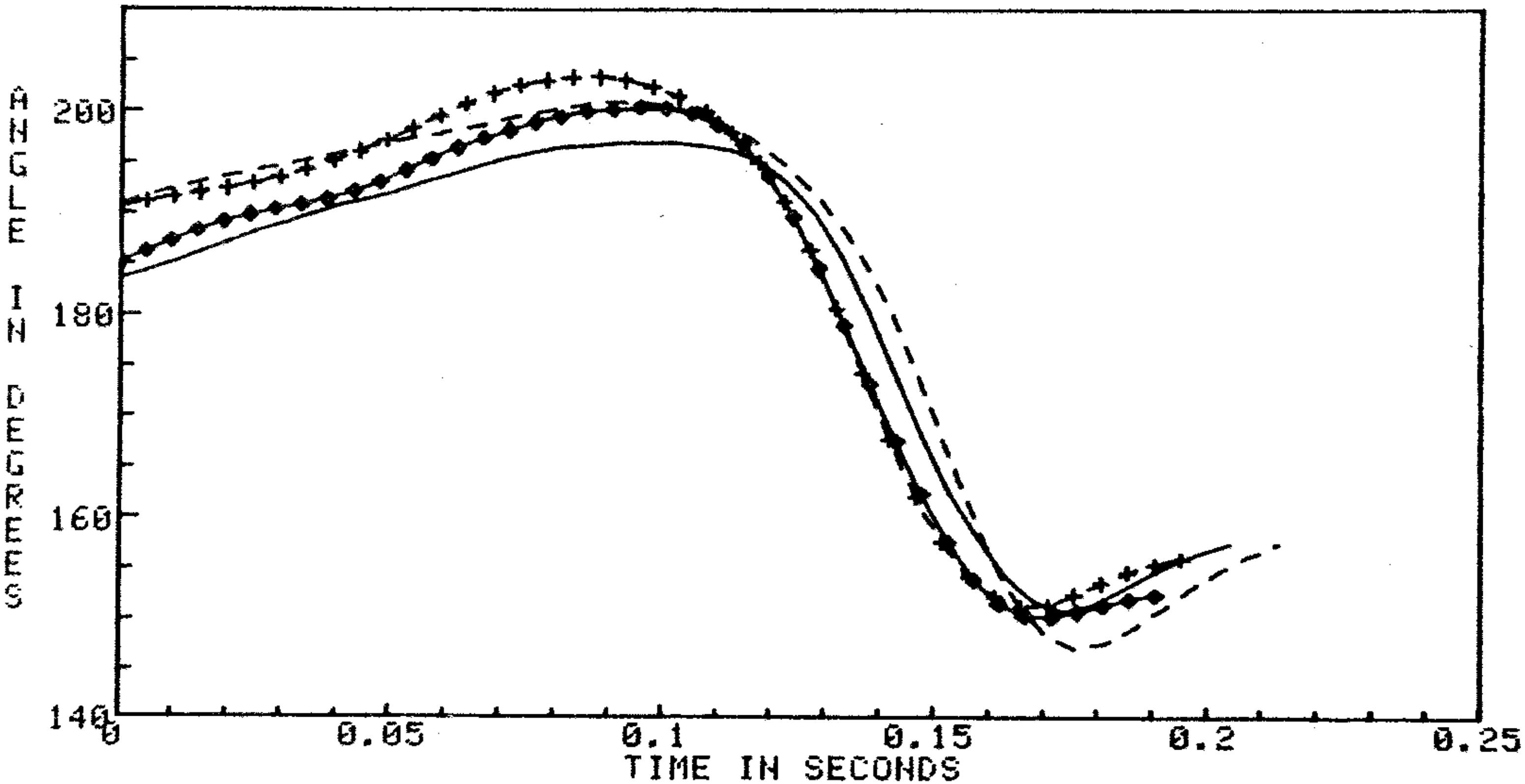
ANGLE BETWEEN THE BAT AND LEFT FOREARM DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 33

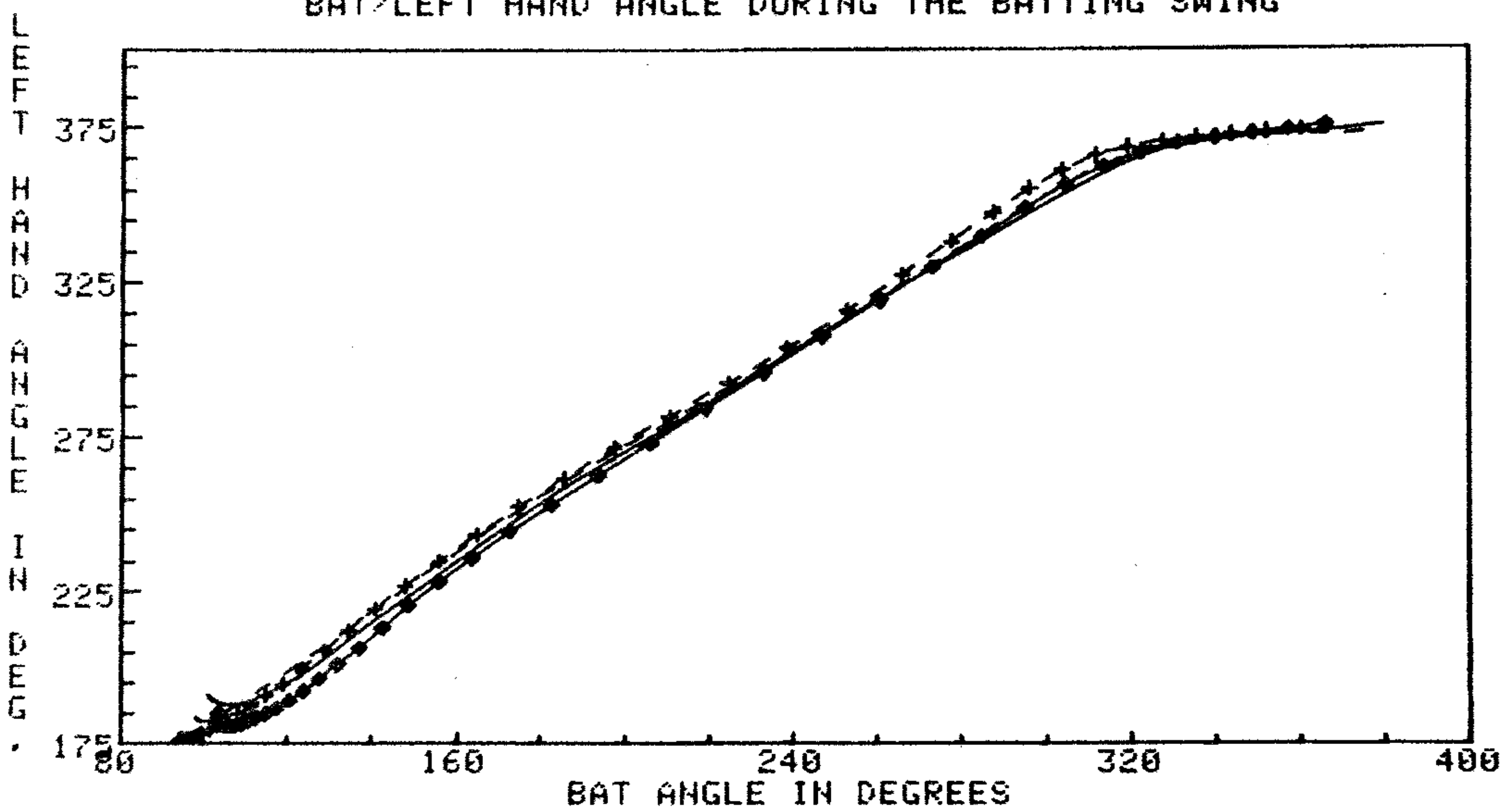
ANGLE OF THE LEFT WRIST JOINT DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 34

BAT/LEFT HAND ANGLE DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group2 Opposite field

TABLE 10

Joint Angles at the Instant Prior to Contact[a]

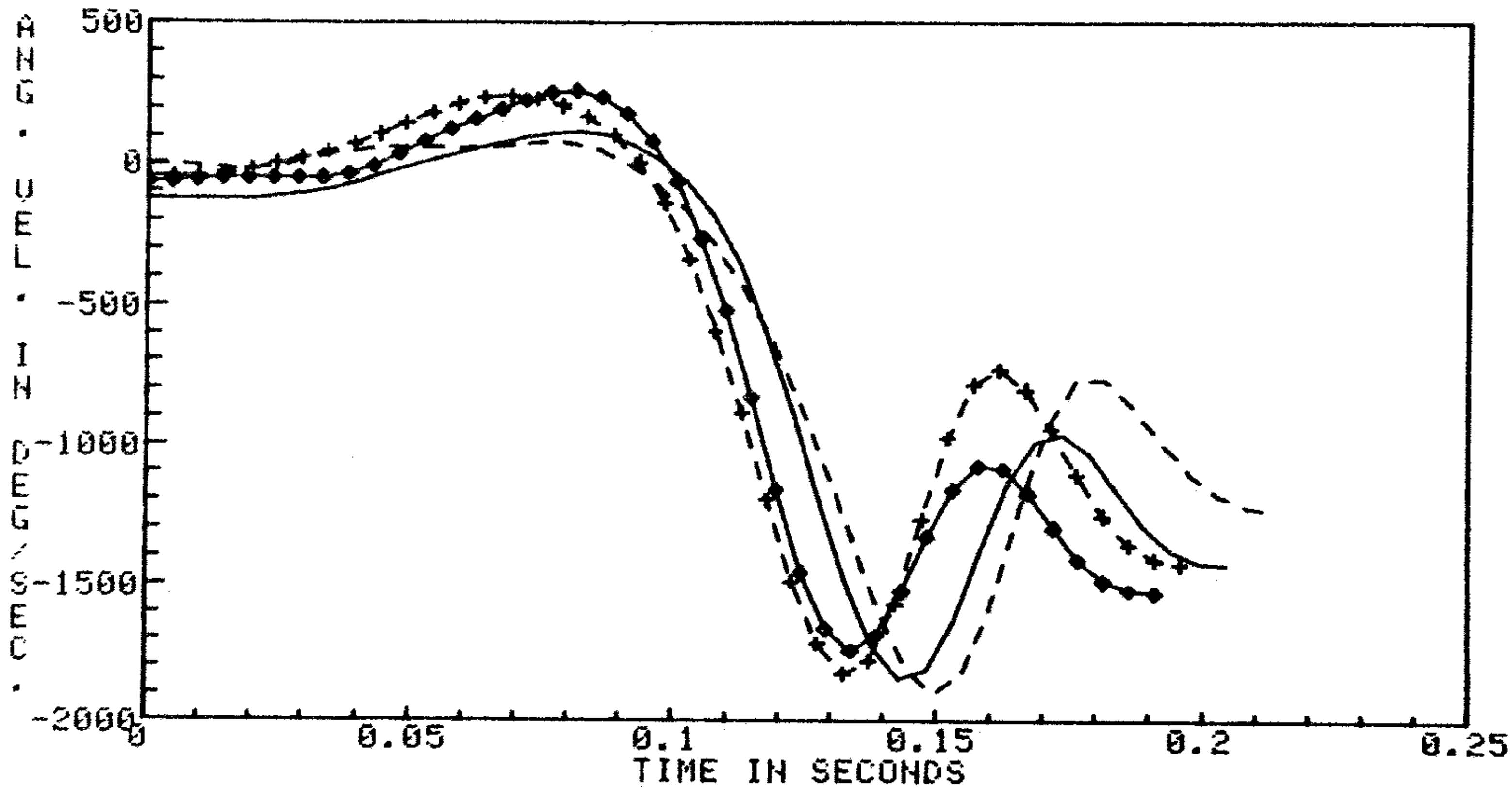
Subject Group	Landmark[b] A	B	C
1			
Same field condition	208.2	157.0	203.2
Opposite field condition	226.7	171.1	210.7
2			
Same field condition	205.0	152.5	195.7
Opposite field condition	227.1	166.8	202.4

[a]Angles measured in degrees.

[b]A = Bat-left forearm
B = Left wrist
C = Left elbow

FIGURE 35

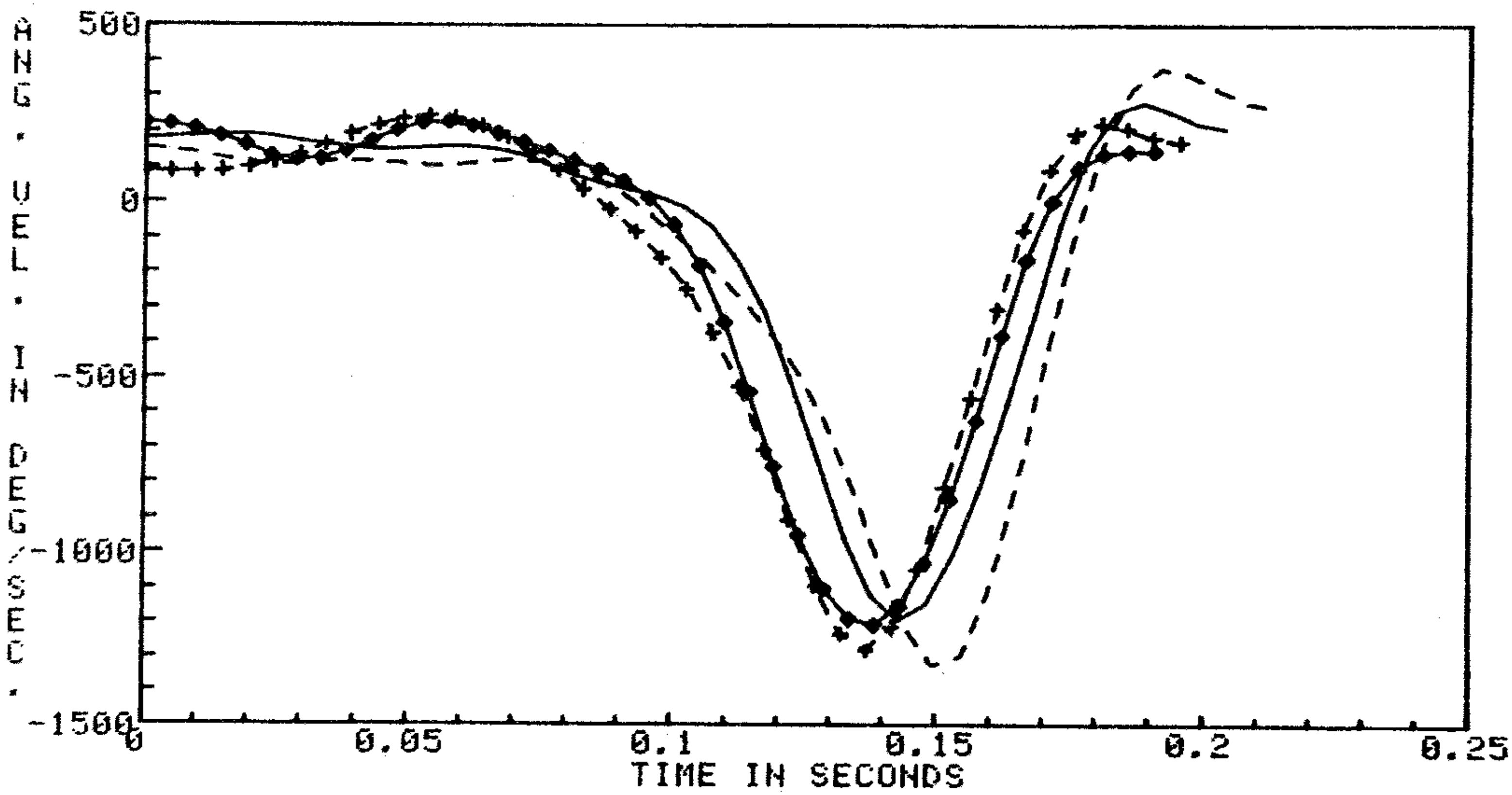
ANGULAR VELOCITY BETWEEN THE BAT AND LEFT FOREARM



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 36

ANGULAR VELOCITY OF THE LEFT WRIST DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

TABLE 11

Joint Angular Velocities at the Instant Prior to Contact[a]

	Joint[b]		
Subject Group	A	B	C
1			
Same field condition	-1711.0	-992.6	-319.9
Opposite field condition	-1973.3	-1465.5	-249.5
2			
Same field condition	-1507.3	-1091.7	-331.1
Opposite field condition	-1681.3	-1333.5	-317.3

[a]Angular velocities measured in degrees per second.

[b]A = Bat-left forearm
B = Left wrist
C = Left elbow

conditions being greater than the same field conditions. The summary tables for the statistical analysis appear in Appendix S and Appendix T.

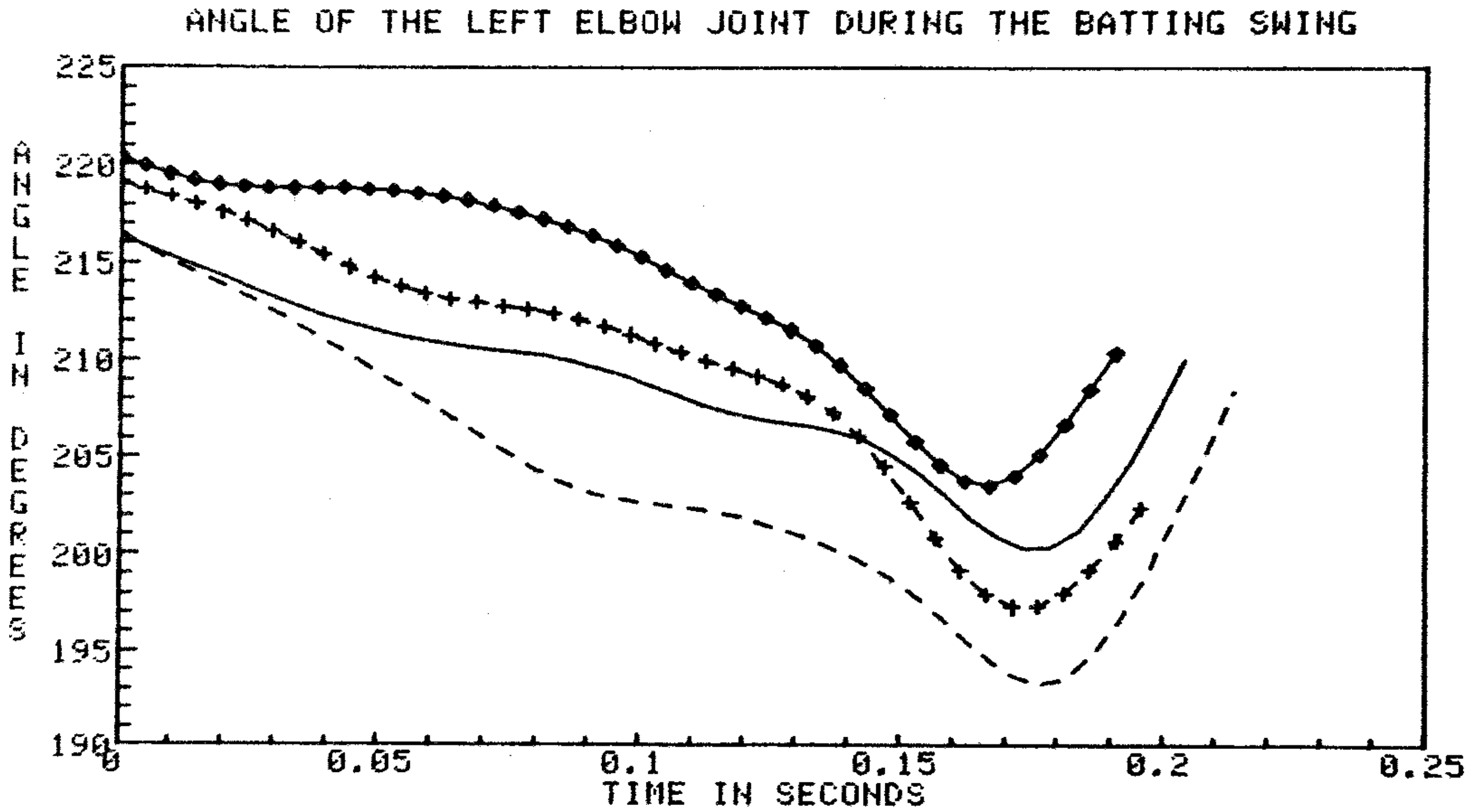
A comparison between the curves illustrated in Figure 35 and Figure 36 reveals that after contact the angular velocity of the left wrist joint decreased to zero whereas the angular velocity of the projected bat-left forearm joint was maintained at a non-zero value. The latter result may be interpreted as a consequence of a "rolling" of the right forearm over the left forearm during the follow-through phase.

The angle of the left elbow joint during the batting swing and the mean angle of this joint at the instant prior to contact for all conditions are shown in Figure 37 and Table 10 respectively. Statistically significant differences were found between the field hits at the instant prior to contact, with the angle being greater for the opposite field conditions. That is, during the same field swing the left elbow joint was more fully extended. Some of these differences may be accounted for by differences in the angles prior to the initiation of the swing. However, it would seem that the desired directional characteristics of the bat at the instant prior to contact are in part a result of motion at this joint along with the previously mentioned motion at the left wrist joint. A summary table for the statistical analysis of the left elbow angle appears in Appendix U.

The contribution of elbow joint extension to the overall speed of the bat would appear to be negligible. Figure 36 and Figure 38 show only slight increases in the angular velocities of the left elbow joint when compared to the angular velocities at the left wrist joint.

Figures 39 through 41 illustrate that increases in the left forearm angle throughout the swing were accompanied by increases in the angles of the bat, the left hand, and the left arm. The angle/angle plots of the bat-left forearm joint/left elbow joint and the left wrist joint/left elbow

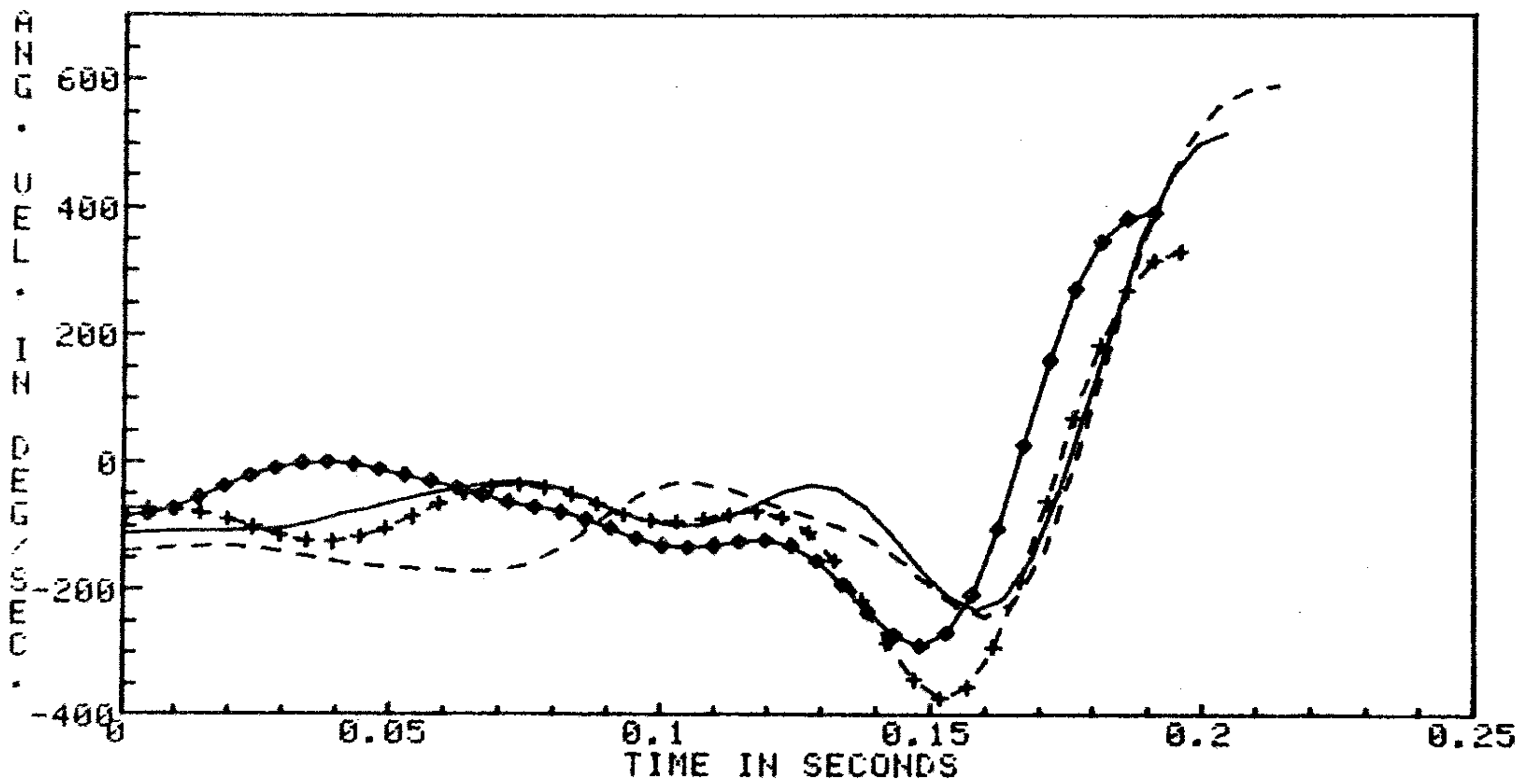
FIGURE 37



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

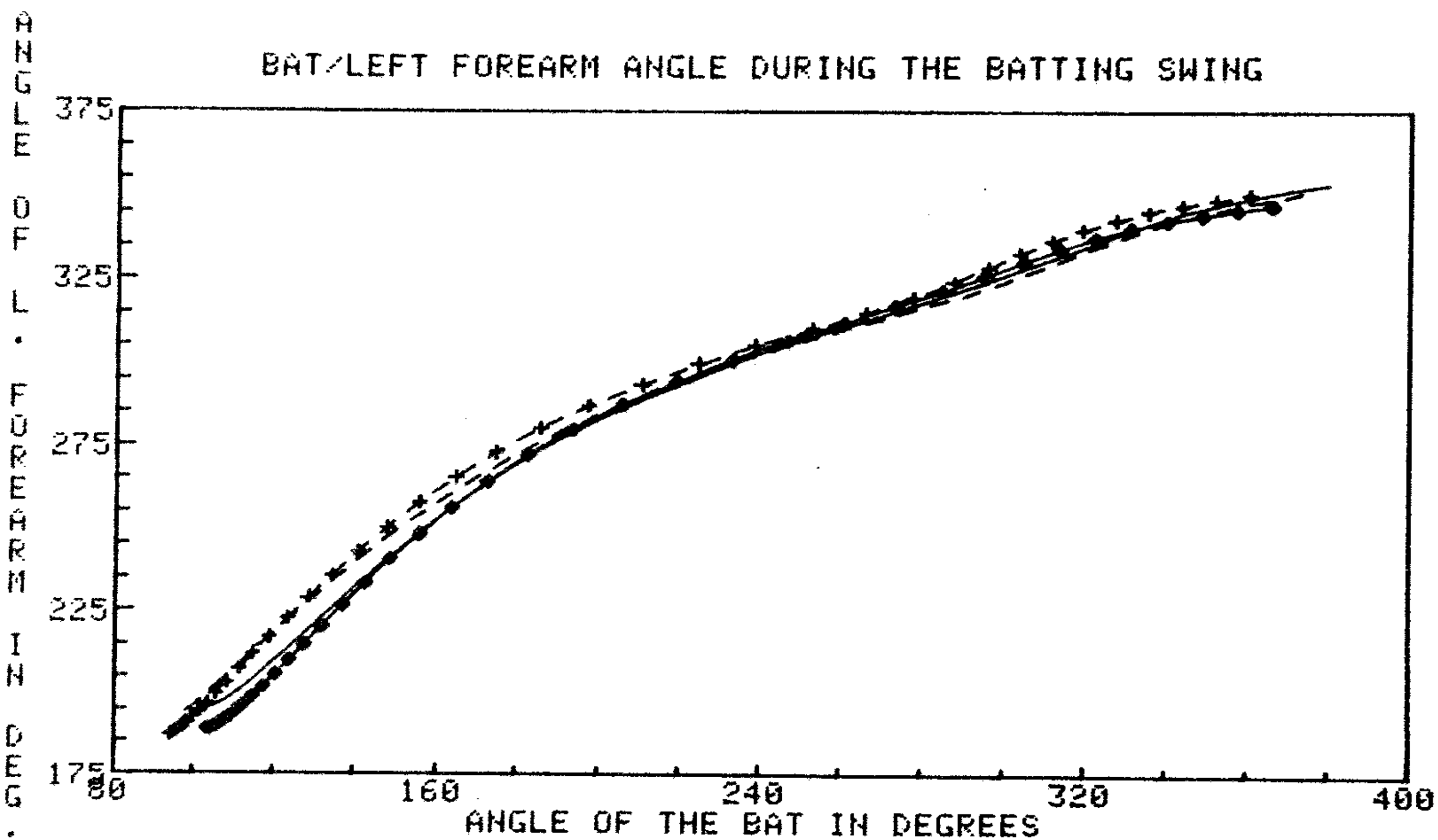
FIGURE 38

ANGULAR VELOCITY OF THE LEFT ELBOW DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 39



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 40

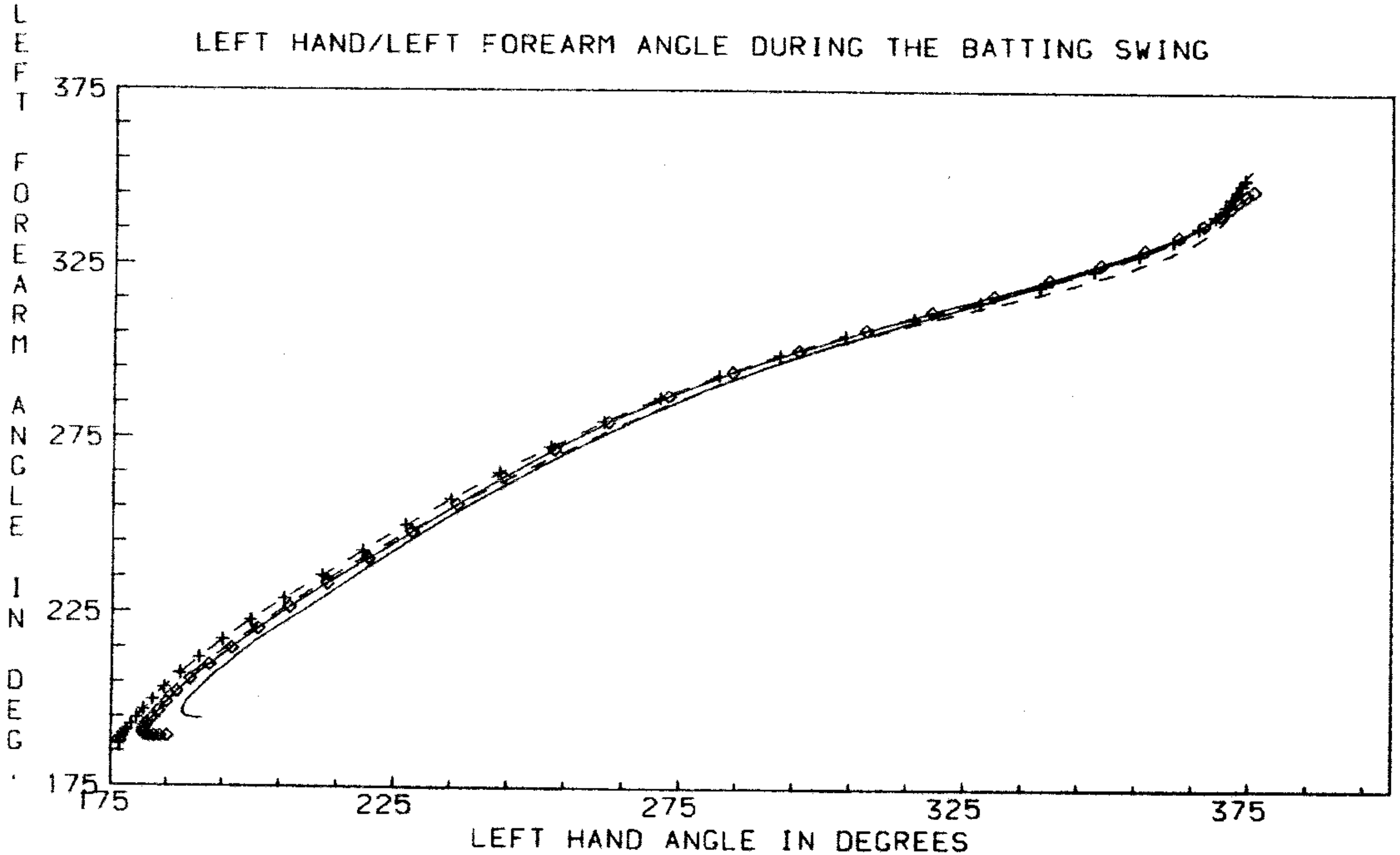
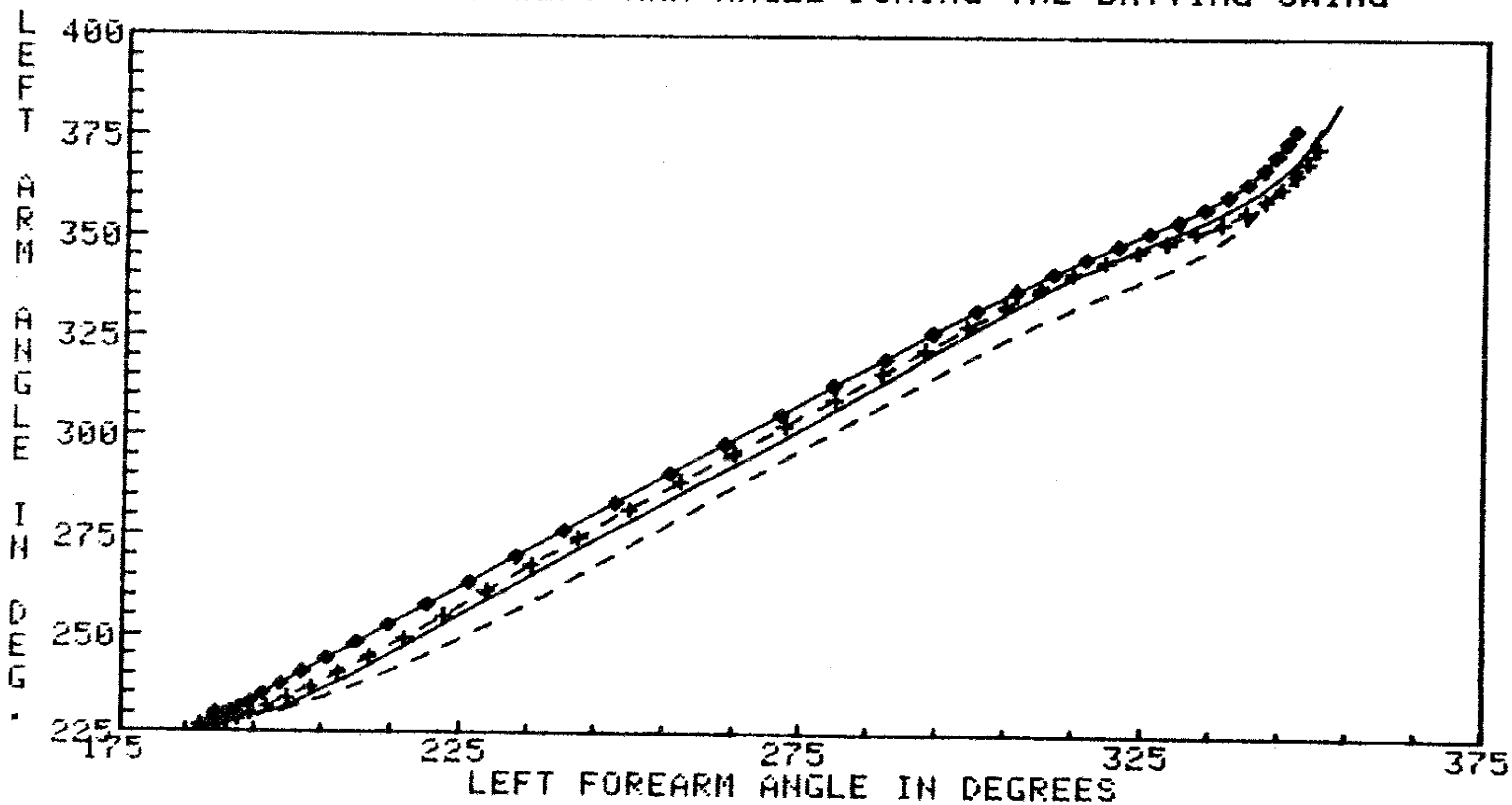

LEFT HAND/LEFT FOREARM ANGLE DURING THE BATTING SWING
LEFT FOREARM ANGLE IN DEG.
375
325
275
225
175
175
225
275
325
375
LEFT HAND ANGLE IN DEGREES

FIGURE 41

LEFT FOREARM/LEFT ARM ANGLE DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

joint are shown in Figure 42 and Figure 43 respectively. The plots show that the initial phases of the swing are characterized by abduction of the left wrist joint and extension of the left elbow joint. This is followed by simultaneous adduction of the left wrist joint and extension of the left elbow joint. During the follow-through, abduction occurs at the wrist joint and flexion occurs at the elbow joint.

The mean angles of incidence and reflection between the bat and ball appear in Table 12.

TABLE 12

Angles of Incidence and Reflection Between The Bat and Ball[a]

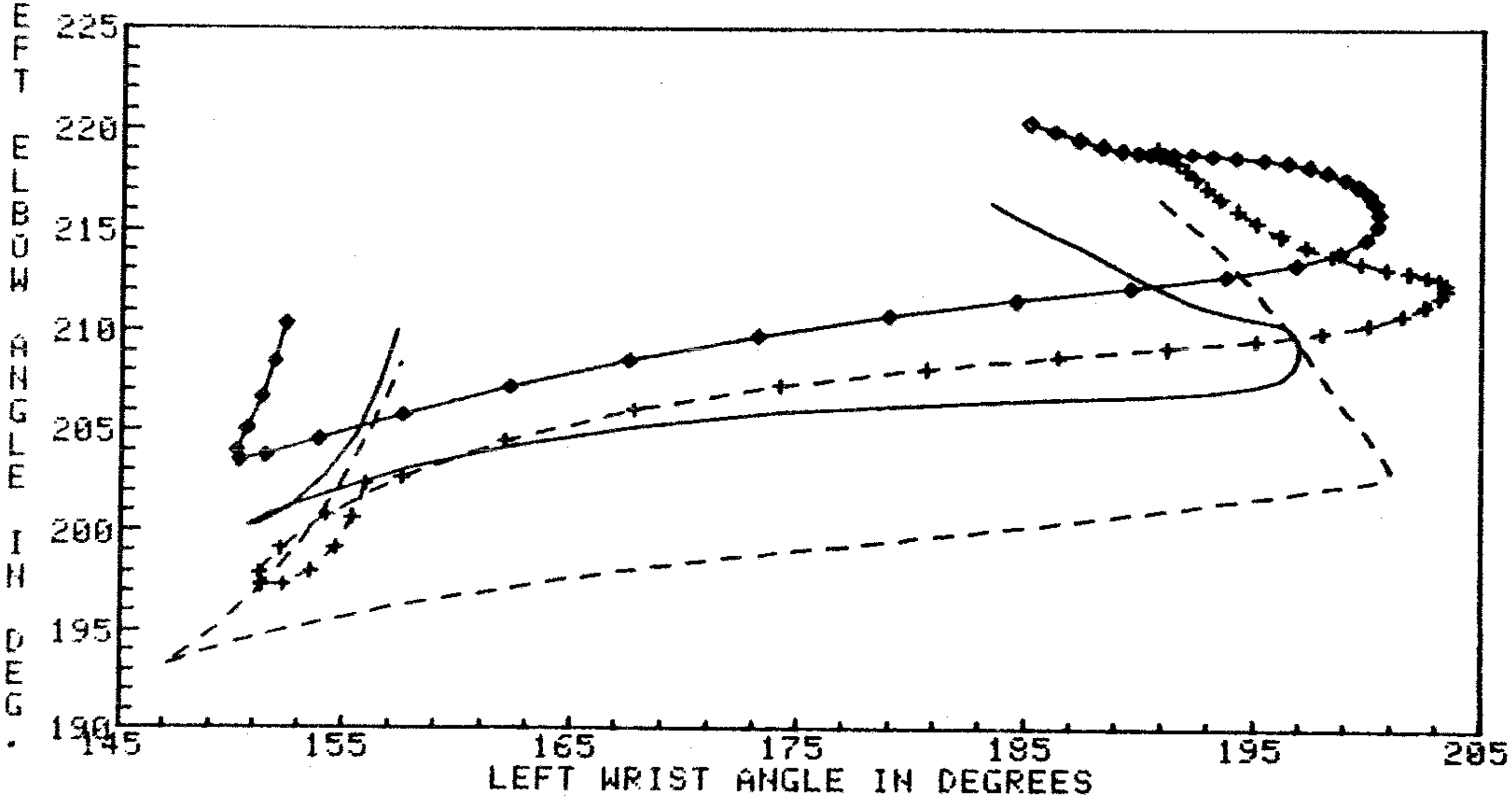
	Angle[b]	
Subject Group	I	R
1		
Same field condition	12.83	16.53
Opposite field condition	13.18	14.79
2		
Same field condition	12.61	17.62
Opposite field condition	11.78	14.88

[a]Angles measured in degrees.

[b]I = Angle of incidence
R = Angle of reflection

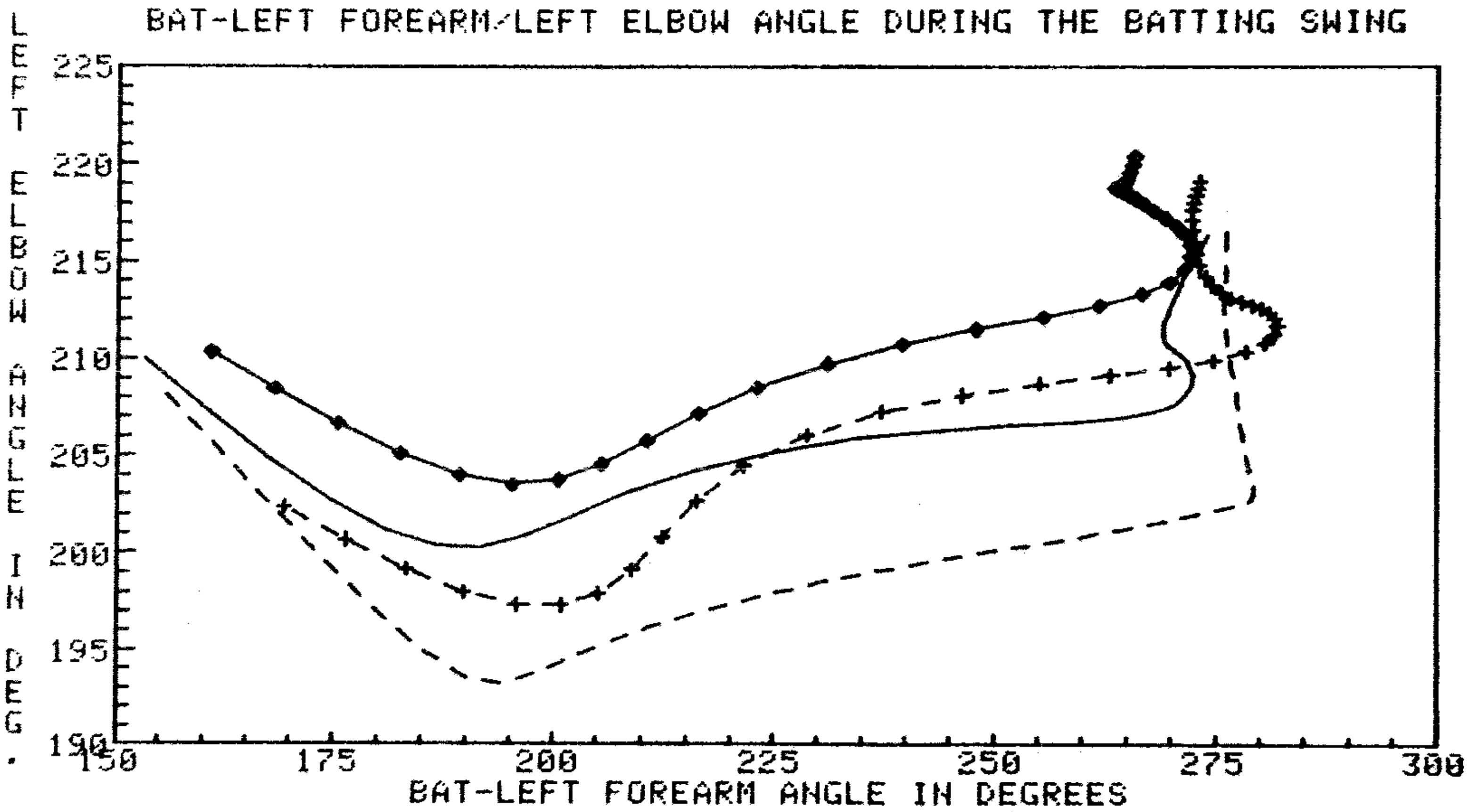
FIGURE 42

LEFT WRIST/LEFT ELBOW ANGLE DURING THE BATTING SWING



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

FIGURE 43



Solid = Group 1 Same field, Solid-Diamond = Group 1 Opposite field
Dashed = Group 2 Same field, Dashed-Plus = Group 2 Opposite field

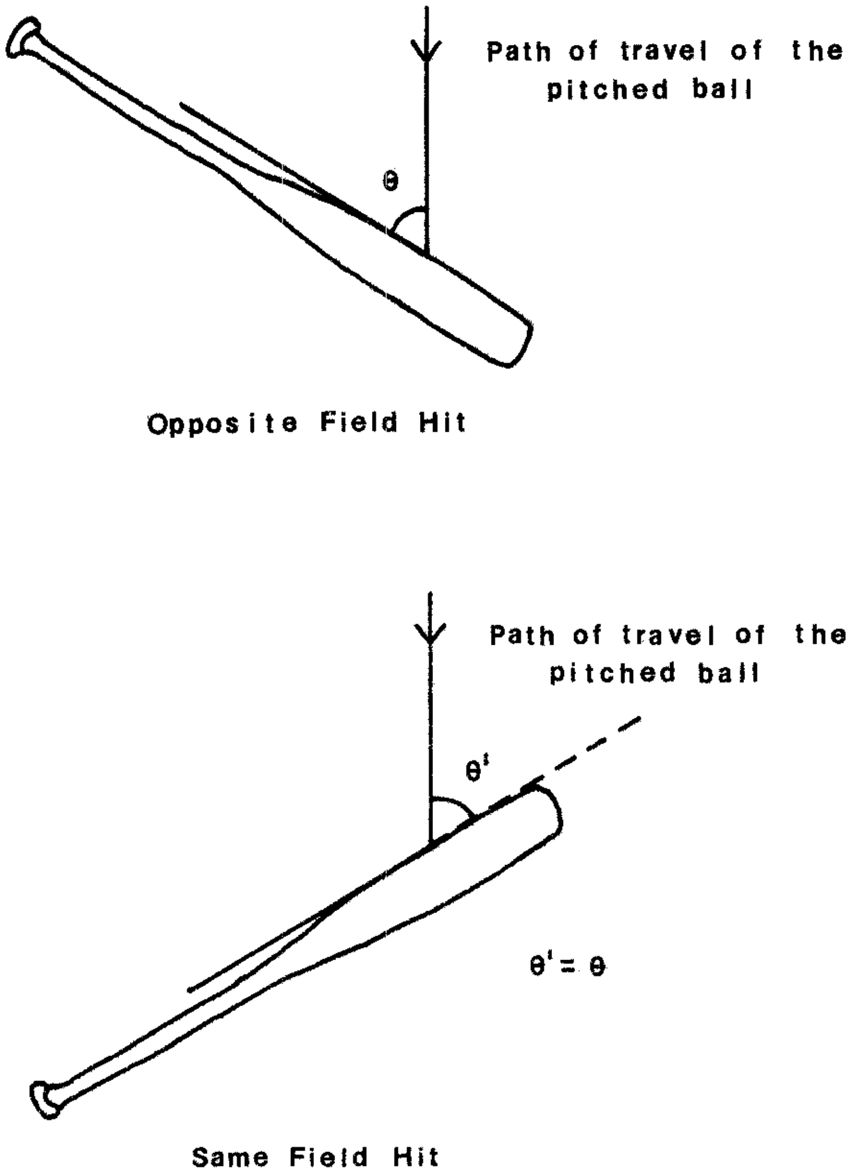
No statisically significant differences were found between the conditions. For the field hitting conditions, the results may be explained by the motion of the bat which was oriented relative to the path of the ball in such a way that the angles between the bat and the flight of the ball were supplementary, as shown in Figure 44. That is, the angles θ and θ' were of the same magnitude.

In summary, the results of the study revealed no significant interaction between subject groups and the two types of field hits. An examination of the main effects revealed that all of the significant differences existed between the field hit conditions. Significant differences between the opposite field and same field swings were found in the x-displacements of the tip of the bat, the left wrist joint, the left elbow joint, and the left shoulder joint and in the y-displacements of the left elbow joint at the instant prior to contact. The majority of the differences may be accounted for by differences in the initial locations, the only exception being the tip of the bat. The x-component of velocity for the tip of the bat, the third metacarpal of the left hand, and the left wrist joint were found to be significiantly greater at the instant prior to contact for the opposite field swing. Similar results were found for the y-component of velocity for the tip of the bat, the left elbow joint and the left shoulder joint.

Figure 44

Angle Between the Bat and Path of the Pitched Ball

at the Instant Prior to Contact



An examination of the displacement and velocity curves showed that the movement patterns for both the opposite field and same field swings were similar in form. Initial differences in the displacements indicate that the subjects adjusted their stance according to the type of field hit condition. Changes that occurred in the initial y-displacements accomplished the same effect as would have adjustment to the location of the pitching machine to cause it to deliver an outside pitch. An outside pitch would have facilitated the subjects hitting the ball to the opposite field.

No differences were found between the field hit conditions for the resultant linear speed of the tip of the bat at the instant prior to contact. This was due in part to a reduction in the "radius of rotation", which was one of the adjustments made by the subjects when performing the opposite field hits. The maximum resultant speed of the tip of the bat was found to occur prior to contact with the ball. These results would indicate that the subjects in this study were not performing in an optimum manner, for in order to hit the ball with the greatest velocity it would seem reasonable to suggest that the timing of the swing should be such that the maximum speed of the tip of the bat should occur just prior to ball contact. Similar results were found for the third metacarpal of the left hand, left wrist joint, left elbow joint, and left shoulder joint with the tendency for the time to reach maximum speed to increase as the segments become more distal. This result supports the contention for a summated contribution of the upper limb segments.

The angular displacement patterns of the bat, the left hand, the left forearm, and the left arm were found to be similar for all conditions. The angular orientations of the bat, left hand, and left forearm for the opposite field swing at the instant prior to contact were found to be significantly less than for the same field swing. In addition, the angular velocities of the bat, left hand, and left arm were found to be significantly greater at the instant prior to contact for the opposite field swing. The angles at the left wrist joint, the left elbow joint, and the projected joint between the bat and left forearm were found to be significantly greater at the instant prior to contact for the opposite field swing with the angular velocity of the left wrist joint being significantly greater. The maximum angular velocities of the four segments occurred before ball contact which supports the results found for the maximum linear speeds of the segment endpoints.

The motion of the bat and left hand were found to be similar in form until just after the instant of contact. Further motion of the bat then appeared to be due to only the motion of the right forearm. In addition, the contribution of elbow joint extension to the motion of the bat just prior to contact was negligible when compared with that of the left wrist joint.

The difference in the angle at the left elbow joint at the instant prior to contact between the two swings, as noted by Williams (1971), appears to be an important factor in the movement patterns of the left limb segments. Decreasing the amount of extension at the left elbow joint, as occurred during the opposite field swing trials, had the effect of decreasing the moment of inertia of the left limb. Thus the angular velocity of the upper limb increased while the limb was horizontally abducting at the left shoulder joint. The end result was that the left arm reached the same approximate location at the instant prior to contact for both types of field hits despite differences in the orientations of the bat, left hand, and left forearm.

The greater angular velocity found to occur at the left wrist joint during the opposite field swing was probably due to the decreased radius of rotation of the bat. The decreased radius of rotation effectively decreased the bat's inertial characteristics and thus the torques produced by muscle action were able to cause a greater change in angular velocity. Although the angular velocity of the bat was greater for the opposite field swing than for the same field swing, the linear speed of the tip of the bat remained the same for both conditions due to the differences in the respective radii of rotation.

The location of the bat at the instant prior to contact was found to be to the front of home plate for all conditions, with the hands preceding the tip of the bat for the opposite field swing. The computed angles of incidence and reflection between the bat and ball were found to be the same for all conditions. The angle of the left wrist joint and the degree of extension at the left elbow joint at the instant prior to contact appeared to be factors in orienting the bat relative to the path of the ball in such a way that the angle of incidence produced the desired field hit. The action at the wrist joint is supportive of the timing of the motion to achieve the desired field hit as elaborated upon by Scott (1963).

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the mechanics of hitting a baseball to the same and opposite fields, with special emphasis placed on an identification of those factors which distinguish players of different hitting abilities.

A review of literature revealed that no scientific studies had been conducted to analyze the mechanical differences between the batting swings involved in hitting a baseball to the same and opposite fields. However, several authors have discussed the mechanical factors related to hitting the ball to different field areas. Hay (1978) and Bunn (1972) emphasized that the direction the ball travelled after impact was primarily dependent upon the angle of incidence between the bat and path of the pitched ball. In addition, Hay stated that an opposite field hit was accomplished by initiating the swing later so that the ball was contacted when it was over home plate. Scott (1963) stressed that the timing of the wrist action was such that when the ball was contacted during an opposite field hit the hands precede the point on the bat where contact is made. Williams (1971) stipulated that when hitting the ball to the opposite field the lead elbow joint should not be extended as much as it is when hitting to the same field.

Twenty male subjects were used in the study, with ten subjects in each of two groups. The assignment of the subjects to one of the groups was based upon recommendation of their respective coaches regarding their ability to hit effectively to the opposite field.

Each subject performed as many trials as were necessary to hit the ball successfully six times, three times each to two assigned areas of the field. The field areas corresponded to the same field and the opposite field. A neutral area between the two designated areas was marked to identify those hits which may have involved characteristics of both opposite field and same field swings. An automatic pitching machine was used to deliver the baseballs.

Each trial by each subject was recorded on film. Only those trials in which the ball was hit successfully within the limits of the assigned areas were analyzed. The filmed data was used to obtain the x- and y-coordinates of selected landmarks. Linear displacements from an origin at the rear corner of home plate were calculated as well as the angular orientations of selected segments and joints. All of the variables were "smoothed" using cubic spline curve-fitting techniques and averaged for each condition. Component linear and angular velocities were calculated from the smoothed data. A statistical analysis using mixed design repeated measures analysis of variance procedures, $p \leq 0.05$, with subject groups serving as the non-repeating factor was conducted to determine whether or not interactions existed between the subject groups and the two types of batting swings. The subsequent statistical analysis consisted of an analysis of the main effects.

Results

The results of the study revealed no significant interaction between the subject groups and the two types of field hits. An examination of the main effects revealed that all of the significant differences existed between the field hit conditions.

The component linear displacement and velocity curves showed that the movement patterns for the opposite field and same field swings were similar in form. Significant differences between the two swings were found in the x-displacements of the tip of the bat, the left wrist joint, the left elbow joint, and the left shoulder joint and in the y-displacements of the left elbow at the instant prior to contact. The x-displacement of the tip of the bat was the only difference not accounted for by differences in the initial locations. The x-component of velocity for the tip of the bat, the third metacarpal of the left hand, and the left wrist joint were found to be significantly greater at the instant prior to contact for the opposite field swing.

Similar results were found for the y-component of velocity for the left elbow and left shoulder joints.

The maximum resultant speeds of the tip of the bat, left hand, left wrist joint, left elbow joint, and left shoulder joint were found to occur prior to ball contact. The time to reach maximum speed increased as the segments became more distal. No differences were found between the opposite field and same field swings for the resultant linear speed of the tip of the bat. This was due in part to adjustments made by the subjects in the hand-grip locations which effectively reduced the radius of rotation of the tip of the bat.

The angular displacement and velocity curves of the bat, the left hand, the left forearm, and the left arm were found to be similar in form for all conditions. Significant differences between the field hits at the instant prior to contact were found for

1. The angular orientations of the bat, the left hand, and the left forearm segments,
2. The angular orientations of the projected joint between the bat and the left forearm, the left wrist joint, and the left elbow joint,
3. The angular velocities of the bat, the left hand, and the left arm segments,
4. The angular velocity of the left wrist joint.

In addition, the maximum angular velocities of the four segments were found to occur prior to ball contact.

The location of the bat at the instant prior to contact was found to be to the front of home plate for all conditions, with the hands preceding the tip of the bat for the opposite field swing. The computed angles of incidence and reflection between the bat and ball were found to be the same for all conditions.

Conclusions

Based on the results of the study, the following conclusions appear to be warranted:

1. No interactions exist between the subject groups and the two types of batting swings in terms of the mechanical factors selected to describe the motion of the batting swings.
2. No differences exist between the subject groups in terms of the mechanical factors selected to describe the motion of the batting swings.
3. The movement patterns of the examined landmarks appear to be similar in form for the opposite field and same field batting swings.
4. Differences in the opposite field and same field batting swings are due to (a) differences in the angular displacements at the left wrist and left

elbow joints and (b) differences in the temporal characteristics.

5. When the subjects are aware of the area of the playing field to which the hit is to be attempted, adjustments are made in the location of the hands on the bat.

Recommendations

Based on the results of this study, additional examination of the mechanical differences between the opposite field and same field batting swings would seem appropriate. Therefore the following recommendations are made for further studies:

1. An examination of the effects of different rotations of pitched baseballs on the angles of incidence and reflection between the bat and ball with regard to opposite field and same field hitting.
2. An analysis, utilizing three-dimensional cinematographical techniques, of the movement patterns of the right upper limb of right-handed batters during the performance of the opposite field and same field batting swings.

APPENDICES

APPENDIX A

SUBJECT'S INFORMED CONSENT FORM
FOR PARTICIPATION: FORM 1

I appreciate your interest in becoming a subject in this study. Please note that your participation is entirely voluntary and that you are free to withdraw yourself as a subject at any time during the course of the study.

The purpose of this study is to investigate the mechanics of the batting swings involved in pull hitting and opposite field hitting, with special emphasis being placed on identification of those factors which distinguish different types of hitters. An attempt will be made to identify some of the factors which contribute to effective opposite field hitting.

At the beginning of the testing session, measurements will be taken of your standing height and body weight. You will be asked to sign a release statement authorizing the taking of the measurements and the subsequent use of the data for report purposes.

You will be filmed as you attempt to hit pitched baseballs delivered by an automatic pitching machine to two different areas of the playing field (roughly corresponding to left field and right field). You will attempt as many trials as are necessary to hit three successful hits to one of the areas then as many trials as are necessary to hit three successful hits to the remaining area. You will be asked to sign a release statement authorizing the photographing of yourself. Opportunities will be afforded to you to view the films and to examine the final documents describing the experimental techniques and obtained results.

At least two investigators will be present at all data collection sessions and will answer all inquiries you may have concerning the procedures. You will be allowed to wear a batting helmet for all trials if you so desire and every attempt will be made to minimize any harmful effects.

INFORMED CONSENT: FORM 2

USE OF HUMAN SUBJECTS

NAME OF SUBJECT: ______________________________

1. I hereby give consent to Eric W. Pfautsch to perform or supervise the following investigational procedure or treatment:

    1. Record anthropometric characteristics (standing height, body weight)
    2. Take motion picture records during batting performances and to use the records for data analysis and report purposes.

2. I have seen a clear explanation and understand the nature and purpose of the procedure or treatment; possible appropriate alternative procedures that would be advantageous to me; and the attendant discomforts or risks involved and the possibility of complications which might arise. I have seen a clear explanation and understand the benefits to be expected. I understand that the procedure or treatment to be performed is investigational and that I may withdraw my consent for my status. With my understanding of this, having received this information and satisfactory answers to the questions I have asked, I voluntarily consent to the procedure or treatment designated in Paragraph 1 above.

______________________ ______________________________

DATE Subject

APPENDIX B

Selected Anthropometric Characteristics and

Batting Statistics of the Subjects

Subject Number	Age (Years)	Height (Meters)	Weight (Kilograms)	BA[a]	DX[b]
1	18	1.88	82.73	.250	.068
2	19	1.85	74.55	.245	.077
3	21	1.85	84.09	.225	.083
4	21	1.70	80.45	.273	.087
5	21	1.80	73.64	.256	.099
6	21	1.80	69.55	.245	.106
7	20	1.78	73.18	.281	.083
8	21	1.75	68.18	.275	.082
9	25	1.73	79.55	.317	.136
10	29	1.85	75.00	N/A	N/A
11	30	1.78	72.73	N/A	N/A
12	21	1.80	76.18	.417	.186
13	19	1.85	71.82	.286	.097
14	19	1.78	70.00	.242	.070
15	20	1.85	76.36	.271	.097
16	19	1.91	74.55	.333	.111
17	19	1.83	91.82	N/A	N/A
18	21	1.75	73.64	.290	.060
19	18	1.73	65.00	.296	.112
20	20	1.85	76.36	.349	.149

Note. The ratio of same field hits to opposite field hits was not available.

[a]BA = Batting average

[b]DX = Scoring index

APPENDIX C

Summary Table for the Analysis of Variance Conducted on the Time from Initial Movement of the Bat to the Instant Prior to Contact

Source[a]	SS[b]	df	MS	F
A	0.133	1	0.133	1.478
S/A	1.618	18	0.090	
B	2.976	1	2.976	114.462*
A x B	0.038	1	0.038	1.462
B x S/A	0.466	18	0.026	

[a]A = Subject groups
S = Subjects
B = Field hits

[b]Numerical values for the Sum of Squares and Mean Square have been multiplied by a factor of 10^3.

*$p < 0.05$

APPENDIX D

Summary Table for the Analysis of Variance Conducted on the Component Displacements of the Tip of the Bat

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.148	1	0.148	1.035
S/A	2.571	18	0.143	
B	0.960	1	0.960	60.000*
A x B	0.012	1	0.012	0.750
B x S/A	0.288	18	0.016	
		Y-Displacement		
A	0.002	1	0.002	0.071
S/A	0.508	18	0.028	
B	0.015	1	0.015	1.875
A x B	0.002	1	0.002	0.250
B x S/A	0.139	18	0.008	

[a]A = Subject groups
S = Subjects
B = Field hits

$*p < 0.05$

APPENDIX E

Summary Table for the Analysis of Variance Conducted on the Component Linear Velocities of the Tip of the Bat

Source[a]	SS	df	MS	F
X-Component of Velocity				
A	59.049	1	59.049	1.701
S/A	624.946	18	34.719	
B	270.816	1	270.816	14.187*
A x B	10.816	1	10.816	0.567
B x S/A	343.578	18	19.088	
Y-Component of Velocity				
A	15.889	1	15.889	0.359
S/A	796.664	18	44.259	
B	1729.094	1	1729.094	189.656*
A x B	0.076	1	0.076	0.008
B x S/A	164.099	18	9.117	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX F

Summary Table for the Analysis of Variance Conducted on the Component Displacements of the Handle of the Bat

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.192	1	0.192	1.641
S/A	2.103	18	0.117	
B	0.001	1	0.001	0.100
A x B	0.008	1	0.008	0.800
B x S/A	0.172	18	0.010	
		Y-Displacement		
A	0.0005	1	0.0005	0.020
S/A	0.457	18	0.025	
B	0.0005	1	0.0005	0.083
A x B	0.015	1	0.015	2.500
B x S/A	0.111	18	0.006	

[a]A = Subject groups
S = Subjects
B = Field hits

APPENDIX G

Summary Table for the Analysis of Variance Conducted on the Component Displacement of the Third Metacarpal of the Left Hand

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.184	1	0.184	1.628
S/A	2.038	18	0.113	
B	0.033	1	0.033	3.300
A x B	0.008	1	0.008	0.800
B x S/A	0.180	18	0.010	
		Y-Displacement		
A	0.0007	1	0.0007	0.028
S/A	0.450	18	0.025	
B	0.002	1	0.002	0.333
A x B	0.016	1	0.016	2.667
B x S/A	0.106	18	0.006	

[a]A = Subject groups
S = Subjects
B = Field hits

APPENDIX H

Summary Table for the Analysis of Variance Conducted on the Component Displacements of the Left Wrist

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.202	1	0.202	1.788
S/A	2.029	18	0.113	
B	0.046	1	0.046	4.600*
A x B	0.008	1	0.008	0.800
B x S/A	0.186	18	0.010	
		Y-Displacement		
A	0.0008	1	0.0008	0.035
S/A	0.409	18	0.023	
B	0.012	1	0.012	2.000
A x B	0.017	1	0.017	2.833
B x S/A	0.107	18	0.006	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX I

Summary Table for the Analysis of Variance Conducted on the Component Linear Velocities of the Third Metacarpal of the Left Hand

Source[a]	SS	df	MS	F
		X-Component of Velocity		
A	0.424	1	0.424	0.117
S/A	65.012	18	3.612	
B	54.196	1	54.196	40.086*
A x B	0.853	1	0.853	0.631
B x S/A	24.334	18	1.352	
		Y-Component of Velocity		
A	0.900	1	0.900	0.167
S/A	96.858	18	5.381	
B	2.550	1	2.550	3.200
A x B	0.064	1	0.064	0.080
B x S/A	14.338	18	0.797	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX J

Summary Table for the Analysis of Variance Conducted on the Component Linear Velocities of the Left Wrist

Source[a]	SS	df	MS	F
		X-Component of Velocity		
A	0.790	1	0.790	0.268
S/A	52.965	18	2.943	
B	24.367	1	24.367	23.229*
A x B	0.529	1	0.529	0.504
B x S/A	18.875	18	1.049	
		Y-Component of Velocity		
A	4.363	1	4.363	0.899
S/A	87.403	18	4.856	
B	0.013	1	0.013	0.018
A x B	0.086	1	0.086	0.121
B x S/A	12.825	18	0.713	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX K

Summary Table for the Analysis of Variance Conducted on the Component Displacements of the Left Elbow

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.220	1	0.220	2.018
S/A	1.954	18	0.109	
B	0.091	1	0.091	9.100*
A x B	0.001	1	0.001	0.100
B x S/A	0.185	18	0.010	
		Y-Displacement		
A	0.002	1	0.002	0.100
S/A	0.353	18	0.020	
B	0.031	1	0.031	6.200*
A x B	0.018	1	0.018	3.600
B x S/A	0.094	18	0.005	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX L

Summary Table for the Analysis of Variance Conducted on the Component Displacements of the Left Shoulder

Source[a]	SS	df	MS	F
		X-Displacement		
A	0.195	1	0.195	1.711
S/A	2.053	18	0.114	
B	0.077	1	0.077	6.417*
A x B	0.002	1	0.002	0.167
B x S/A	0.218	18	0.012	
		Y-Displacement		
A	0.012	1	0.012	0.600
S/A	0.356	18	0.020	
B	0.012	1	0.012	1.500
A x B	0.002	1	0.002	0.250
B x S/A	0.148	18	0.008	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX M

Summary Table for the Analysis of Variance Conducted on the Component Linear Velocities of the Left Elbow

Source[a]	SS	df	MS	F
		X-Component of Velocity		
A	0.344	1	0.344	0.131
S/A	47.148	18	2.619	
B	2.555	1	2.555	2.795
A x B	1.914	1	1.914	2.094
B x S/A	16.444	18	0.914	
		Y-Component of Velocity		
A	3.058	1	3.058	0.845
S/A	65.149	18	3.619	
B	11.004	1	11.004	33.651*
A x B	0.130	1	0.130	0.398
B x S/A	5.883	18	0.327	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX N

Summary Table for the Analysis of Variance Conducted on the Component Linear Velocities of the Left Shoulder

Source[a]	SS	df	MS	F
		X-Component of Velocity		
A	0.010	1	0.010	0.005
S/A	33.507	18	1.862	
B	0.015	1	0.015	0.037
A x B	0.028	1	0.028	0.069
B x S/A	7.275	18	0.404	
		Y-Component of Velocity		
A	0.224	1	0.224	0.454
S/A	8.871	18	0.493	
B	3.020	1	3.020	14.950*
A x B	0.032	1	0.032	0.158
B x S/A	3.640	18	0.202	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX O

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Bat

Source[a]	SS	df	MS	F
		Angular Displacement		
A	1.980	1	1.980	0.018
S/A	1932.625	18	107.368	
B	6888.000	1	6888.000	108.585*
A x B	4.160	1	4.160	0.066
B x S/A	1141.805	18	63.434	
		Angular Velocity		
A	263.682	1	263.682	3.702
S/A	1281.975	18	71.221	
B	122.710	1	122.710	4.491*
A x B	0.151	1	0.151	0.006
B x S/A	491.817	18	27.323	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX P

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Left Hand

Source[a]	SS	df	MS	F
		Angular Displacement		
A	131.406	1	131.406	0.813
S/A	2910.509	18	161.694	
B	4225.080	1	4225.080	66.787*
A x B	28.392	1	28.392	0.449
B x S/A	1138.723	18	63.262	
		Angular Velocity		
A	48.973	1	48.973	0.903
S/A	975.886	18	54.216	
B	620.471	1	620.471	28.914*
A x B	47.262	1	47.262	2.202
B x S/A	386.255	18	21.459	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX Q

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Left Forearm

Source[a]	SS	df	MS	F
		Angular Displacement		
A	1.260	1	1.260	0.010
S/A	2296.893	18	127.605	
B	485.112	1	485.112	15.983*
A x B	45.156	1	45.156	1.488
B x S/A	546.327	18	30.352	
		Angular Velocity		
A	5.191	1	5.191	0.287
S/A	325.507	18	18.084	
B	0.452	1	0.452	0.089
A x B	2.357	1	2.357	0.460
B x S/A	92.182	18	5.121	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX R

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Left Arm

Source[a]	SS	df	MS	F
		Angular Displacement		
A	4732.800	1	4732.800	1.510
S/A	56416.953	18	3134.275	
B	3036.306	1	3036.306	1.384
A x B	1169.642	1	1169.642	0.533
B x S/A	39496.837	18	2194.269	
		Angular Velocity		
A	47.764	1	47.764	1.204
S/A	714.079	18	39.671	
B	52.327	1	52.327	14.293*
A x B	4.685	1	4.685	1.280
B x S/A	65.906	18	3.661	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX S

Summary Table for the Analysis of Variance Conducted on the Projected Joint Between the Bat and Left Forearm

Source[a]	SS	df	MS	F
		Angular Displacement		
A	19.600	1	19.600	0.232
S/A	1520.651	18	84.481	
B	4145.296	1	4145.296	98.314*
A x B	32.041	1	32.041	0.760
B x S/A	758.943	18	42.164	
		Angular Velocity		
A	187.056	1	187.056	2.126
S/A	1583.738	18	87.985	
B	144.932	1	144.932	3.569
A x B	5.929	1	5.929	0.146
B x S/A	730.960	18	40.609	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX T

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Left Elbow Joint

Source[a]	SS	df	MS	F
		Angular Displacement		
A	192.282	1	192.282	1.753
S/A	1974.843	18	109.714	
B	2014.980	1	2014.980	68.453*
A x B	0.132	1	0.132	0.004
B x S/A	529.853	18	29.436	
		Angular Velocity		
A	0.827	1	0.827	0.014
S/A	1075.560	18	59.753	
B	388.939	1	388.939	21.065*
A x B	40.663	1	40.663	2.202
B x S/A	332.353	18	18.464	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX U

Summary Table for the Analysis of Variance Conducted on the Angular Displacement and Velocity of the Left Elbow Joint

Source[a]	SS	df	MS	F
		Angular Displacement		
A	623.310	1	623.310	2.567
S/A	4371.515	18	242.862	
B	507.656	1	507.656	6.210*
A x B	1.406	1	1.406	0.017
B x S/A	1471.363	18	81.743	
		Angular Velocity		
A	4.754	1	4.754	0.291
S/A	294.111	18	16.340	
B	5.395	1	5.395	0.746
A x B	2.445	1	2.445	0.338
B x S/A	130.165	18	7.231	

[a]A = Subject groups
S = Subjects
B = Field hits

*$p < 0.05$

APPENDIX V

Summary Table for the Analysis of Variance Conducted on the Angles of Incidence and Reflection

Source[a]	SS	df	MS	F
		Angle of Incidence		
A	6.569	1	6.569	0.556
S/A	212.574	18	11.810	
B	0.564	1	0.564	0.049
A x B	3.416	1	3.416	0.295
B x S/A	208.769	18	11.598	
		Angle of Reflection		
A	3.440	1	3.440	0.038
S/A	1609.661	18	89.426	
B	50.199	1	50.199	1.678
A x B	18.591	1	18.591	0.622
B x S/A	538.379	18	29.910	

[a]A = Subject groups
S = Subjects
B = Field hits

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