

**Kinematic Comparison of Same and Opposite-Field
Hitting in Baseball**

by
© Marc Paul Gélinas

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Department of Physical Education

**Division of Graduate Study and Research
Faculty of Education
McGill University
Montréal, Québec, Canada**

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ABSTRACT

The primary purpose of the study was to compare the effects of two levels of a field-hit condition (same (SF) and opposite-field (OF) hitting) on the kinematics of the batting swing. A secondary question examined the effects of different pitch locations (pitches aimed at the inside and outside parts of home plate) on the kinematics of SF and OF hitting. One professional, major league player participated in the study. The following variables were measured in the horizontal plane at contact with the ball: (1) absolute bat angle, (2) left bat-forearm angle, (3) left elbow angle, (4) left shoulder angle, (5) hip rotation, and (6) shoulder rotation. The subject executed four series of 12 consecutive hits, alternating between the two designated field areas, for a total of 48 trials. The subject's performance was filmed in the horizontal plane, with the camera lens perpendicularly positioned 4.62 m above the ground, and its speed nominally set at 200 fps. In all, 24 trials were selected for analysis. Independent T-tests (alpha set at .05) revealed that the significantly smaller bat angles required to produce the OF trials resulted from restrictions in the displacements measured about the left bat-forearm joint, and in the amount of hip and shoulder rotation. Consideration of the effects of pitch location on the kinematics of SF and OF hitting permitted to examine the results of the initial statistical comparisons in greater depth. The resulting sub-groupings were: (1) same-field inside-pitch (SFIP), (2) same-field outside-pitch (SFOP) and (3) opposite-field outside-pitch (OFOP) conditions. Adjustments for pitches aimed at different parts of home plate were made at the left elbow and shoulder joints. SFIP trials necessitated significantly less elbow extension at contact than in the other two conditions. SFOP trials required the least humeral extension amongst the three groups. Relatively high variability characterized the movements about the left elbow and shoulder joints, implying their involvement in effectuating the fine adjustments to the batting swing as per the environmental constraints. Results were discussed in relation to the scientific and coaching literature, and implications for coaching were presented.

RESUME

Le but premier de cette étude était de comparer les effets de deux niveaux d'un facteur (le coup de bâton au même champ (MC) et au champ opposé (CO)) sur le patron cinématique de l'élan au bâton. En deuxième lieu, les effets de la direction des lancers (tirs dirigés vers la partie intérieure et extérieure du marbre) sur le coup de bâton au MC et au CO ont été étudiés. Un joueur professionnel des ligues majeures participait à cette étude. Les paramètres suivants ont été mesurés dans le plan horizontal, au contact avec la balle: (1) l'angle absolu du bâton, (2) l'angle formé par le bâton et l'avant-bras gauche, (3) l'angle au coude gauche, (4) l'angle à l'épaule gauche, ainsi que (5) la rotation des hanches et (6) des épaules. Le sujet a exécuté quatre séries de 12 essais, alternant entre le MC et le CO, pour un total de 48 essais. La performance du sujet était filmée dans le plan horizontal, avec la lentille de la caméra fixée perpendiculairement, à 4.62 m du sol, et sa vitesse ajustée à 200 photos/sec. En tout, 24 essais ont été retenus pour analyse. L'analyse statistique (T-Tests indépendants, $\alpha = .05$) a révélé que la différence d'orientation du bâton produisant les balles frappées au CO résultait de restrictions dans les déplacements à l'articulation formée par l'avant-bras gauche et le bâton, ainsi que dans l'amplitude de la rotation des hanches et des épaules. La considération des effets de la direction des lancers sur le patron cinématique du coup de bâton au MC et au CO a permis d'examiner les résultats initiaux de façon plus approfondie. Les sous-groupes résultants étaient les suivants: (1) même-champ, balle à l'intérieur (MCBI), (2) même-champ, balle à l'extérieur (MCBE), et (3) champ-opposé, balle à l'extérieur (COBE). Les ajustements pour les tirs dirigés à différents endroits étaient effectués aux niveaux du coude et de l'épaule gauche. Les essais MCBI nécessitaient une restriction de l'extension du coude, comparativement aux deux autres conditions. Les essais MCBE nécessitaient une réduction de l'extension de l'humérus, relativement aux deux autres groupes. Une variabilité relativement élevée a pu être observée dans les déplacements autour du coude et de l'épaule gauche, ce qui sous-entendait leur

implication dans les ajustements à l'élan au bâton, selon les contraintes environnantes. Les résultats ont été discutés relativement à la littérature scientifique et sportive, et les implications pour l'entraînement du coup de bâton ont été présentées.

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CHAPTER I

INTRODUCTION

Baseball is one of many popular sports in which the central event involves a collision between an implement and a ball. Hitting a baseball is a complex skill, in that the performer's goal is to achieve maximal transfer of momentum to a round baseball by making contact with the curved surface of the bat. The nature of the contact surfaces, the high velocity of pitched baseballs, and the variety of ball trajectories combine to increase the difficulty of the task. In addition, the hitter often faces the problem of directional guidance. All these factors must be dealt with at an appreciable personal risk, under an intense feeling of individual responsibility, and often subject to high-level acoustic annoyances. In batting, the vertical coordinate of the bat at contact is both important and hard to control. Most strike-outs result from its mismanagement, and a 1 mm bat position error at contact often determines whether the batted ball will land safely (Kirkpatrick, 1963). It is thus generally agreed that hitting a baseball is one of the more difficult skills to learn in sport (Breen, 1975; Williams and Underwood, 1971).

The ability to hit the ball to all areas on the playing field is thought to be a distinguishing factor between batting skill levels (Williams and Underwood 1971). The better hitters are said to be able to hit equally well to either side of second base, if the field were

divided in two halves. The two field areas can be called "opposite" and "same" field interchangeably, according to the preparatory position of the batter relative to the plate.

It is often desirable to direct the baseball to a specific part of the playing field. To achieve optimal transfer of momentum from the bat to the ball, the batter must achieve maximal bat linear velocity and modify some temporal and/or kinematic characteristics of the swing in order to ensure that the ball is contacted as close as possible to the bat's center of percussion, commonly known as the "sweet spot". Some strategic constraints may also dictate that the ball be directed to a specific part of the field, regardless of the pitch location relative to home plate.

The mechanical factors contributing to the ability of hitting to specific parts of the playing field have received little attention to date. The coaching literature deals primarily with the point of contact between the bat and the ball in relation to the hands and to home plate. Hay (1978) discussed the importance of the point of contact relative to home plate. He explained that to hit the ball to the same-field, the swing should be initiated relatively earlier, with the contact between the bat and ball being made in front of home plate. Conversely, for the opposite-field hit, the swing would be initiated relatively late, with the contact being achieved as the ball crosses home plate. Williams and Underwood (1971) contend that the position of the hands relative to the point of contact on the bat and the angle formed at the elbow of the leading arm are the primary differences existing between the same and opposite-field swings. The authors further stated that the hands should

be behind the point of contact when executing the same-field swing, with the lead elbow nearly fully extended, while the opposite-field swing is performed without full extension of the elbow, and with the hands preceding the point of contact. Pfautsch's research (1980) corroborated their contentions.

With the importance given to the ability to hit the ball to specified areas on the field, it is surprising to note that little scientific attention has been directed toward the kinematic differences existing between the same and opposite-field hit swings.

1.1 Nature and scope of the study

From the instant the ball is delivered by the pitcher, the batter has approximately 0.5 seconds in which to hit the ball before it passes the plate (Hay, 1978). During this time, the batter's task is to evaluate the ball's initial trajectory, velocity and spin, then predict its final position relative to the strike zone, and finally decide whether to attempt to hit it. The length of time necessary for this decision process is called decision time (Hay, 1978). The longer the decision time, the more accurate is likely to be the prediction of the ball's final position. The length of time allotted to the decision making would logically appear to be inversely related with the performer's information processing speed and batting swing time.

The batter's goal usually consists of transferring maximum momentum to the pitched baseball. To increase the striking mass and improve the transfer of momentum to the ball, the batter must satisfy the following requirements: (1) the grip on the bat must be firm, (2) the

wrists, arms, hips and legs must be braced one against another, and (3) the feet must be firmly braced against the ground (Hay, 1978). The velocity vector of a ball struck by a bat is a function of the ball and bat velocities and masses, bat orientation, the deviation of the point of contact on the bat from its center of percussion, and certain constants such as: the mass of the ball and bat, the spin of the ball, and their mutual coefficients of friction and restitution (Bryant et al., 1977; Hay, 1978; Kirkpatrick, 1963). Reaction forces at the bat handle (at contact) were found to be directly related to the deviation from its center of percussion, affecting the transfer of momentum to the ball (Bryant et al., 1977). The width of the center of percussion of wooden bats was reported to be approximately 2 cm (Bryant et al., 1977). All else remaining equal, the speed of the ball after impact can be improved by any or all of the following: (1) increasing the striking mass, (2) decreasing the mass of the ball, (3) increasing the pre-impact velocities of the bat and ball, (4) increasing the angle of incidence, (5) increasing the values of the coefficients of restitution and friction, (6) moving the center of mass of the bat distally, and (7) minimizing the deviation between the contact point and the bat's center of percussion. The variables manipulated by the batter include: (1) the striking mass, (2) the tangential velocity of the bat, (3) the angle of incidence, (4) the length of the lever arm at contact, and (5) the deviation from the contact point to the bat's center of percussion.

The state of the bat at impact is controlled by complex, coordinated sequential applications of joint torques, proceeding from the ground, to the forearms and hands. In addition to the goal of

maximal transfer of momentum to the ball, the batter frequently faces some problems of directional guidance, due to certain strategic and mechanical requirements. The ability to project the ball to selected areas of the playing field is recognized as a distinguishing factor in batting efficiency (Williams and Underwood, 1971). More specifically, these authors emphasized the importance of being able to hit to the opposite-field.

Opposite-field hitting presents strategical advantages. Certain strategies to advance baserunners, such as the hit-and-run play, require the batter to direct the ball to the opposite-field, regardless of the location of the ball relative to home plate at contact. The goal in opposite-field hitting is to direct the ball to the opposite-field while achieving optimal transfer of momentum. If the ball is pitched on the outside part of the plate, batters may be forced to modify their swing and direct the ball to the opposite-field. This adjustment is necessary, in order to minimize the deviation of the contact point on the bat from its center of percussion, and achieve maximal transfer of momentum.

The kinematics typical of opposite-field hitting have not received extensive scientific attention to date. Pfautsch (1980) examined college baseball players, conducting a kinematic comparison of the same and opposite-field hits, to identify differences existing between the two types of hits. The involvement of the hip and shoulder segment rotation in opposite-field hitting has not yet been assessed. Finally, the effects of pitch location (relative to home plate) on the batting swing have not been studied.

An accurate method of quantifying and qualifying the dynamics of a movement is to obtain high-speed film recordings of the actual performance. The subsequent analysis of performance permits comparisons of segmental kinematics across selected experimental conditions. The results of these comparisons may allow for a better understanding of the actual body mechanics typical of different movement patterns. By quantifying selected spatial and temporal characteristics of the same and opposite-field hits as performed by an elite baseball athlete it may be possible to document and identify parameters which characterize each type of field-hit.

There is a recent tendency in biomechanics to increase the number of trials per condition for each subject in order to stabilize the within subject variance. For this reason, an increasing number of researchers in the field of sports biomechanics now opt to decrease the sample size and increase the number of trials performed. When analyzing a motion which may be occurring in three dimensions, perspective errors are introduced in the analysis during the transformation of the angular displacement data to the plane of interest (Atwater, 1981; Ramey and Nicodemus, 1977). Therefore, when investigating such movements with conventional two-dimensional high-speed cinematography, efforts must be made to minimize perspective errors. In the current study, controlling the height at which the ball entered the strike zone alleviated this problem, by ensuring that the batter performed both types of field-hits in approximately the same plane for all trials. In addition, a video camera was used to assist in the calibration of the two-dimensional film data.

1.2 Purpose of the study

The results of the study are intended to provide coaches with a clearer understanding of the kinematic characteristics of successful executions of each type of field-hit swing, and subsequently offer insight for coaching applications.

The primary purpose of this study was to compare selected kinematic parameters involved in hitting the ball to the same and opposite-fields. A secondary purpose was to examine the effects of pitch location on the kinematics of same and opposite-field hitting. Consideration was given to identifying those parameters which contribute to the success of hitting in general, and opposite-field hitting specifically.

1.3 Hypotheses

The data obtained from this study were examined in light of the following research hypotheses, focused on the differences existing between the same- and opposite-field hit conditions:

1. The opposite-field hit will be achieved with a smaller absolute angle of the bat at impact when compared to the same-field hit.
2. The opposite-field hit will be achieved with a smaller angle about the bat-forearm projected joint at impact when compared to the same-field hit.
3. The opposite-field hit will be achieved with a smaller angle about the elbow joint at impact when compared to the same-field hit.

4. The opposite-field hit will be achieved with a greater angle about the left shoulder joint at impact when compared to the same-field hit.
5. The opposite-field hit will be achieved with less counter-clockwise rotation of the shoulders at impact when compared to the same-field hit.
6. The opposite-field hit will be achieved with less counter-clockwise rotation of the hips at impact when compared to the same-field hit.

1.4 Limitations and Delimitations

The limitations of this investigation of baseball batting performances included the following:

1. The assumption was made that the primary movements involved in the batting swings performed by the subject occurred in a single (horizontal) plane, perpendicular to the optical axis of the camera. The height of each pitched ball was kept as constant as possible, so as to minimize the effects of perspective errors in the analysis. In addition, a video camera was located behind the pitching mound so as to facilitate the calibration of the horizontal plane data.
2. The assumption was made that the subject was endowed with excellent visual acuity and hand-eye coordination, and that these characteristics are typical of major league professional athletes.
3. Spatial and temporal aspects of the batting swings were indirectly measured from film recordings of selected trials, and

were subject to the measurement errors characteristic of film analysis. These errors were minimized by maintaining consistent and accurate analysis techniques.

4. The assumption was made that each trial was performed with maximal effort.

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

1. Only one subject participated in the study, representing the elite professional hitters proficient at opposite-field hitting.
2. The subject participating in the study was a male adult, 35 years old and a 13-year major league professional athlete.
3. The subject was a right-handed batter.
4. The analysis was limited to situations in which the batter knew which type of field-hit to attempt.
5. The analysis was limited to situations in which the batter knew where each pitch was to be directed to by the pitching machine.

1.5 Definitions and abbreviations

The following definitions are presented to clarify terms appearing in the text.

Left bat-forearm angle: 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.

Closed stance: This preparatory stance is characterized by the position of the batter's front foot being closer to home plate than the back foot.

Closed stride: This type of stride is performed by stepping with the front foot toward home plate during the swing.

Decision time: Length of time the batter takes to make a decision whether to swing at the ball.

Hip segment: The movements of this segment were depicted indirectly, as defined by two markers placed on a fin (Appendix C), which was firmly fixed onto a weight training belt. The belt was worn so that the fin was located perpendicular to and over the mid-posterior aspect of the iliac crests.

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

Open stance: This preparatory stance is characterized by the position of the batter's feet relative to home plate. This stance places the batter's front foot further away from the plate than the back foot.

Open stride: This type of stride is performed by moving the front foot away from home plate during the swing.

Opposite-field: For right handed batters, this is defined as the area of the baseball field delimited by lines extending from home plate through first and second base (right field).

Opposite-field hitting: Hitting the pitched ball to the opposite-field.

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

Parallel stance: This preparatory stance is characterized by a equidistant placement of the batter's feet to an imaginary line linking the mid-points of home plate and the pitching rubber.

Parallel stride: This type of stride is performed by stepping with the front foot directly toward the pitcher during the swing.

Same-field: For right handed batters, it is defined as the area of the baseball field delimited by lines extending from home plate through second and third base (left field).

Shoulder segment: This segment was defined by two markers placed on the acromion processes of the subject's right and left shoulders.

Strike zone: It is that space over home plate, the top border of which is lying between the top of the batter's shoulders and the top of the uniform pants, and the bottom border defined by the top of the knees, when a natural stance is assumed (Official Baseball Rules, 1988).

Swing time: The length of time necessary for the batter to complete the swing from the preparatory stance, to impact with the ball. The time is calculated beginning with the initiation of the stride.

CHAPTER II

REVIEW OF THE LITERATURE

Many theories and practices of baseball have been the focus of research in recent years. Studies have been conducted on all aspects of the sport. The coaching literature is abundant in books and articles treating many different subjects in baseball, particularly those concerning the art of pitching and hitting a baseball.

Several researchers have conducted cinematographic and electromyographic investigations of baseball hitting, without concern for the direction in which the hit baseball travels (Breen, 1967; Kitzman, 1964; Puck, 1964; Race, 1961; Shapiro, 1974, 1979; Swimley, 1964). Only one scientific study (Pfautsch, 1980) however, focussed on the mechanical factors involved in same and opposite-field hitting.

In this chapter an attempt will be made to present a brief biomechanical description of the movement patterns involved in the execution of the batting swing. In addition, a summary of the coaching and scientific literature concerning hitting, specifically same and opposite-field hitting is provided. The chapter is sub-divided into five sections: (1) body mechanics, (2) grip, (3) stance, (4) stride and swing and (5) opposite-field hitting.

2.1 Body mechanics

There are wide variations in such preparatory actions as stance, angle of wrist cock (abduction), position of the back elbow (the elbow furthest away from the pitcher), distance of hands away from the body and the distance through which the bat is moved in a counter-direction to the forward swing (this action is commonly referred to as the cocking action). While baseball batting coaches often seek to modify these actions in their athletes in an effort to improve performance, attempts to find correlations between these factors and personal batting and slugging averages were unsuccessful (Race, 1961). Thus, there seems to be little justification for emphasis on any of the above actions beyond preparedness, alertness and relaxation or comfort.

It was reported that the motion of the bat occurs in two phases, the first being the change in position from a vertical to a horizontal orientation of the long axis of the bat (Shapiro, 1979). The second phase is characterized by the rapid rotation of the bat into the hitting area, being initiated approximately 120 ms prior to contact to permit the generation of the required bat speed.

The basic hitting sequence appears to be as follows: (1) a short stride into the ball, (2) hip and shoulder segment rotation toward the ball, (3) rapid extension of the forearms, and finally (4) rapid adduction of the wrists (Reiff, 1971). The movements involved in the swing thus proceed in a sequential fashion, with the hips, shoulders, arms, and finally the hands and bat being driven forcefully around to the front. The optimal summation of joint torques is accomplished by the sequential positive and negative accelerations of the body segments,

proceeding from the larger to the smaller segments. Each successive segment should move faster than its predecessor in the chosen direction if the the optimal bat velocity is to be obtained (Bunn, 1972).

The initiation of the stride approximates the pitcher's release of the ball, moving the body's center of mass toward the approaching ball. As soon as the striding foot finds its grip in the ground, the forward rotation of the hips is initiated. Hip rotation, followed by shoulder rotation, commences the movement which will ultimately bring the bat into the contact zone. Concurrently with the initiation of the stride, the hips, shoulders and bat are rotated slightly backward, in a cocking motion (Shapiro, 1974). The hip action, is the result of the reaction to forces exerted against the ground by the batter's legs. Once the hip rotation is well advanced, the rotation (forward) of the shoulder segment begins, with the arm swing initiated when the shoulders have been brought around approximately parallel with the hips. The amount of hip and shoulder rotation was reported to be directly related to the height of the pitch (Shapiro, 1974). That is to say that hip and shoulder rotation increases as the height of the pitch increases in the strike zone. Moreover, the coaching literature suggested that the amount of hip rotation is related to the direction in which the ball is to be batted (Weiskopf, 1977). A smaller amount of hip rotation is said to be necessary to project the ball to the opposite-field. In this study, the height of each pitch was held constant so that the hip and shoulder segment rotation observed accurately reflected the characteristics of the field-hits performed.

The extension of lead arm and lead forearm follow the hip and shoulder rotations to increase the length of the lever arm and the bat's tangential velocity. The change in the angle formed by the bat and leading forearm during the early part of the swing is due more to centrifugal force than to muscular work (Kirkpatrick, 1963). Lastly, the angle between the leading forearm and bat is further increased through extension of the back elbow producing passive adduction of the hands (Jorgenson, 1970; Shapiro, 1979). The follow-through is characterized by the rolling action of the top hand (on the bat) over the bottom hand, the flexion of the forearms, and the continuing motion of the body's center of mass forward (Shapiro).

Highly skilled batters appear to possess the following characteristics (Breen, 1967):

1. The path of the body's center of mass is approximately horizontal throughout the swing, whereas hitters of lower skill levels tend to exhibit a downward path of their body's center of mass.
2. Batters adjust their head position during each pitch to obtain the best possible view of the flight of the incoming ball.
3. The lead elbow joint tends to extend fully at the beginning of the swing, resulting in a greater bat tangential velocity.
4. The length of the stride remains relatively constant with all types of pitches.
5. After contact between the bat and the ball, the weight of the body shifts to the front foot and the upper body moves in the same direction as the flight of the batted ball.

2.2 Grip

The grip on the bat should be firm throughout the swing so as to increase the striking mass at contact with the ball. The position of the hands on the bat should be adjusted to the strength of the grip, wrists and arms, the weight of the bat, the resulting swing time (Hay, 1978), and the type of pitcher being faced. It is generally agreed that the proper batting grip has the middle joints of the fingers of both hands in approximate alignment (Bubalo, 1981; Ellis, 1977). This grip affects the angles formed at the wrists, putting the hand adductors and flexors at a stretch, thus potentially improving the tension developed by their subsequent contraction. Carroll (1959) reported that gripping the bat in this manner produced greater ranges of wrist joint movements, resulting in higher linear bat velocities.

2.3 Stance

The preparatory stance varies between players. Mason and Burton (1985) studied members of the Australian National Baseball Team. and discussed two different styles of waiting for the pitch. Some batters remain relatively motionless, while others sway (continuously transfer their weight from lead to trail foot and so forth) during this waiting period. Approximately 70% of the batters studied displayed the sway style, while 30% opted to remain motionless. The authors reported average weight distribution figures of 65% on the lead foot and 35% on the trail foot.

The body position adopted by the batter waiting for the on-coming pitch has a marked influence in determining the batter's subsequent

actions. The distance of the feet from a midline through home plate as well as from the pitcher is dependent upon the batter's ability to bring the bat's center of percussion in contact with the ball at any point across the width of the plate in a timely fashion (Hay, 1978). There are three possible feet alignments: open, parallel, and closed stances, and these do not appear to significantly affect the generation of bat velocity (G.W. Marino, personal communication, February 7, 1986).

2.4 Stride and swing

The basic purpose of the stride is to increase the momentum of the batter's center of mass, with the principal consideration of its length being related to allowing the proper motion of the hands backward, in preparation for the swing. The stride is initiated by a posteriorly directed horizontal force produced by the trail foot, reported to be in the magnitude of 30 to 50% of body weight (Mason and Burton, 1985). This force is opposed by the front foot soon after the stride forward is completed. The combined action of the front and back legs result in the initiation of the batter's hip rotation.

There are three basic methods of striding: open, parallel and closed. While the direction of the stride does not appear to have any effect on the bat linear velocity, it was found that the closed stride produces slower swing times (Messier, 1982; Messier and Owen, 1984). The direction of the stride is likely to affect the amount of hip rotation permitted. It is unlikely however that batters employ different strides according to the type of field-hit being attempted, in light of the elite batters strides that tend to be consistent in length and direction, and

the limited available time during the flight of the incoming pitch (Breen, 1967, 1975; Shapiro, 1974).

The velocity at which the bat is swung is considered one of the most important factors in the swing, representing the primary means of controlling the force imparted to the ball (Hay, 1978). Supportive evidence was provided by Vaughn's (1969) work with college varsity and junior varsity players. Research with major league professional players on the other hand, showed no relationship between peak velocity and batting average (Braveler, 1965). This would seem to suggest that, once a critical velocity is reached, batters do not improve their chances of success with further increments in bat velocity. Reported bat velocities range from approximately 33.0 m/s (Shapiro, 1979) to 42.2 m/s (McIntyre & Pfautsch, 1982). Shapiro (1979) noted maximum linear velocities coinciding with impact in two of three trials, which is theoretically desirable. Because of the importance of bat velocity at contact to transfer of momentum to the ball, better hitters forcefully extend their leading arm early into the swing to increase the length of the lever arm (Breen, 1967; Hay, 1978). Pfautsch (1980) found that although the length of the lever arm was reduced through the interaction of the wrist and elbow joints, the bat tangential velocities generated in opposite-field hitting were similar to those of the same-field hits. The author speculated that the reduction in the lever arm's moment of inertia allowed for greater angular velocities to be attained, thus keeping the bat tangential velocities at similar magnitudes for both types of field-hits.

It was suggested that the rotations about the hips, shoulders and arms should take place in an approximately horizontal plane (Hay, 1978). This allows the bat to be appropriately aligned when swung forward into the contact zone and project the ball in the desired direction. The final contribution to the swing coincides with the adduction of the wrists in the instant prior to contact with the ball. The wrist action has been the focus of a number of controversial opinions. The suggestion that the wrists should be forcefully adducted just prior to contact (Hay, 1978) conflicts with some published data (Shapiro, 1979). Shapiro's data revealed bat acceleration peaks coinciding with the extension of the right (back) forearm. These findings supported the contentions of Williams and Underwood (1968), which described the swing as a "hard push swing". Shapiro (1979) concluded that the adduction of the wrists appeared to be passive, concurring with similar findings in golf (Jorgenson, 1970). Jorgenson explained that the major function of the wrists in the golf swing is to hold the club back until the proper time. At which point the wrists relax, contributing no moment, allowing the club to rotate into the hit. It would seem therefore, that the role of the wrists may be to allow (same-field hit) or delay (opposite-field hit) the rotation of the bat into the contact area, and possibly to assist in making the fine adjustments for batting the pitches contacted at different heights. Following contact with the ball, the top hand is rolled over the bottom hand, commencing the follow-through phase (Hay, 1978; Weiskopf, 1968). Supporting evidence was later provided by Messier and Owen

(1984) who found relatively small rotations of the bat around the long axis occurring during the swing.

2.5 Opposite-field hitting

The ability to hit the ball to the opposite-field is considered to be an important skill in baseball (Williams and Underwood, 1971). There are several situations which require the ball to be directed toward the opposite-field, for example the direction of the incoming ball's trajectory relative to home plate, and the hit-and-run play. Most of the documented explanations relating to same and opposite-field hitting have been concerned with the point of contact between the ball and bat in relation to home plate.

The state of the bat at the moment of contact with the ball is defined by 13 variables, all of which are subject to the batter's control. These quantities are the three positional coordinates of the mass center of the bat, three coordinates of angular orientation, three of linear momentum, three of angular momentum, and one coordinate of time (Kirkpatrick, 1963). It has been reported that the ball is struck anywhere from several centimeters (Kirkpatrick) to 1.2 meters (Puck, 1964) in front of home plate. It is generally agreed that balls directed at the inside part of the plate are contacted further in front of it than are balls on the outside (Breen, 1975; Hay, 1978; McIntyre and Pfautsch, 1982). Moreover, the point of contact relative to home plate is reported to be located in front of home plate, regardless of the ball's relative position (Pfautsch, 1980).

Few authors have discussed the factors relevant to hitting a ball to different areas of the playing field. Williams and Underwood (1971) stated that in an opposite-field hit the hands precede the point of contact on the bat and that the lead elbow should not be fully extended at impact. For a same-field hit, the authors went on to explain that the hands are kept behind the hitting area, and full elbow extension should occur. Pfautsch (1980) examined the kinematic characteristics of the same and opposite-field hits, and his data supported the contentions of Williams and Underwood. Similarly, it was suggested that batters control the angle of incidence to direct the ball to the desired field (Bunn, 1972; Hay, 1978). The batter would initiate the swing relatively early, and contact the ball well in front of the plate to project the ball to the same-field. Pfautsch (1980) found swing times significantly smaller in the opposite as compared to the same-field hits, suggesting that batters may in fact be able to delay the initiation of the swing, so as to contact the ball with a desirable angle of incidence.

Pfautsch (1980) divided 20 active or former college players into two groups, termed efficient and inefficient opposite-field hitters. Each subject was assigned to either group according to an evaluation by his college coach. The subjects were allowed to take as many trials as desired to hit an automatically pitched ball three times to the same-field and three times to the opposite-field. All trials were filmed in the horizontal plane, the underlying assumption being that the movements of interest occurred primarily in a horizontal plane. Only the successful executions were analyzed. Significant kinematic differences were found between the field-hit conditions. The angles of

the bat, as well as at the left wrist and elbow joints were found to be significantly less for the opposite-field hits at impact. That is to say that the opposite-field hit was characterized by less adduction of the bottom hand and less forearm (lead) extension at contact. Moreover, the angular velocities of the bat, the left hand segments, and about the left wrist joint were found to be significantly greater in the opposite-field hitting condition.

2.6 Summary

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 are made in order to project the ball toward the opposite-field. It would appear that the 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 appropriate angle of incidence for an opposite-field hit is said to be obtained by timing the swing so that the hands are ahead of the point of contact at impact with the ball, and by keeping the front wrist and elbow joints less than fully extended. The coaching literature has also suggested that the amount of trunk rotation is modified according to the field area in which the ball is to be directed. The contribution of hip and shoulder segment rotation to opposite-field hitting has not yet been scientifically examined. There has been no investigations conducted to establish an elite model for hitting the ball to the opposite-field. Finally, the effects of pitch

location relative to home plate on the kinematics of the batting swing have not been studied to date.

CHAPTER III

METHODOLOGY

The following section includes a description of the subject selection and preparation, cinematographical procedures, measurement of data, and finally data analysis.

3.1 Subject selection and preparation

The primary purpose of this study was to compare kinematic patterns involved in the execution of the same and opposite-field hit in order to establish an elite model for hitting to the opposite-field. A secondary purpose was to examine the effects of different pitch locations on the kinematics of same and opposite-field hitting.

The single subject approach was chosen in an effort to minimize within subject variability, which was compounded by the inherent difficulty of the performance tasks being studied. This permitted the experimenter to maximize the number of trials in an attempt to stabilize the data. The subject was a major league professional baseball player, batting right-handed. The subject possessed 13 years of major league experience, and had previously been identified by his coaches as an efficient opposite-field hitter.

A consent form (Appendix A) was read and signed by the subject, acknowledging that the testing procedures and the subject's options had been fully explained. The subject's age, height, mass, segmental

lengths and career batting statistics were obtained for descriptive purposes. The subject was asked to wear his uniform pants, a loose short-sleeve shirt top and competition shoes.

The following landmarks were fixed onto the subject and bats to facilitate digitization (Appendix B):

1. Acromion processes
2. Medial/lateral epicondyles of both arms
3. Radial and ulnar styloid process of both arms
4. Metacarpo-phalangeal joints (radial and ulnar side) of both arms
5. Mid-posterior aspect of iliac crests (identified by fin, Appendix C)
6. Seventh cervical vertebrae
7. Distal end of the bat
8. Midpoint of the bat handle immediately above the right (top) hand
9. Tip of both shoes
10. Two origin points, located 1.0 meter apart, along a straight line joining the middle of home plate with the center of the pitching rubber.

3.2 Experimental set-up

The baseballs used in this study were official National League baseballs. A Casey pitching machine was used to ensure adequate consistency in pitch location and velocity within each trial. The apparatus was positioned on the pitching mound (Figure 1) so that balls would be launched 17.1 meters from the front edge of home plate (Pfautsch, 1980) and approximately 1.5 meters from the ground.

Adjustments were made so that the baseballs were released at an average velocity of 33.5 m/s, as confirmed on a DECATUR radar gun. The velocity was set lower than reported values for average major league fastball (35.9 m/s; Atwater, 1977), to account for the increased ball tracking difficulty associated with the use of the pitching machine as compared to a live pitcher.

The accuracy of the pitching machine was measured prior to data collection. The procedure was performed using a plywood board (freshly coated with black paint) positioned at home plate. The machine was then aimed at the center of home plate, and a series of ten baseballs were fired at the board. The horizontal distance between the resulting marks on the board and the center of home plate were measured, yielding an average deviation from the center of home plate of (+/-) 6.7 cm, which was considered comparable to live pitching conditions. The height of the launched balls passing through the strike zone was set at approximately 80.0 cm from the ground, at a level between the subject's mid-thigh and waist, to help in minimizing the perspective errors in filming while controlling the difficulty of the task of hitting, thus reducing the number of miss-trials. The average height of the pitches for the 48 trials was 78.7 cm (SD: 5.9 cm), as measured via the video camera. The subject was allowed to use his own bats, preferred batting grip and stance. Some landmarks were fixed on the bat for film analysis purposes.

The field was divided into three zones: (1) opposite-field (right), (2) same-field (left), and (3) a neutral zone (center), in a manner (Figure 1) similar to that described by Pfautsch (1980). The trials

landing in the neutral zone were eliminated from the study, as it was reasoned that the movement pattern producing these trials may incorporate characteristics of both types of field-hits.

3.3 Cinematographical Procedures

3.3.1 Filming

All filming took place at Ahuntsic park, located in the city of Montréal, Québec. The filming area selected was the home plate area. Arriving at a pre-determined time, the subject was familiarized with the testing procedures, encouraged to perform his habitual pre-game warm-up routine, which was concluded by the execution of a total of 30 practice hits to the same and opposite-fields.

In an attempt to minimize the subject's variability, and because of the inherent difficulty in performing the required tasks (particularly hitting to the opposite-field), the subject was asked to execute his trials in series of twelve consecutive hits to a designated field area in a pre-set order, for a total of 48 trials. In addition, the subject was allowed to execute 5 practice trials between each series, to familiarize himself to each new treatment combination.

The criterion used for selecting the trials for analysis was that the ball was stroked firmly in the desired direction. This included ground balls, line drives and fly balls batted into the desired field area. Consequently, trials producing foul balls, infield fly balls and miss-hit ground balls were excluded from the study.

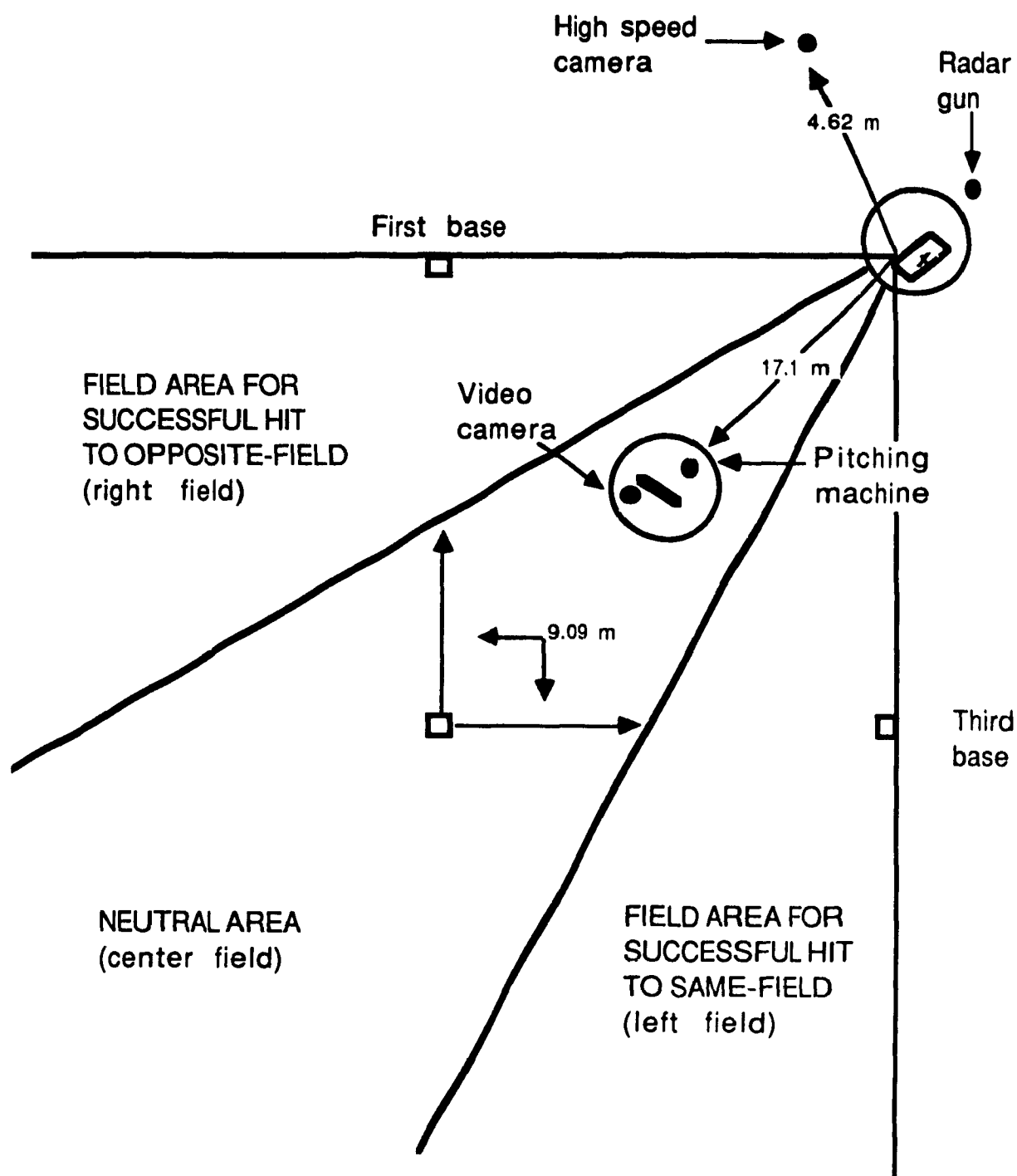


Figure 1. Diagram of the experimental set-up

The type and quality of each hit were recorded on a chart (Appendix D), and radar gun records provided further documentation. The location of each pitched ball passing through the strike zone was charted (Appendix E), and later validated through the combined use of a video tape (recorded with a camera located behind the pitching mound), and the high-speed film record.

The high-speed camera was started prior to the release of each ball by the pitching machine, to ensure that the camera had reached its frame speed setting during the trials. Subsequent to data collection, all the trials meeting the selection criteria were retained for analysis. In all, 24 trials were retained for the study.

3.3.2 Camera Position

A RedLake Locam camera was set up above the filming area, at a lens-to-ground distance 4.62 m (Figure 1), yielding a resulting camera frame of 2.65 X 3.58 m. The camera was adjusted so that its optical axis was perpendicular to the horizontal plane, with the front inside edge of home plate lying in the center of the camera frame. A VHS video camera was positioned behind the pitching mound, and kept running throughout the data collection.

3.3.3 Camera Technical Data

The RedLake Locam 1 camera (model 51-003) was loaded with color Kodak 4X reversal film (type 7277) ASA 250, and fitted with a 10 mm lens. The exposure time setting on the camera was 1/1500 sec (.667 msec) with the shutter opening set at 48°, yielding a shutter factor of 7.5. The camera was nominally set at 200 frames per second. A hand-held light meter measured the luminosity of the filming area at

15, and consequently the f-stop was set at 8. An internal LED generator firing at 100 Hz recorded marks onto the roll of film to permit accurate frame rate calibration. Two sets of identification numbers were placed in the camera frame, depicting the trial number and condition. To permit conversions of film distances to actual values, a matrix was filmed in the plane of action. Two origin markers were placed one meter apart in the camera frame, along a straight line joining the center of the pitching rubber and home plate.

3.4 Measurement of Data

For each selected trial all film frames from the initial (counter-clockwise) hip rotation movement of the subject to 10 frames past the ball-bat contact were digitized and later used in the analysis. The direction of the batter's stride was measured using tracings of the film records, taken in the last frame allowing full vision of both shoe markers shortly after the batter had firmly planted his front foot onto the ground.

The data were obtained from the film by the use of a L-W pin-registered stop-action projector, projecting each film image onto a Summagraphics digitizing board. The L-W projector was equipped with a frame counter, permitting accurate frame counting during each trial. A hand-held cursor, connected to a Summagraphics digitizer, was used to digitize the x and y coordinates of the markers and the two origin points. The digitizer was connected on-line to the McGill University mainframe computer, permitting immediate storage of the x,y film

coordinates into a MUSIC (McGill University System for Interactive Computing) library file.

3.4.1 Transformation of Digitized Coordinates

A WATFIV program adjusted each frame to two common x and y origin points thereby compensating for any vibration of the camera during the filming, or movement of the projected image as the film advanced during the digitizing process. This program also re-formatted the x,y coordinates file, which was used as input to the McGill University Biomechanics Laboratory's kinematic analysis programs. The raw x,y coordinates were filtered using a low-pass, recursive digital filter, with the cut-off frequency set at 6 Hz (Winter, 1979). The kinematic analysis programs then used the filtered coordinates to calculate the landmark and segmental kinematics, and the angular kinematics of selected joints.

3.5 Statistical Analysis

The one-subject approach was employed in this investigation. Several factors, such as subject variability, the time necessary to reduce the film data and the financial expense of computer time and analysis often preclude the use of inferential statistics in biomechanical investigations. As a result, studies are often hindered by the low number of subjects per cell. The low number of subjects make it difficult to test for the validity of the assumptions underlying inferential statistics, including normal distribution of the sample and the homogeneity of variance between the groups. For this reason, much of the research in biomechanics has employed inferential or non-

parametric statistics to describe the differences existing between skill levels, or between technical performances. Bates (1983) stated that as long as the researcher is aware of the possible violations of the underlying assumptions, and recognizes the limitations of using inferential statistics with small sample sizes, then such statistics represent a valuable tool in biomechanics research.

The primary independent variable in this study was the field-hit condition. Further, the effects of pitch location (Appendix F) on the movement patterns characteristic of same and opposite-field hitting were examined following the initial statistical comparison of the two types of field-hits, in order to attempt to qualify the difference(s) existing between the two types of field-hits. There were two levels of field-hit condition (same and opposite-field), and two levels of pitch location (inside or outside part of the plate). The pitch location of each trial was ascertained using the video and high-speed film recordings. Due to the difficulty of the task, the subject failed to perform any successful trial in the opposite-field, inside-pitch condition. Consequently, this treatment cell was eliminated from the experimental design, resulting in three groups of trials. Independent, one tailed T-Tests (SAS PROC TTEST procedure 1985, with alpha set at .05) were used to test the hypotheses.

The dependent variables in this study were measures taken in the horizontal plane of the absolute angular position of the bat, hip and shoulder segments, and relative displacement about the left shoulder, elbow and bat-forearm joints at contact with the ball (Appendix G). Finally, the following variables were measured for descriptive

purposes: (1) direction of the stride during the swing, (2) magnitude and relative time of peak angular velocities, (3) tangential velocity of the tip of the bat, and (4) swing time.

CHAPTER IV

RESULTS

This chapter presents the results of the study. The primary purpose of the study was to examine the kinematic patterns characterizing same and opposite-field hitting in baseball, using high-speed cinematography. A secondary purpose was to examine the effects of different pitch locations (inside and outside) on the kinematics of same and opposite-field hitting.

Efforts were made to ensure adequate design sensitivity by controlling undesirable sources of variability. Potential sources included: (1) the difficulty of the performance task being studied, (2) within-subject variability, and (3) the subject's adjustments to the variation existing within each condition. The latter variation resulted from the combination of the following factors: a) small inconsistencies in pitch location and b) pitch velocity from one trial to the next, c) the absence of the habitual visual cues (i.e. live pitching delivery) before and during the launching of each ball, d) the difficulty in anticipating the release of the ball from the pitching machine, and finally e) the effects of the wind. Consequently, the single-subject case study approach was employed to allow for a greater number of trials performed within each condition in order to increase the sensitivity of the experimental design.

The following variables were measured in the horizontal plane at the time of contact with the ball: (1) bat angular displacement, (2)

displacement about the left bat-forearm, (3) left elbow, and (4) left shoulder joints, as well as (5) shoulder and (6) hip rotation. The research hypotheses stated that for all variables, the opposite-field hit conditions would be performed with significantly less angular displacement at the time of contact. The data collected in this study are presented along with the statistical summary of the comparisons.

4.1 Subject Description

The subject participating in the study was a 35 year old, 13-year veteran major league professional player, and his descriptive data are presented in Table 1. The subject had been identified as efficient opposite-field hitter by his coaches.

Table 1. Subject descriptive data

Age : 35	Height : 1.78 m	Mass : 81.8 Kg
Bats : right	Throws : right	Position : outfielder

Career Batting Statistics (major league experience: 13 years)											
Avg.	G	AB	R	H	2B	3B	HR	RBI	BB	SO	SB
.260	1150	2955	339	768	121	31	20	294	232	359	89

Avg :	Batting average	H :	Hits	R :	Runs scored
G :	Games played	2B :	Doubles	RBI :	Runs batted in
AB :	Times at bat	3B :	Triples	BB :	Bases on balls
SB :	Stolen bases	HR :	Home runs	SO :	Strike outs

4.2 Comparison of the two types of field-hits

4.2.1 Measurement of the angles

Hip and shoulder rotation, as well as bat angular displacement were measured in the horizontal plane relative to the x axis (Appendix G). This axis was formed by an imaginary line joining the middle of the pitching rubber with the center of home plate. Positive displacements reflected motion in the counter-clockwise direction. Hence, negative angles depicted hip and shoulder segments held in a closed position, while positive values indicated that these segments were in an open position, and finally a parallel position was depicted by a zero degree angle. Bat displacement values greater than 90° reflected an orientation toward the same-field (left field), while values less than 90° depicted a bat orientation toward the opposite (right-) field (Appendix G).

In reviewing the data, the amount of perspective error during the digitizing process precluded the use of the wrist joint data, as well as the data collected for the right arm as dependent variables. Thus the left bat-forearm joint angle was selected, to depict the actions occurring about the wrist joint. The bat-forearm angle was more clearly defined, and reflected the composite action of: (1) adduction, (2) hyper-extension, and (3) supination of the front (left) hand. Subjective evaluation of the high-speed film recordings revealed that the latter two movements occurred primarily in the deceleration phase, after contact with the ball. The left shoulder and elbow angles were also measured in the horizontal plane, and positive displacements reflected humeral (horizontal) and elbow extension at both joints. The

batter employed similar preparatory stances prior to each trial. The view from the overhead camera did not allow a clear view of the feet in the batter's stance, precluding close examination of the stance and stride for all treatment combinations.

4.2.2 Data and statistical results

4.2.2.1 Differences between same and opposite-field hits

The displacement patterns exhibited during the execution of both types of batting swings were generally similar, differing primarily in amplitude. The data collected are presented in tabular format in Table 2, and schematically in Figures 2-13. All displacement curves were plotted upon the onset of hip (counter-clockwise) rotation. The total swing times were similar for both types of field-hits (mean times were 0.407 sec for same-field hits (SF), and 0.396 sec for opposite-field hits (OF)). For purposes of comparison, all trials were synchronized as per the instant of contact with the ball.

The results of the two-tailed Independent T-Test comparisons (alpha set at .05) between the two conditions are presented in Table 2. As expected and shown in Figure 2, opposite-field (OF) hits required a significantly different bat orientation at contact than same-field (SF) hitting (mean angles of 73.1° and 103.3° respectively). That is to say that the bat was actually positioned so as to face the direction in which the ball was projected. The smaller bat angles in the OF hits were obtained through three significant modifications to the batting swing: (1) less displacement about the left bat-forearm joint, (2) and less hip and (3) shoulder (counter-clockwise) rotation.

The mean angles at contact measured about the left bat-forearm joint in the opposite-field hits were significantly smaller (137.9°) than in the same-field hits (157.3°). From an initial cocked position, this angle increased consistently throughout the swing, in both types of field-hits. Figure 3 illustrates representative movement patterns. Prior to contact with the ball, the displacements about the joint were primarily the result of the adduction of both hands at the wrist joint, probably facilitated by the rapid extension of the back (right) elbow immediately prior to contact (Shapiro, 1979). Other actions occurred during the follow-through phase (hyper-extension/supination of the bottom (left) hand with flexion/pronation of the top, right hand) to combine with the adduction of the hands. No significant difference was found between both types of field-hits for the displacements about the left elbow and shoulder joints, at contact with the ball. The movement patterns about the left elbow joint were similar in both types of field-hits, as shown by the representative curves in Figure 4. After a period of elbow flexion earlier in the swing, extension followed. Both types of hits were contacted during a period of elbow extension, with impact occurring at mean angles of 147.0° and 144.5° for the opposite-field (OF) and same-field (SF) hits respectively.

The mean angles measured about the left shoulder joint at contact were 85.3° in the OF and 83.3° in the SF hits. Figure 5 illustrates typical displacement patterns about this joint in both conditions. The OF hit displacement curve suggests that the subject delayed the onset of his humeral horizontal extension, then proceeded at a constant rate until contact. Conversely, the SF hit exhibits earlier

activity about the left shoulder joint, followed by a higher rate of extension, then the joint was stabilized until contact. Further, the data showed relatively high variability (as depicted by the computed standard deviation values) characterizing the movements about the left shoulder and elbow joints, implying their involvement in making fine adjustments to the environmental constraints. This was later verified when considering the effects of pitch location of the batting swings, as discussed in the next section.

Some of the data collected in the present study lend support to observations made earlier in the coaching literature (Weiskopf, 1968) regarding the contribution of hip and shoulder rotation to hitting. Table 2 shows that opposite-field hits (OF) were performed with significantly less shoulder rotation (mean angle of 51.2°) than same-field hits (62.2°), as shown in Figure 6. Similar findings were made upon examination of the batter's hip segment rotation. As shown in Figure 7 and in Table 2, the subject significantly restricted his hip rotation in batting the opposite-field hits (mean angles of 53.3° and 67.5° for the OF and SF hits respectively). When comparing the displacement curves of the hip and shoulder segments, the slope of these curves depicts a greater shoulder angular velocity being attained. In both cases the batter rotated his shoulder and hip segments from an initial closed or cocked position into an opened position at contact. However these segments did not rotate past 90° in order to face left field at contact, as was implied in the coaching literature (Weiskopf, 1968). In other words, the hip and shoulder segments were actually

facing the opposite-field during the performance of both types of field-hit.

Table 2. Comparative statistics of the execution of the two types of field-hits at contact ($^{\circ}$, Mean $\pm$ SD)

Variable	SF (n=14)	OF (n=8)	F'	p'	df	T	p
BAT	103.3* (8.3)	73.1 (10.3)	1.56	0.464	20.0	7.53	0.000
HROT	67.5* (6.9)	53.3 (5.0)	1.95	0.380	20.0	5.07	0.000
SROT	62.2* (8.1)	51.2 (9.0)	1.24	0.703	20.0	2.93	0.016
LSAN	83.3 (16.3)	85.3 (10.5)	2.42	0.245	20.0	-0.31	0.761
LEAN	144.5 (18.5)	147.0 (13.9)	1.78	0.450	20.0	-0.33	0.744
LBFAN	157.3* (4.8)	137.9 (6.9)	2.01	0.262	20.0	7.71	0.000

Note: * = $p < 0.05$

SF : same-field hit
 OF : opposite-field hit
 BAT : bat [angle]
 HROT : hip [angle]
 SROT : shoulder [angle]
 LSAN : left shoulder angle
 LEAN : left elbow angle
 LBFAN : left bat-forearm angle
 F' : test of homogeneity of variance
 p' : probability of obtaining a greater F'
 T : test of equality of the means
 p : probability of obtaining a greater T

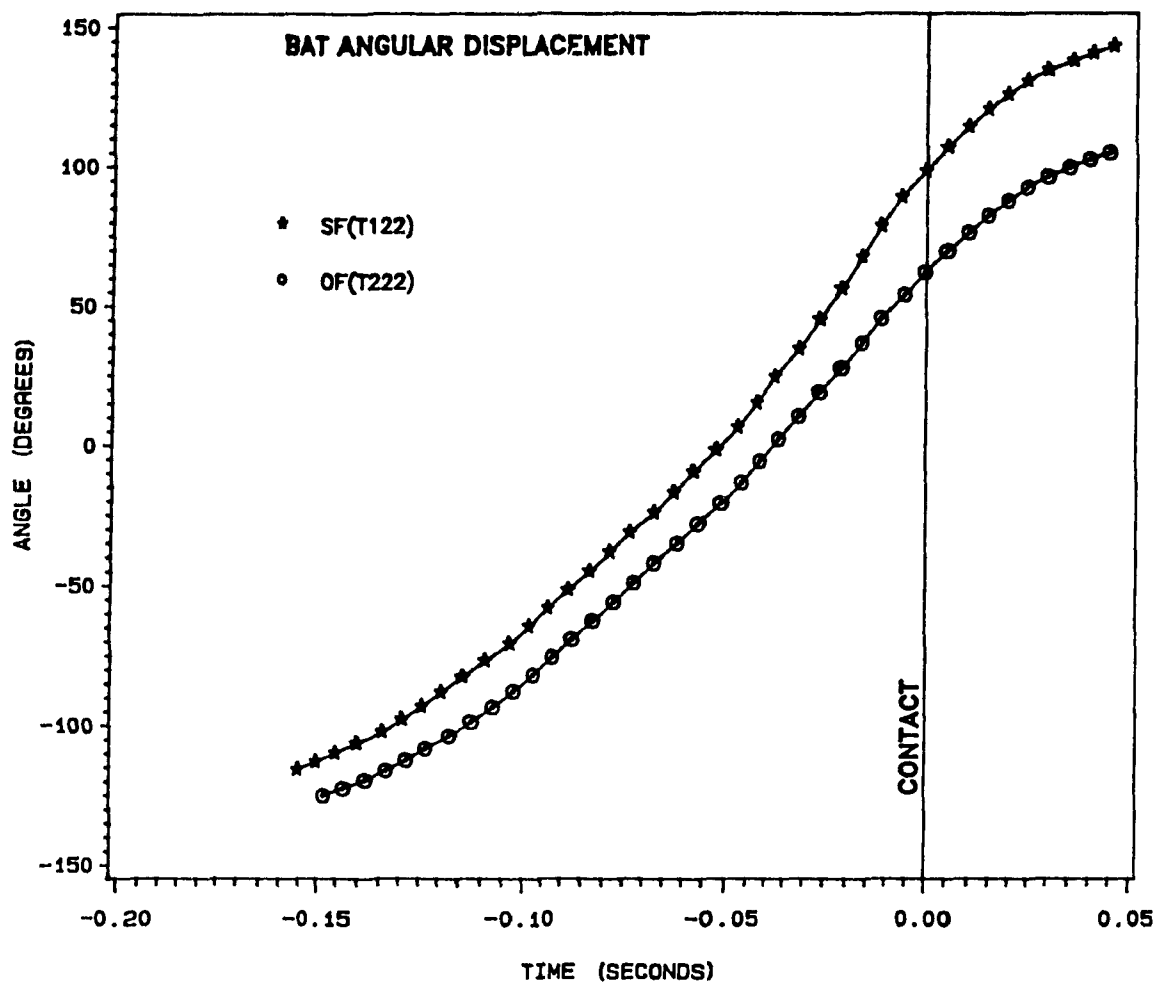


Figure 2. Bat angular displacement in the horizontal plane during the batting to the same (SF) and opposite-fields (OF) (representative trials).

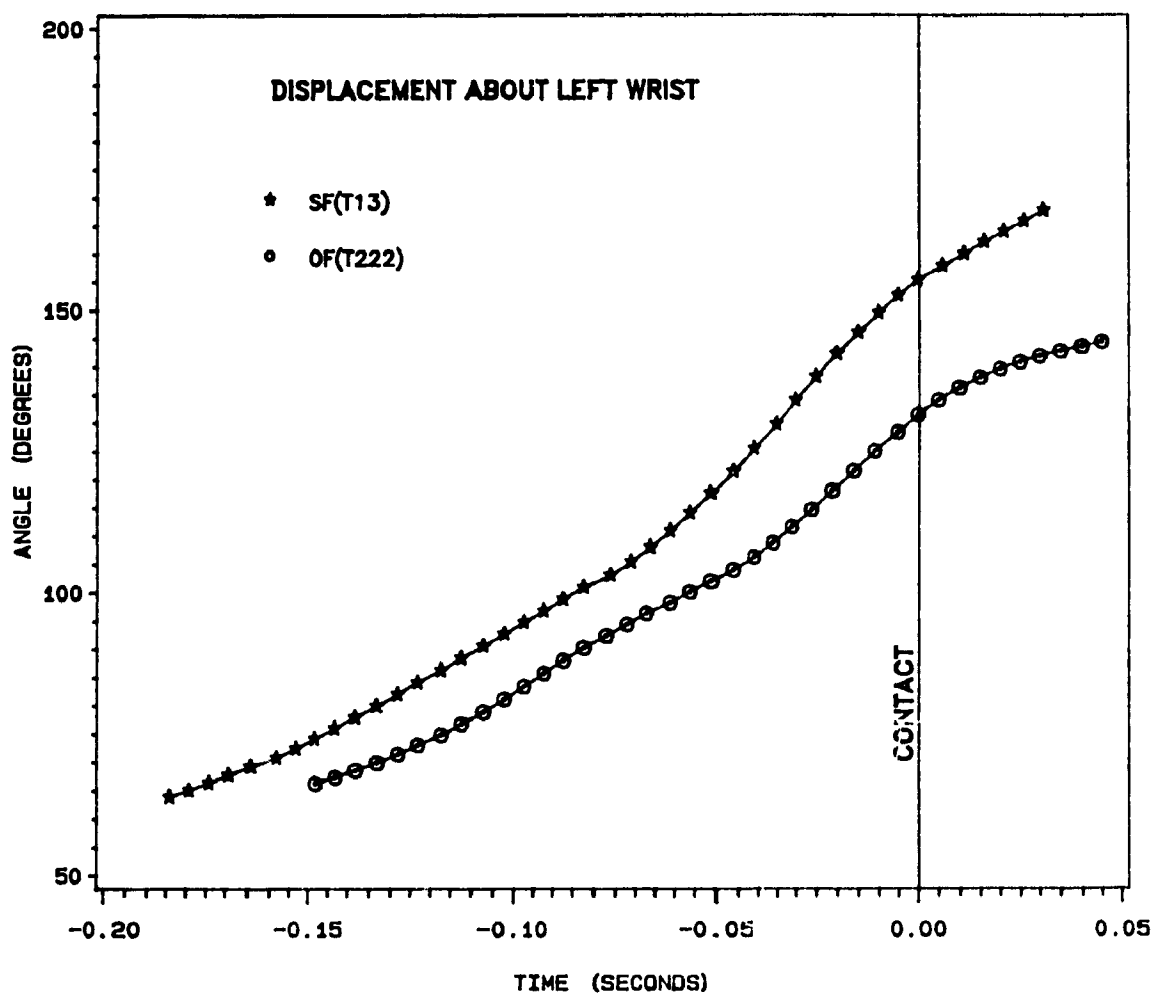


Figure 3. Displacement about the left bat-forearm joint during the batting to the same (SF) and opposite-fields (OF) (representative trials).

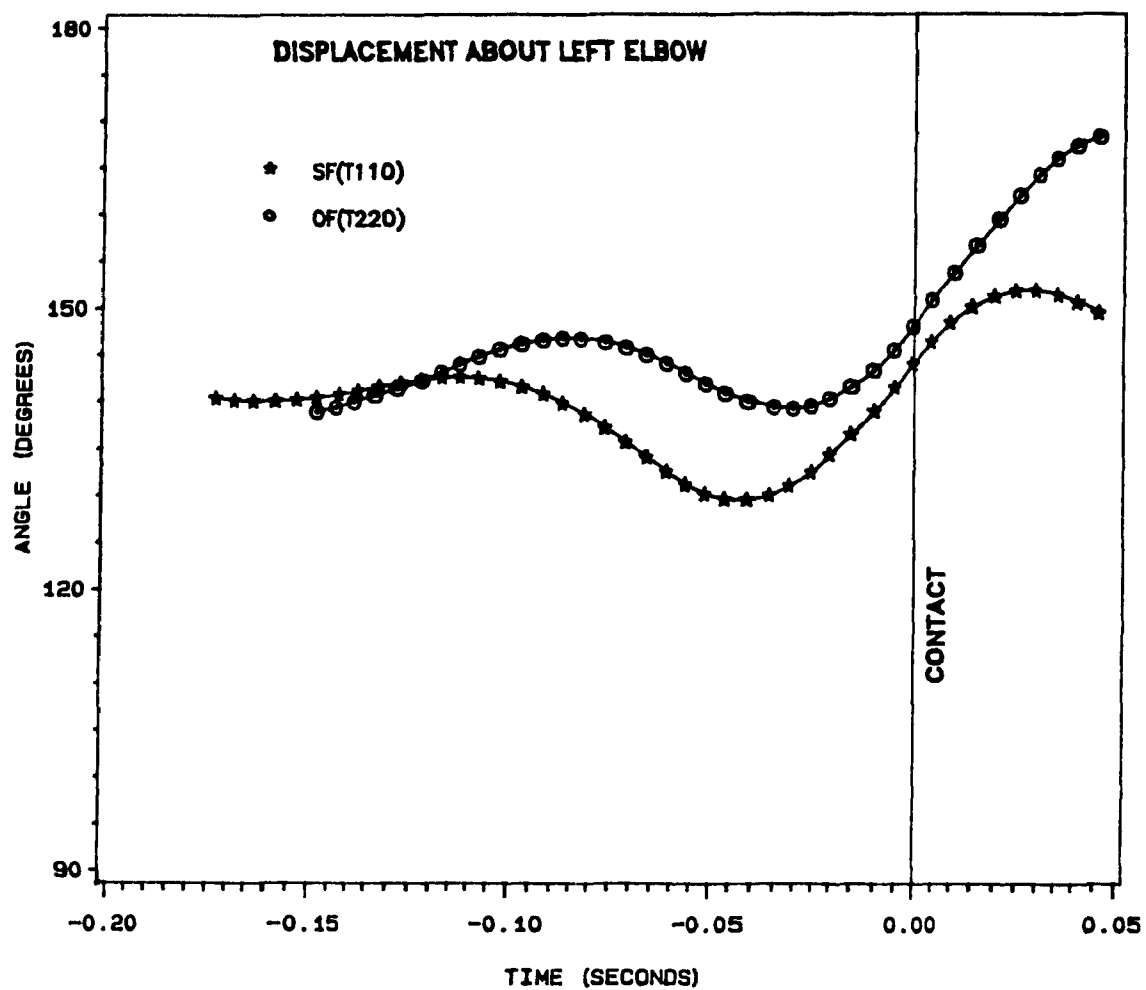


Figure 4. Displacement about the left elbow joint during the batting to the same (SF) and opposite-fields (OF) (representative trials).

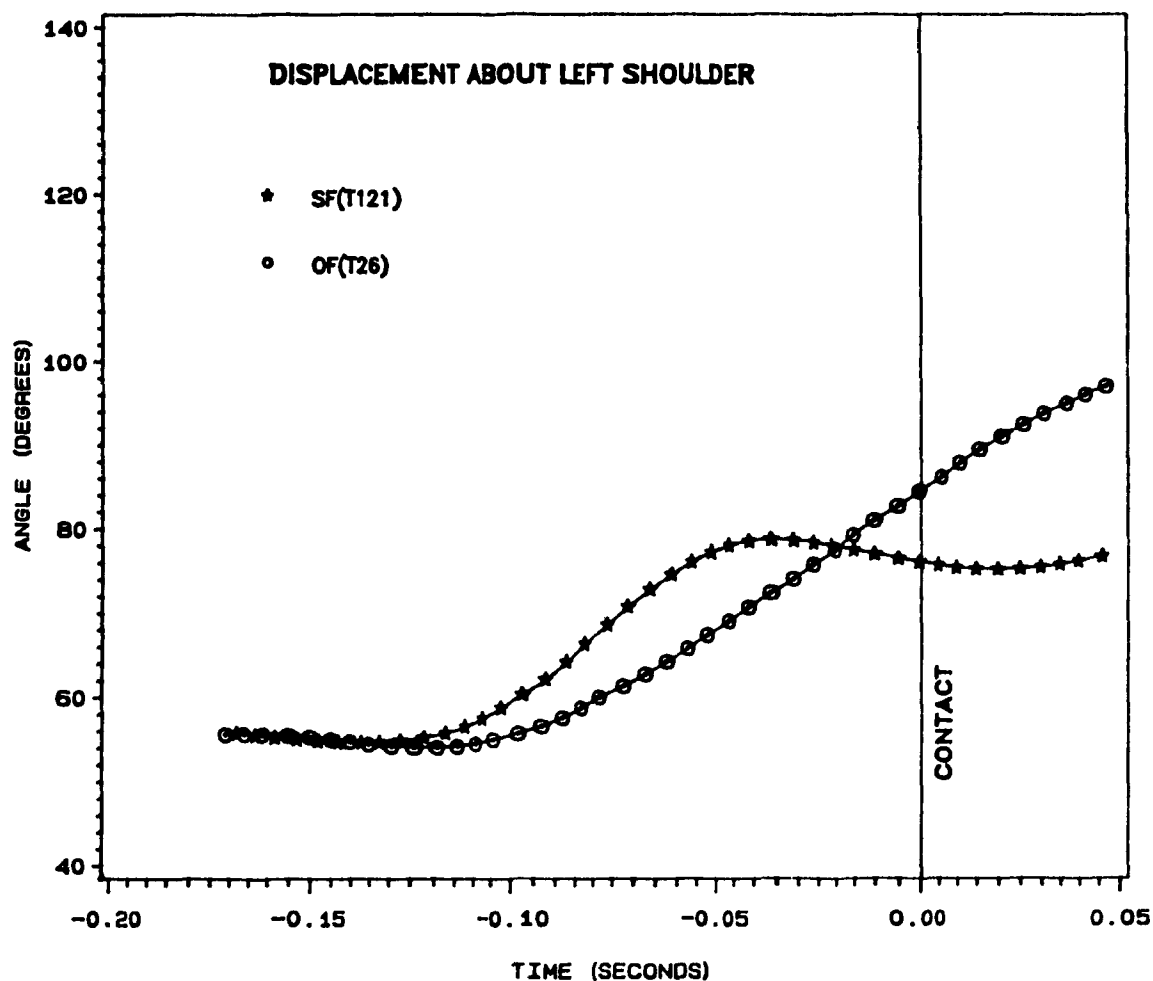


Figure 5. Displacement about the left shoulder joint during the batting to the (SF) and opposite-fields (OF) (representative trials).

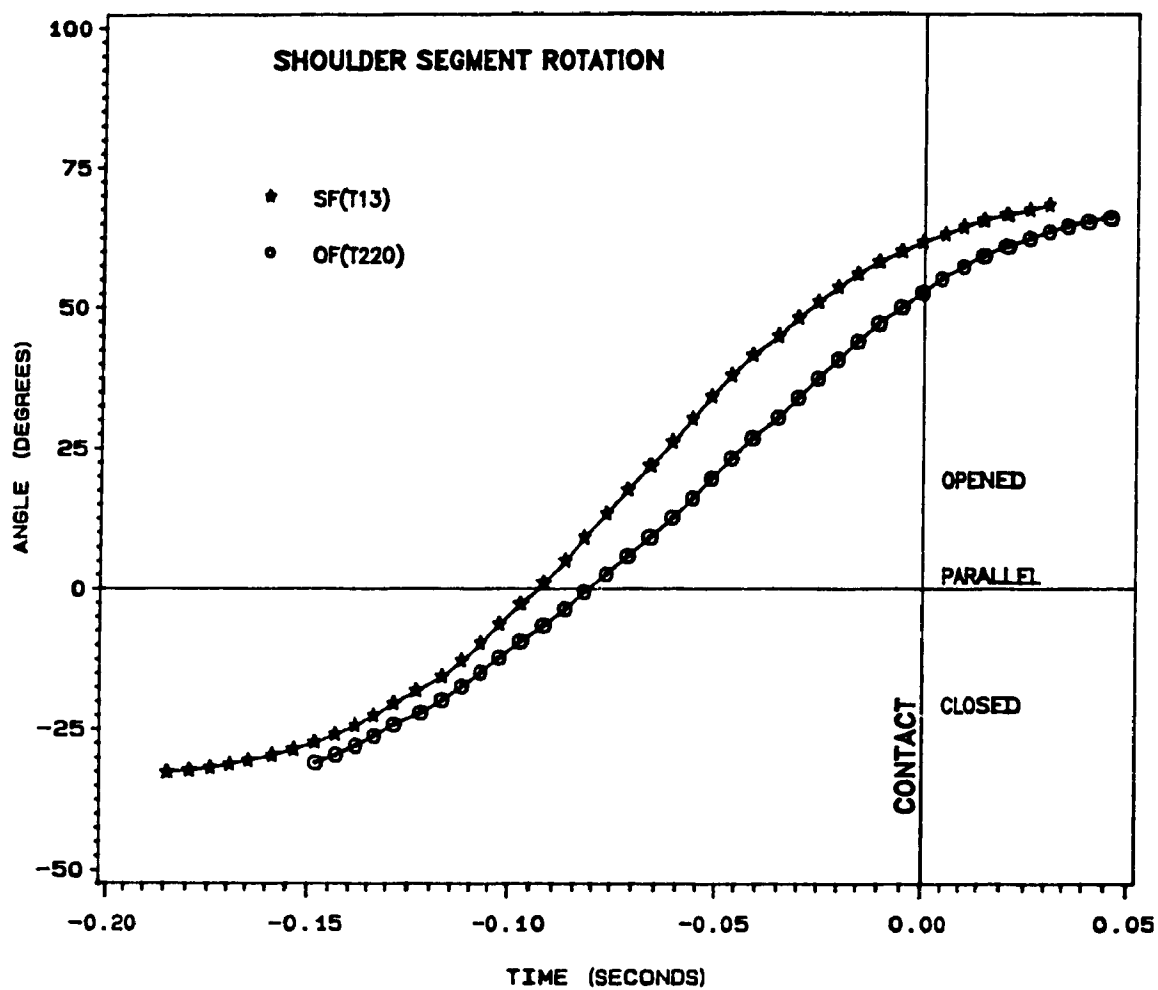


Figure 6. Shoulder segment rotation during the batting to the same (SF) and opposite-fields (OF) (representative trials).

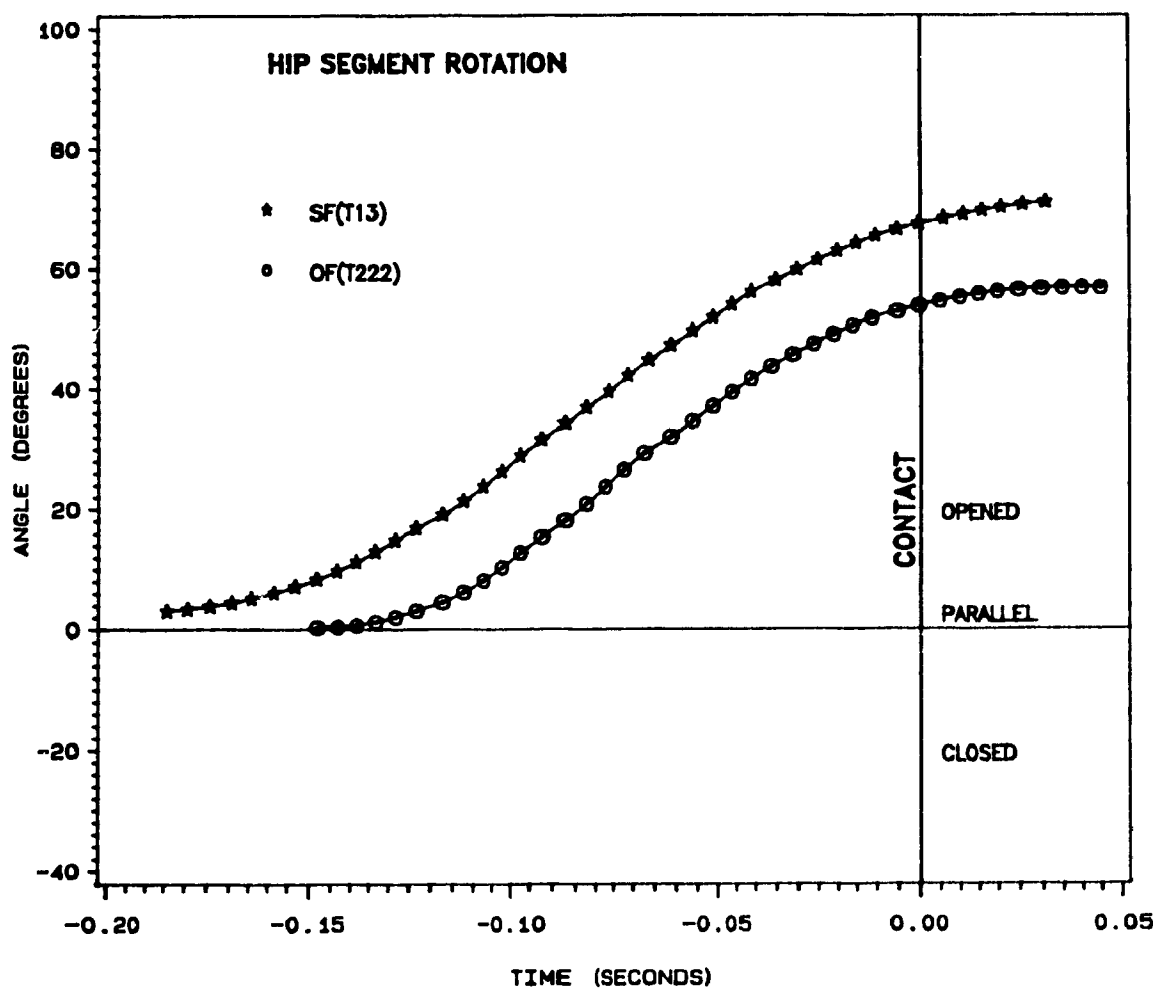


Figure 7. Hip segment rotation during the batting to the same (SF) and opposite-fields (OF) (representative trials).

4.2.2.2 Effects of pitch location

The secondary purpose of the study was to assess the effects of pitch location on the kinematics of both types of field-hits. Pursuant to the initial comparison, the trials were re-grouped according to the pitch location in each trial, for further analysis. The pitch location for each trial was confirmed using the video and high-speed camera records. Consequently, four treatment groups were created (same-field hits on (1) inside and (2) outside pitches, and opposite-field hits on (3) inside and (4) outside pitches). One condition (opposite-field, inside-pitch condition) was subsequently dropped from the analysis, as none of the trials within this treatment group were successful. It should be noted that in live competition opposite-field hitting is very difficult to perform successfully, even more so when attempting to hit a pitch aimed at the inside part of the plate. The resulting treatment groups were: (1) same-field inside-pitch (SFIP), (2) same-field outside-pitch (SFOP) and (3) opposite-field outside-pitch hits (OFOP). A two-tailed T-Test procedure ($\alpha = .05$) was employed to evaluate the significance of the differences existing between each group. The results are collated in Table 3, and the summaries of the individual comparisons between each of the three conditions are presented in Tables 4, 5 and 6. Figures 8-13 present typical displacement curves for the variables selected in this study.

The statistical analyses yielded interesting results. Expectedly, the mean bat angles at contact in the two same-field groups (SFOP: 106.6° , SFIP: 98.9°) were significantly greater than in the opposite-field, outside-pitch condition (OFOP: 73.2°). Representative trials

illustrate the bat angular displacements for the three conditions in Figure 8. The modifications made to the swing identified earlier in comparisons between same and opposite-field hits were still evident: the opposite-field outside-pitch hits were performed with significantly less displacement about the left bat-forearm joint (Figure 9) and less shoulder and hip rotation (Figures 12 and 13 respectively) than in both types of same-field hits. Adaptations to the different pitch location appeared to be made at the level of the left elbow and shoulder joints (Figures 10-11).

4.2.2.2.1 Comparisons between the SFIP and SFOP hits

The subject employed similar strategies to perform the two types of same-field hits (inside (SFIP) and outside pitch (SFOP)). The results of the comparisons between these conditions are presented in Table 4. As shown in Figure 9, 12 and 13, the batter exhibited similar left bat-forearm joint (Figure 9) displacement patterns up to contact (SFIP: 157.4° , SFOP: 157.3°), as well as shoulder (SFIP: 61.8° , SFOP: 62.6°) and hip (SFIP: 67.5° , SFOP: 67.6°) rotation (Figures 12 and 13). As evidenced in Table 4 and Figure 10, the subject produced similar bat angles at contact by using significantly different movement patterns about the left elbow joint. This resulted in less elbow extension at contact in the same-field inside-pitch condition (SFIP: 127.8° , SFOP: 157.1°).

Figure 10 shows that the SFOP and opposite-field outside-pitch (OFOP) hits were characterized by an initial period of relative stabilization at the elbow joint up to approximately .05 sec and .03 sec before contact respectively, followed by rapid extension up to impact.

In contrast, the patterns in the SFIP condition were distinguished by elbow flexion throughout most of the swing, with extension initiated at approximately .02 seconds prior to contact with the ball.

Table 3. Descriptive statistics of the execution of the three types of field-hits at contact ($^{\circ}$, Mean $\pm$ SD)

COND	BAT	HROT	SROT	LSAN	LEAN	LBFAN
SFIP (n=6)	98.9 ² (6.8)	67.5 ² (7.6)	61.8 ² (7.0)	92.7 (22.0)	127.8 ¹² (16.6)	157.4 ² (3.6)
SFOP (n=8)	106.6 ³ (8.0)	67.6 ³ (7.0)	62.6 ³ (9.3)	76.3 ³ (3.9)	157.1 ¹ (4.4)	157.3 ³ (5.9)
OFOP (n=8)	73.2 ²³ (10.3)	53.4 ²³ (5.0)	51.3 ²³ (9.1)	85.3 ³ (10.5)	147.0 ² (13.9)	137.9 ²³ (6.9)

Notes: • 1,2,3 = $p < 0.05$
 • 1 = SFIP vs SFOP ; 2 = SFIP vs OFOP ; 3 = SFOP vs OFOP

SFIP : same-field, inside pitch hit
 SFOP : same-field, outside pitch hit
 OFOP : opposite-field, outside pitch hit
 BAT : bat [angle]
 HROT : hip [angle]
 SROT : shoulder [angle]
 LSAN : left shoulder angle
 LEAN : left elbow angle
 LBFAN : left bat-forearm angle

The adjustment in the inside-pitch condition was required to get the bat into the contact zone rapidly, and properly orient the bat's center of percussion with the incoming ball in order to optimize the transfer of momentum to the ball. The mean angles measured at contact about the left shoulder joint in the SFIP hits were 92.7° , as compared to 76.3° in the SFOP condition, but this difference was not found to be statistically significant. Both displacement curves display a similar pattern earlier in the swing, horizontally extending the humerus at a relatively greater rate. During the last .05 seconds prior to contact with the ball, the batter appeared to modify his movement pattern. He continued to extend his upperarm for the inside pitch, but initiated horizontal flexion for the outside pitch. Flexion of the upperarm in the SFOP hits coincides with the onset of rapid extension of the left elbow up to contact (Figure 10). Conversely, the prolonged humeral extension observed in the OFOP hits may have combined with the movement about the left elbow in positioning the hands in front of the point of contact on the bat.

Relatively high variability characterized the displacements about the elbow ($SD = 16.6^\circ$) and shoulder (SD of 22.0°) joints in the SFIP condition, implying that these joint actions may be important for adapting to environmental constraints such as a different pitch location.

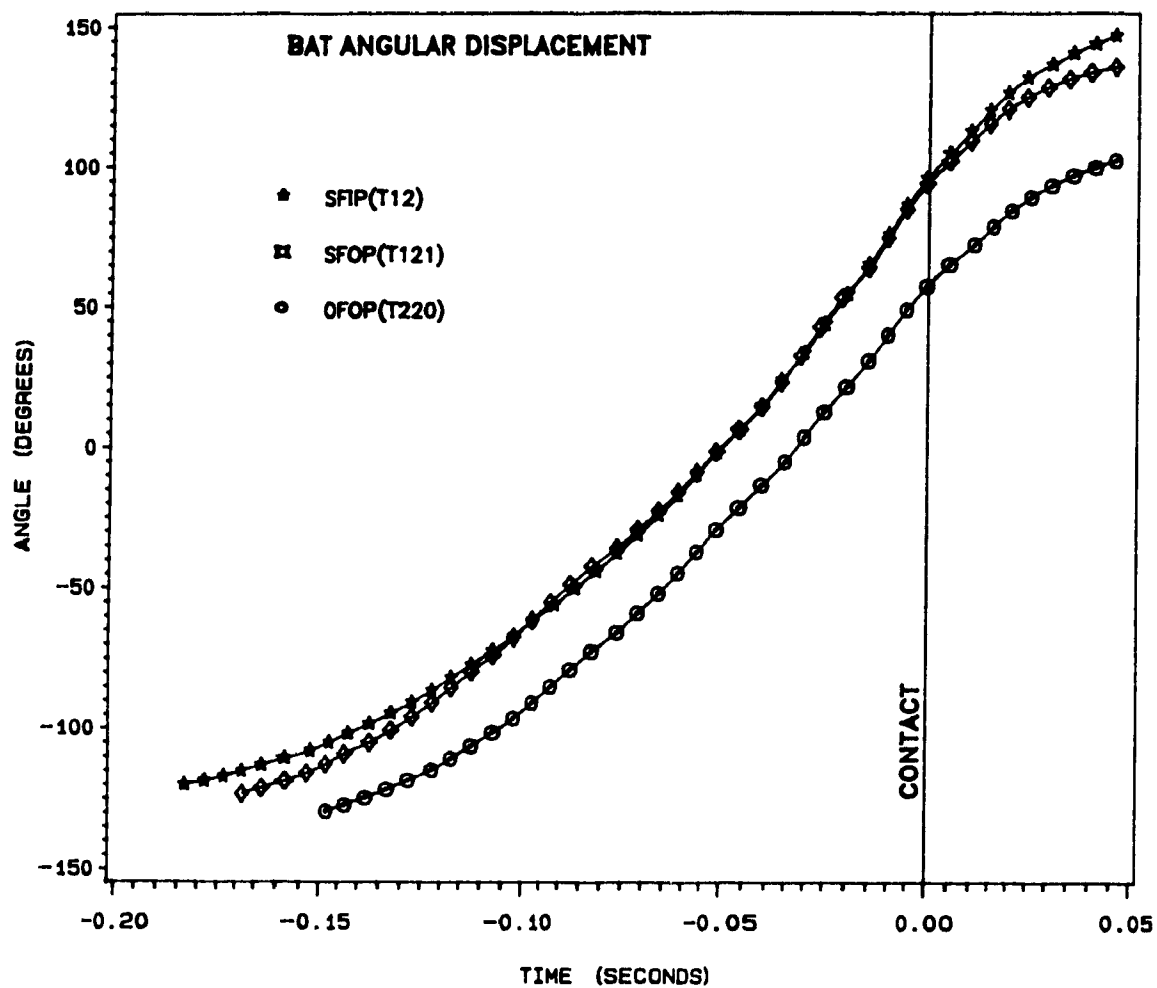


Figure 8. Bat angular displacement in the horizontal plane during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

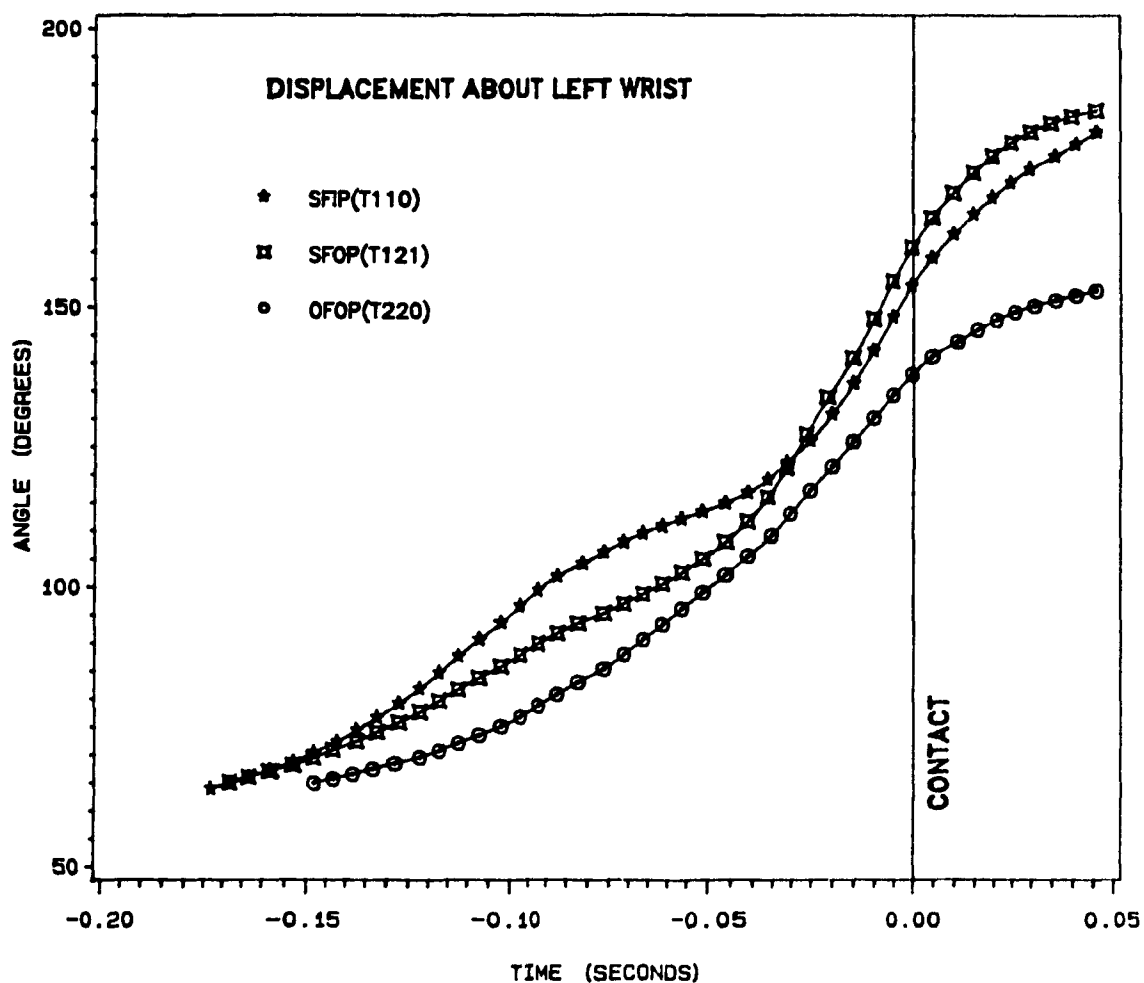


Figure 9. Displacement about the left bat-forearm joint during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

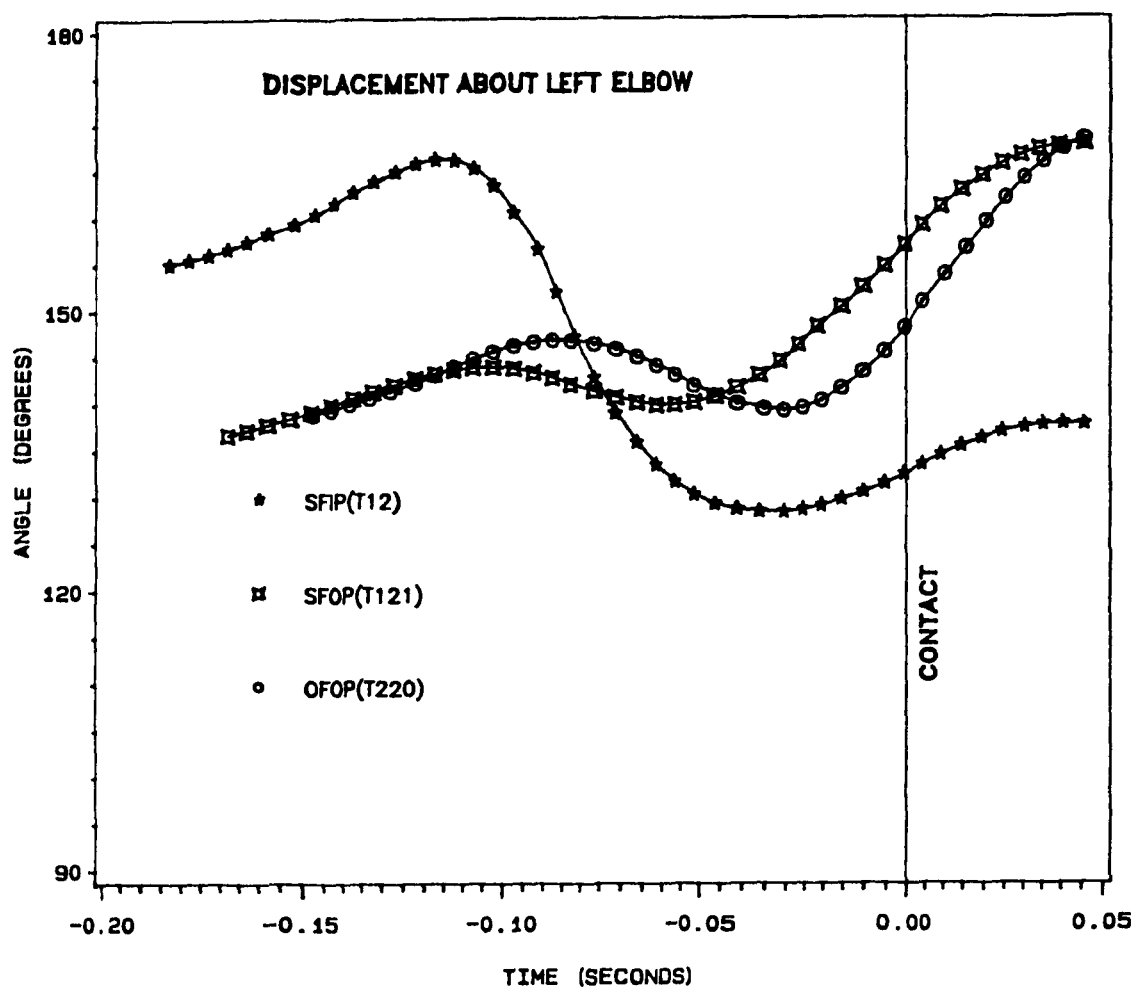


Figure 10. Displacement about the left elbow joint during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

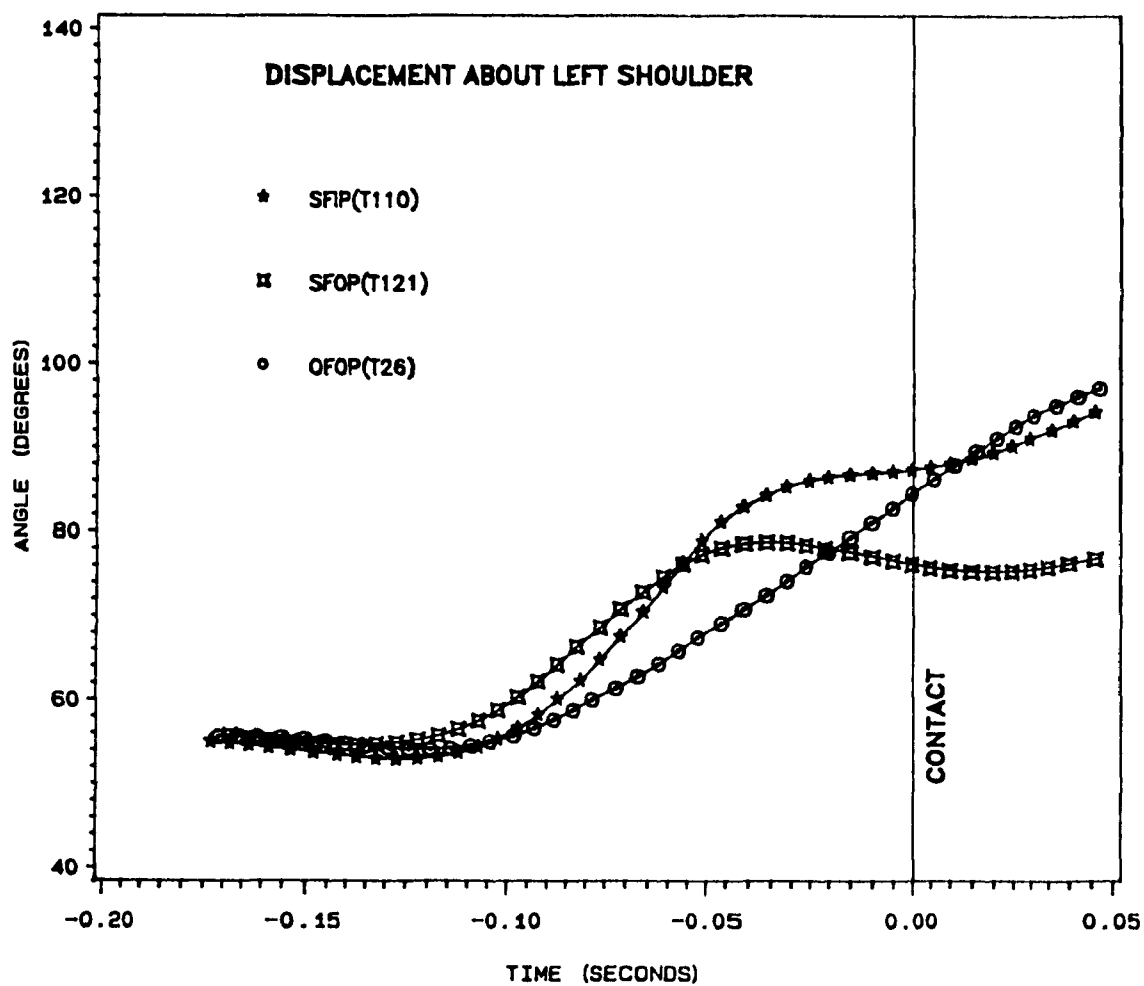


Figure 11. Displacement about the left shoulder joint during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

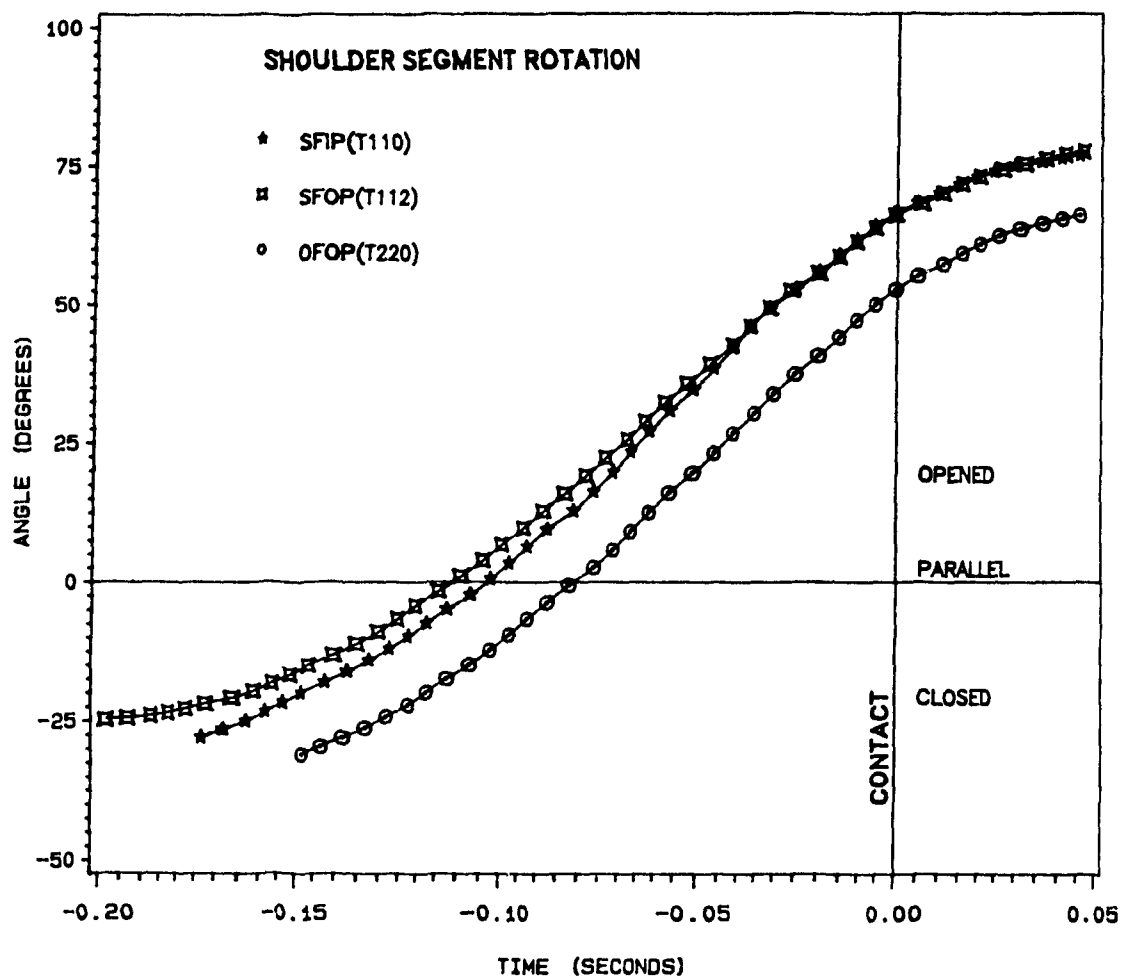


Figure 12. Shoulder segment rotation during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

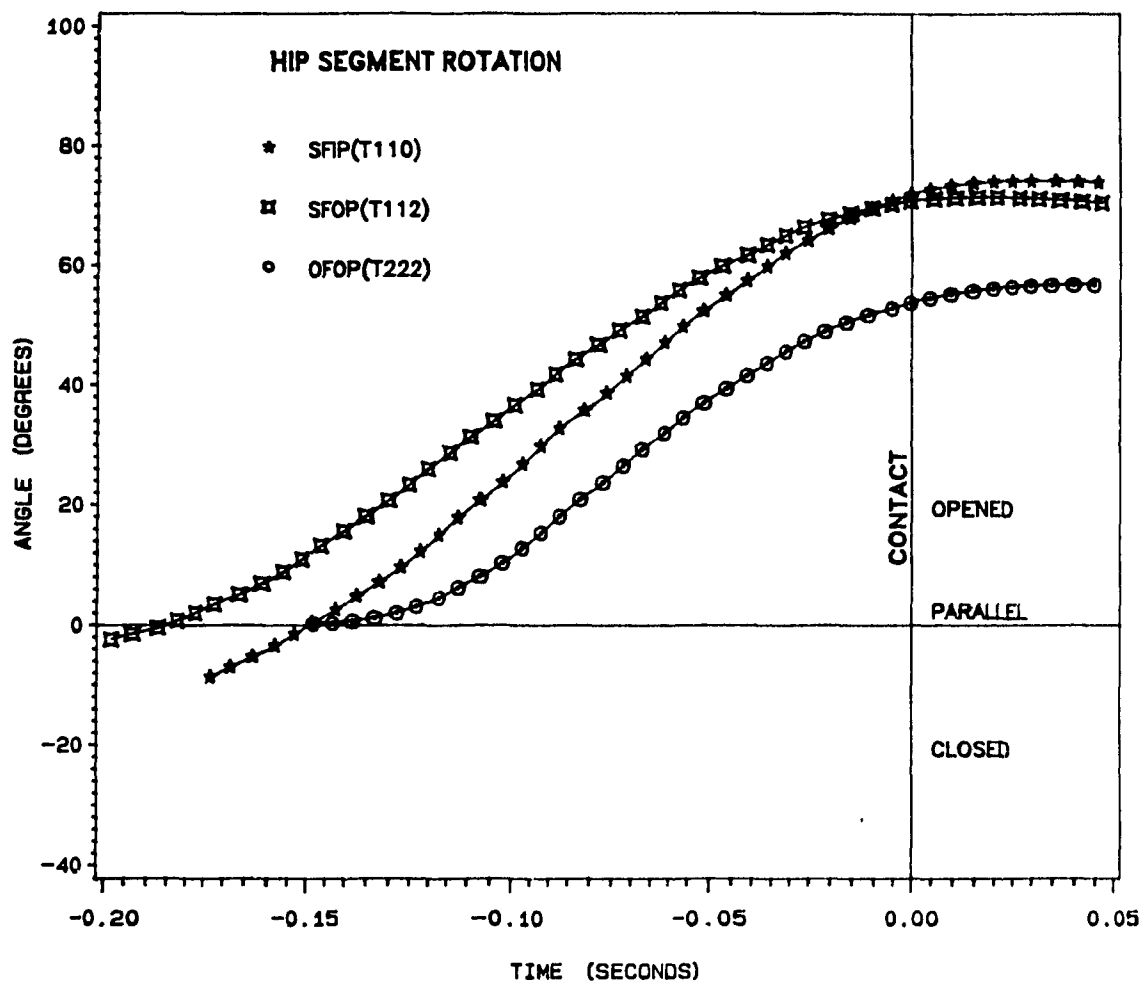


Figure 13. Hip segment rotation during the batting of the same-field inside-pitch (SFIP), same-field outside-pitch (SFOP), and opposite-field outside-pitch (OFOP) hits (representative trials).

Table 4. T-Test comparisons between the same-field inside and outside pitch conditions ($^{\circ}$, Mean $\pm$ SD)

Variable	SFIP	SFOP	F'	p'	df	T	p
BAT	98.9 (6.8)	106.6 (8.0)	1.38	0.745	12.0	-1.89	0.083
HROT	67.5 (7.6)	67.6 (7.0)	1.19	0.804	12.0	-0.03	0.976
SROT	61.8 (7.0)	62.6 (9.3)	1.76	0.553	12.0	-0.17	0.865
LSAN	92.7 (22.0)	76.3 (3.9)	31.97	0.000	5.2	1.80	0.130
LEAN	127.8* (16.6)	157.1 (4.4)	14.41	0.003	5.5	-4.21	0.007
LBFAN	157.4 (3.6)	157.3 (5.9)	2.66	0.298	12.0	0.05	0.959

Note: * = $p < 0.05$

SFIP : same-field, inside pitch hit
 SFOP : same-field, outside pitch hit
 BAT : bat [angle]
 HROT : hip [angle]
 SROT : shoulder [angle]
 LSAN : left shoulder angle
 LEAN : left elbow angle
 LBFAN : left bat forearm angle
 F' : test of homogeneity of variance
 p' : probability of obtaining a greater F'
 T : test of equality of the means
 p : probability of obtaining a greater T

4.2.2.2.2 Comparisons between the SFIP and OFOP hits

Relative to the SFIP treatment, the smaller bat angular displacements in the OFOP (opposite-field outside-pitch hits) condition were produced through several adjustments, as shown in Table 5. As was found earlier in the initial comparisons between same and opposite-field hits, the subject significantly restricted the displacements about the left bat-forearm joint (OFOP: 137.9°, SFIP: 157.4°, Figure 9) in projecting the OFOP hits. Further, the OFOP hits were contacted with significantly greater elbow extension (OFOP: 147.0°, SFIP: 127.8°, Figure 10), reflecting adaptations for pitch locations. While no significant difference was found in the angles measured at the left shoulder, Figure 11 appears to show that the batter may have used different approaches. In the SFIP hit, the subject horizontally extended his left humerus earlier in the swing while simultaneously flexing at the elbow, then stabilized the upperarm at approximately .03 sec prior to contact, possibly allowing elbow extension to occur. During the OFOP hits humeral horizontal extension was delayed, then the upperarm was extended at a constant rate through contact, while the elbow joint was held relatively stable until extension was triggered, at approximately .03 seconds prior to contact. The subject ultimately contacted the ball with his left humerus horizontally extended at approximately 90° during opposite OFOP and SFIP hitting (SFIP: 92.7°, OFOP: 85.3°; Table 3 and Figure 11). Finally, shoulder (OFOP: 51.3°, SFIP: 61.8°, Figure 12) and hip (OFOP: 53.4°, SFIP: 67.5°, Figure 13) rotation were significantly restricted during the performance of the OFOP hits.

4.2.2.2.3 Comparisons between the SFOP and OFOP hits

Table 6 presents the comparisons between the OFOP and SFOP conditions. As discussed earlier, the smaller bat angles measured at contact for the OFOP hits (Figure 8) necessitated modifications to hip and shoulder rotation, and to left bat-forearm joint displacement. The subject significantly restricted the adduction about the left bat-forearm joint (OFOP: 137.9° , SFOP: 157.3° , Figure 9) up to contact with the ball. In addition, the OFOP hits were executed with significantly greater shoulder horizontal extension than the SFOP trials (85.3° vs 76.3° , Figure 11). This modification allowed the batter to keep the hands ahead of the point of contact on the bat, and to control its orientation within the contact zone. Finally, significantly less shoulder (OFOP: 51.3° , SFOP: 62.6° , Figure 12) and hip rotation (OFOP: 53.4° , SFOP: 67.6° , Figure 13) were required to perform the OFOP hits. Less extension about the left elbow was noted at contact in the OFOP hits (OFOP: 147.0° , SFOP: 157.1° , Figure 10), however this difference was not found to be statistically significant. However, the relatively high variability exhibited in the displacements about the left elbow and shoulder joints within the OFOP group probably reflects their role in performing the fine adjustments to the swing required by this particular task.

Table 5. T-Tests comparisons between the same-field inside-pitch and opposite-field outside pitch conditions ($^{\circ}$, Mean $\pm$ SD)

Variable	SFIP	SFOP	F	p'	df	T	p
BAT	98.9* (6.8)	73.2 (10.3)	2.29	0.380	12.0	5.29	0.000
HROT	67.5* (7.6)	53.4 (5.0)	2.33	0.300	12.0	4.23	0.001
SROT	61.8* (7.0)	51.3 (9.1)	1.65	0.601	12.0	2.36	0.036
LSAN	92.7 (22.0)	85.3 (10.5)	4.42	0.778	12.0	0.84	0.419
LEAN	127.8* (16.6)	147.0 (13.9)	1.44	0.638	12.0	-2.36	0.036
LBFAN	157.4* (3.6)	137.9 (6.9)	3.66	0.172	12.0	6.24	0.000

Note: * = $p < 0.05$

SFIP : same-field, inside pitch hit
 SFOP : opposite-field, outside-pitch hit
 BAT : bat [angle]
 HROT : hip [angle]
 SROT : shoulder [angle]
 LSAN : left shoulder angle
 LEAN : left elbow angle
 LBFAN : left bat-forearm angle
 F' : test of homogeneity of variance
 p' : probability of obtaining a greater F'
 T : test of equality of the means
 p : probability of obtaining a greater T

Table 6. T-Tests comparisons between the same-field outside-pitch and opposite-field outside-pitch conditions ($^{\circ}$, Mean $\pm$ SD)

Variable	SFIP	SFOP	F'	p'	df	T	p
BAT	106.6* (8.0)	73.2 (10.3)	1.65	0.524	14.0	7.24	0.000
HROT	67.6* (7.0)	53.4 (5.0)	1.96	0.394	14.0	4.72	0.000
SROT	62.6* (9.3)	51.3 (9.0)	1.07	0.934	14.0	2.47	0.027
LSAN	76.3* (3.9)	85.3 (10.5)	7.23	0.018*	8.9	-2.28	0.049
LEAN	157.1 (4.4)	147.0 (13.9)	10.03	0.007	8.4	1.96	0.085
LBFAN	157.3* (5.9)	137.9 (6.9)	1.37	0.686	14.0	6.01	0.000

Note: * = $p < 0.05$

SFOP : same-field, outside-pitch hit
 OFOP : opposite-field, outside-pitch hit
 BAT : bat [angle]
 HROT : hip [angle]
 SROT : shoulder [angle]
 LSAN : left shoulder angle
 LEAN : left elbow angle
 LBFAN : left bat-forearm angle
 F' : test of homogeneity of variance
 p' : probability of obtaining a greater F'
 T : test of equality of the means
 p : probability of obtaining a greater T

4.2.2.3 Descriptive statistics

Various descriptive statistics were computed for the three subsequent sub-groupings (SFIP, SFOP, and OFOP), and are presented in Tables 7, 8, 9 and 10. It is important to note that the task demands made on the subject may have influenced the velocity trajectories. The subject was specifically asked to project the baseballs to specified field areas while making firm contact with the ball. He therefore had prior knowledge of where to direct the batted ball, as opposed to simply reacting to the pitch. The reason for the selection of the design was two-fold: (1) there are a number of instances during the course of baseball games when strategy does require a batter to direct the ball to specified field areas regardless of the location of the incoming pitch; and (2) this approach was the most effective in controlling the task difficulty, the total amount of film needed, and the resulting analysis. Thus, the following data are presented for descriptive purposes only.

Table 7 presents temporal and spatial data, showing similarities in the three types of field-hits. The mean swing times were larger in the SFOP (.422 sec) hits than in the other two groups (SFIP: .388; SFOP: .396). The same-field inside-pitch hits were initiated earlier, while the opposite-field outside-pitch swings commenced relatively late. This allowed the subject to make contact with the ball further in front of, or closer to home plate respectively.

In light of the very limited time afforded to batters during the flight of a pitched baseball, it is doubtful that during a competitive game hitters actually modify the direction of their stride to propel the

ball in a specific direction on the playing field. The mean values measured for the direction of stride (Table 7) indicate that the subject took a closed stride during the performance of all three types of hits. Positive displacement would correspond to an open stride being taken in a counter-clockwise direction.

Mean ranges of motion for selected segments and articulations are presented in Table 8. The data show that the subject adopted similar batting stances prior to each swing, as indicated by the minimum values of range of motion. The bat was swung through approximately 260° in the two same-field

Table 7. Temporal and directional characteristics of the batting swings (Mean values)

CONDITION	SWING TIME	DIRECTION OF STRIDE
SFIP	.388 sec	-17.4°
SFOP	.422 sec	-15.6°
OFOP	.396 sec	-19.9°

hits, and 230° in the opposite-field hits. Displacement values about the left bat-forearm joint approaching or past 180° reflect the subject's "wrist roll" (supination of the bottom hand and pronation of the top hand on the bat) which occurs during the follow-through phase. The range of motion (ROM) values about the left elbow were similar in the SFOP and OFOP hits. The ROM values for same-field inside pitch hits were misleading, due to the distinct strategy employed by the subject

to bring the bat into the contact zone (Figure 10). Contrary to the other two conditions, maximum elbow extension tended to coincide with ball contact. From a preliminary position of approximately 54.0° , the humerus was horizontally extended up to 102.7° in the SFIP hits, 89.2° in the OFOP hits and 77.5° in the SFOP trials. These values support some comments made earlier in this chapter. The control of trunk rotation required by the opposite-field hit is apparent in Table 8. The hip and shoulder segments were in a "closed" position initially, and rotated approximately 70° during the two types of same-field hits, while the opposite-field trials exhibited smaller ranges of motion (maximum of 56.0°).

The peak tangential velocity values for the tip of the bat reported in this study are relatively low, as compared to previously published data (Pfautsch, 1980; Shapiro, 1979). The data presented in Table 9 show that greater peak tangential velocities of the tip of the bat were achieved in both types of same-field hits, contradicting Pfautsch's earlier findings. The bat handle velocities remained similar in all three treatment groups. The timing of the peak tangential velocities of the tip and handle of the bat relative to contact with the ball compared favorably with previously published data (McIntyre and Pfautsch, 1982). Peak velocities of the tip of the bat nearly coincided with the impact with the ball in all three types of field-hits (SFIP: .01 sec; SFOP: .015 sec; OFOP: .008 sec). The smaller velocities of the tip of the bat in the OFOP condition may result from a combination of factors: (1) the smaller lever arm caused by less elbow extension characteristic of this type of field-hit, and (2) relatively smaller bat angular velocities

(Table 10) which possibly resulted from restricted movement about the left bat-forearm and shoulder joints.

The data in Table 10 may partly explain how the subject adapted to the different conditions. As mentioned earlier, adjustments to the inside pitch location (SFIP) still produced similar bat tangential velocities to that of the SFOP hits through greater bat angular velocities. The different body position at contact of the SFIP hits resulted in a smaller lever arm and a smaller, accompanying moment of inertia of the batter-bat system; these changes may in turn have facilitated the generation of greater bat angular velocities. Additional contributing factors may include higher velocities about the left wrist and shoulder joints, and greater rates of shoulder and hip segment rotation. In addition, the SFIP trials were characterized by smaller angular velocities about the left elbow joint ($187.5^\circ/\text{s}$), as compared to the other two types of hits (SFOP: $445.2^\circ/\text{s}$, OFOP: $431.3^\circ/\text{s}$). This reflected an emphasis on elbow flexion during the majority of the swing in the SFIP hits, in order to delay elbow extension and bring the bat to the appropriate position at contact.

Relative to the SFIP hits, the smaller bat angular velocities observed in the OFOP trials may have resulted from smaller velocities about the left wrist and shoulder joints, and smaller hip and shoulder rotational velocities. The reasons for the smaller velocities about the left wrist joint may reflect the wrists' role in controlling the rotation of the bat through the contact zone, projecting the ball to the opposite-field.

Table 9. Maximum values and temporal characteristics of the bat tangential velocities (Mean $\pm$ SD)

	MAX. VELOCITY (m/s)			TIME MAX VEL.-CONT (sec)		
	SFIP	SFOP	OFOP	SFIP	SFOP	OFOP
TIP	22.0 (0.8)	23.0 (1.2)	18.5 (1.0)	.010 (.005)	.015 (.007)	.008 (.010)
HANDLE	8.8 (0.4)	9.2 (0.5)	8.8 (0.2)	.023 (.012)	.029 (.029)	.018 (.009)

MAX. VELOCITY : peak tangential velocity
 TIME MAX VEL.-CONT : time from peak velocity to contact

Elbow extension commenced relatively late in the OFOP hits (approximately .03 sec prior to contact), possibly to assist in producing the desired bat orientation at contact with the ball. This may have resulted in a "pushing" action to propel the ball towards the opposite-field, as was suggested in the coaching literature (Williams and Underwood, 1971).

The same-field outside pitch (SFOP) differed from the same-field inside-pitch hits (SFIP) in several ways. The bat angular velocities in the SFOP hits were smaller, as were the velocities measured about the left wrist and shoulder joints, and the rates of hip and shoulder rotation (Table 10). The velocities recorded about the left shoulder joint in the SFOP hits were in fact negative, implying humeral horizontal flexion during contact with the ball. Higher rates of elbow extension were observed in the SFOP hits, which were assisted by the horizontal flexion of the subject's left upperarm.

Table 11 presents various peak angular velocity values for the various field-hit groups, and their timing relative to contact with the ball. The temporal characteristics of the swing followed an expected trend (Pfausch, 1980; Messier and Owen, 1984; Shapiro, 1979), with the more distally located segments reaching their peak velocities relatively later. With one exception (velocities about the left elbow joint in the OFOP hits), all peak velocities occurred before contact. The subject closely synchronized the bat's peak velocities with contact with the ball in all three types of field-hits, which is mechanically desirable.

Table 10. Mean angular velocity values at contact (°/sec, $\pm$ SD)

COND	BAT	LBFAN	LEAN	LSAN	SROT	HROT
SFIP	1969.6 (126.3)	1235.1 (128.2)	187.5 (157.9)	49.0 (93.2)	498.0 (80.8)	255.0 (69.3)
SFOP	1611.9 (366.1)	890.1 (306.6)	445.2 (166.2)	-11.8 (137.3)	346.6 (79.7)	162.7 (65.9)
OFOP	1583.6 (72.3)	746.9 (108.2)	431.3 (196.2)	- 0.3 (203.5)	363.4 (183.2)	150.1 (70.5)
SFIP	: same-field inside-pitch					
SFOP	: same-field outside-pitch					
OFOP	: opposite-field outside-pitch					
LBFAN	: left bat-forearm joint					
LEAN	: left elbow joint					
LSAN	: left shoulder joint					
SROT	: shoulder rotation					
HROT	: hip rotation					

Pfautsch (1980) reported bat angular velocities ranging from 2416.0 to 2701.2°/s for same-field hits, and from 2607.6 to 2908.1°/s for opposite-field hits. The data collected in the present investigation not only show much lower values, but also imply a conflicting tendency. This may have been a consequence of the task demand and the experimental method employed. The values collected in the current study may not accurately reflect the batting swing. Such focus probably requires the use of a different experimental method, one that would allow greater latitude to the subject, requiring him to simply react to various pitches, without prior knowledge of their location in the strike zone.

Table 11. Mean peak values and temporal characteristics of the resultant angular velocities ($\pm$ SD)

	PEAK ANGULAR VEL. ($^{\circ}$ /s)			TIME PEAK-CONT (s)		
	SFIP	SFOP	OFOP	SFIP	SFOP	OFOP
BAT	2138.5 (84.9)	2101.8 (98.5)	1771.4 (71.6)	-0.008 (.004)	-0.010 (.013)	-0.011 (.003)
LBFAN	1322.4 (97.7)	1281.7 (145.1)	860.1 (99.0)	-0.008 (.005)	-0.008 (.015)	-0.011 (.004)
LEAN	225.4 (142.6)	464.6 (153.4)	502.0 (144.3)	-0.116 (.055)	-0.004 (.008)	+0.004 (.006)
LSAN	777.3 (313.4)	385.2 (91.1)	478.0 (216.4)	-0.061 (.013)	-0.065 (.022)	-0.051 (.020)
SROT	829.7 (150.1)	668.2 (198.5)	696.4 (73.4)	-0.051 (.011)	-0.062 (.014)	-0.056 (.021)
HROT	547.5 (45.1)	563.4 (51.4)	515.2 (32.4)	-0.083 (.012)	-0.092 (.014)	-0.073 (.029)

Notes: - indicates peak velocity occurring before contact
+ indicates peak velocity occurring after contact

SFIP : same-field inside-pitch
SFOP : same-field outside-pitch
OFOP : opposite-field outside-pitch
LBFAN : left bat-forearm
LEAN : left elbow
LSAN : left shoulder
SROT : shoulder rotation
HROT : hip rotation

The relative timing of peak velocities about the elbow joint in the three field-hit conditions appears to be reflecting the subject's response to the task demands. In the SFOP and OFOP conditions, the subject had to delay before committing to the swing then reach out to the ball on the outside part of the plate to make contact within the bat's center of percussion; hence the greatest displacements and greater velocities about the elbow joint, and the near-perfect synchronization of the joints' angular velocities with time of contact. The OFOP hits required the subject to control the amplitude and timing of the angular velocities about the left wrist and elbow joints. The subject accelerated the rate of elbow extension during contact with the ball, "pushing" it in the desired direction. Peak elbow extension velocity occurred much earlier in the SFIP condition (0.116 seconds prior to contact), while maxima in the SFOP (0.004 sec. prior to) and OFOP (0.004 sec. after) hits were closely synchronized with contact.

4.3 Summary

Hypothesis 1 stated that the OF hits would be achieved with a smaller bat angle at impact. The hypothesis was accepted, and subsequent analysis of the effects of pitch location revealed that the subject produced similar bat orientations at contact in both same-field conditions (SFIP and SFOP), and that these displacements were greater than those of the OFOP hits.

Hypothesis 2 stated that the OF hits would be projected with a smaller angle about the left bat-forearm joint. The hypothesis was accepted. Subsequent analysis of the effects of pitch location revealed

similar results, in that the OFOP hits were also characterized by smaller angles than the two types of same-field hits.

Hypothesis 3 stated that the OF hits would be impacted with a smaller angle about the left elbow joint. Relatively high variability was noted in both types of field-hits, hence this hypothesis was rejected. High variability was noted in the SFIP and the OFOP hits, which decreased the likelihood of obtaining statistical significance. Further analysis revealed that the effects of pitch location partly accounted for the high variability within the SFIP trials. Consideration of these effects revealed that the angles at the left elbow were significantly smaller in the SFIP hits than in the other two conditions. In fact, the displacement pattern observed in the SFIP condition was distinct from the two other types of field-hits. Moreover, the angles at the elbow measured in the opposite-field trials were approximately 10° smaller than in the SFOP, but statistical significance was not obtained.

Hypothesis 4 stated that the OF hits would be achieved with a smaller angle about the left shoulder joint at impact. This hypothesis was rejected, as relatively high variability was observed for the displacements occurring at this joint. Further analysis revealed significantly greater angles measured at the shoulder joint in the OFOP conditions relative to the SFOP group. The greatest angles were measured in the SFIP hits, but the difference was not significantly greater than in the other two groups.

Hypothesis 5 stated that the OF hits would be achieved with less shoulder rotation at contact with the ball. The hypothesis was

and also held true in the subsequent analysis, with both types of same-field hits showing significantly greater values.

Hypothesis 6 stated that the OF hits would be achieved with less hip rotation at contact with the ball. The hypothesis was accepted and also held true in the subsequent analysis, with both types of same-field hits showing significantly greater values.

CHAPTER V

SUMMARY AND CONCLUSIONS

In this chapter, the results of the present study are summarized and integrated with existing literature, conclusions are drawn, implications for coaching discussed, and finally recommendations for future research formulated.

Achieving optimal transfer of momentum is a primary batting objective requiring different positioning of the bat in relation to the ball in order to satisfy a number of mechanical and strategical objectives. The literature described the ability to project the ball to selected areas of the playing field as a distinguishing factor in batting efficiency (Williams and Underwood, 1971). The angle of incidence between the bat and path of the pitched ball appears to be the primary means by which the ball is hit to different field areas (Bunn, 1972; Hay, 1978; Pfautsch, 1980). Some of the modifications to the batting swing required for opposite-field hitting were discussed in the literature. The hands were shown to precede the point of contact on the bat through restriction of the adduction about the left bat-forearm joint, and the extension of the lead elbow (Pfautsch, 1980).

The contribution of hip and shoulder segment rotation to batting has received little scientific attention to date. A review of the literature produced a study by Shapiro (1974) which revealed an inverse relationship between the amount of hip and shoulder rotation

and pitch height. Further, some support was given to the theory that horizontal resultant torques acting on the bat during the swing are largely due to hip, trunk and shoulder movement (Shapiro, 1979; Swimley, 1964). To date, no investigation has focused specifically on the involvement of hip and shoulder rotation in opposite-field hitting. Finally, there was little information in the literature treating the effects of different pitch locations on the kinematics of the batting swing. Therefore, the purpose of the study was two-fold: (1) to compare the kinematic patterns characteristic of the same and opposite-field hits in baseball, and (2) to study the effects of different pitch locations on these patterns.

The current study's one-subject approach focused on the displacements about the left wrist, elbow, and shoulder joints, as well as hip and shoulder rotation occurring during the performance of both types of field-hits. A pitching machine was used to deliver the baseballs to the subject. The subject performed 24 hits to the same and opposite-fields, for a total of 48 trials. Twenty-four trials were selected for analysis, which included ground balls, line drives, and fly balls stroked firmly into the desired field area.

All trials were recorded on high-speed film in the horizontal plane. Undesirable sources of variability were minimized during the experiment, yet few trials were performed in identical conditions. This resulted in greater variability being observed in the subject's movement patterns, and affected the sensitivity of the statistical analyses. The data however, appear to accurately describe the motor patterns characteristic of each type of field-hit. Independent T-Tests

(alpha set at .05) were used to test the significance of the comparisons.

5.1 Summary of Results

5.1.1 Characteristics of Opposite-Field Hitting

The mean values for bat positions at contact recorded in this study for both types of hits paralleled those previously reported (Pfautsch, 1980). Further, the opposite-field hits were contacted with the hands positioned ahead of the point of contact on the bat through restricted adduction about the left bat-forearm joint, corroborating earlier findings (Pfautsch, 1980). This was also consistent with research in golf (Jorgenson, 1970) and dart throwing (Anderson and Pitcairn, 1986), which depicted the critical role of the wrist joint in achieving fine motor control. In this study, the angular displacements measured at contact about the left elbow and shoulder joints were nearly identical in both field-hit conditions (same and opposite-field). Pfautsch (1980) did not report displacement data for the left shoulder joint. However, the displacement data for the left elbow joint appeared to be in conflict with Pfautsch's conclusions that batters restrict the extension of their left elbow in performing the opposite-field hits. Relatively high variability was however noted for the displacements about the left elbow and shoulder joints. Subsequent analysis revealed that adjustments to pitches aimed at different locations accounted for the higher variability observed at the latter two articulations, thus increasing the difficulty of obtaining

statistical significance when disregarding the effects of pitch location.

The trunk angular displacement data support suggestions made in the coaching literature (Weiskopf, 1968). The batter was said to control the amount of hip and shoulder rotation so that his navel is actually facing the direction in which the ball is to be hit, at contact with the ball. In this study, opposite-field hits were indeed characterized by significantly less rotation of the hip and shoulder segments at contact with the ball. However when observing the same-field hits, these segments (mean values of 67.5° and 62.2° for the hip and shoulder segments respectively) were never so rotated so as to actually face the field area in which the ball was being hit, as was implied by the Weiskopf's (1968) earlier descriptions. Rather, these segments were still facing the opposite-field on contact with the same-field hits.

The direction of the strides taken in each of the field-hit conditions was held relatively constant. Due to the fact that reported flight times of baseball pitches (Hay, 1978) closely approximate typical batters' swing times (Marino, 1983), it is unlikely that hitters modify the direction of their stride according to the direction in which the ball is to be batted.

5.1.2 Effects of Pitch Location on Batting

Subsequent to the initial comparison of the types of field-hits, the trials were re-grouped in order to investigate the effects of pitch location on the kinematics of the same and opposite-field hits, in order to facilitate the interpretation of the statistical comparisons

between the two conditions. The subject did not successfully perform opposite-field hits off of pitches aimed at the inside part of the plate, thus only three groups were formed.

Results indicated that, when batting to the same-field, the subject made adjustments for different pitch locations at the level of the left elbow and shoulder joints. He adapted to the inside pitch by employing a distinct movement pattern about the left elbow joint, as compared to the swings observed in the other two experimental groups. The batter flexed at the elbow through most of the swing (Figure 10), followed by extension immediately prior to impact. This pattern resulted in significantly less elbow extension at contact with the ball. This probably allowed the subject to reduce the batter-bat system's moment of inertia, increase the bat's angular velocity, and reduce the swing time (time required to bring the bat into the contact zone). These changes minimized the distance between the point of impact and the bat's center of percussion. Conversely, more extension at the elbow on such pitches would cause the batter to make contact with the ball closer to the hands, further away from the bat's center of percussion, resulting in poor transfer of momentum. Further, higher angular velocities were noted for left wrist adduction, shoulder horizontal extension, and finally hip and shoulder rotation, which may have partially contributed to the generation of higher bat angular velocities observed for the inside-pitch hits.

Examination of the displacement curves about the left shoulder joint in each of the three field-hit groups revealed that the batter employed a different strategy in each condition. The subject however

achieved similar joint angular orientation at contact during the same-field inside-pitch (SFIP) and the opposite-field outside-pitch (OFOP) conditions (approximately 90°). By contrast, the same-field outside-pitch (SFOP) hits were characterized by the upperarm being in a relatively flexed position (76.3°) at contact with the ball. A significant difference was found when the SFOP trials were compared to the OFOP hits, but not when tested against the displacements typical of the same-field inside-pitch (SFIP) trials.

High variability characterized the displacements about the left elbow and shoulder joint in the SFIP and OFOP hits, which affected the sensitivity of the statistical comparison between these experimental conditions, as well as when collapsing over the pitch location factor. This relatively high variability may however reflect their involvement in making the adjustments to environmental conditions such as the pitch location. The contribution of these articulations to the fine-tuning of the batting kinematic pattern as per the environmental conditions such as varied pitch locations merits further investigation.

5.2 Discussion

Motor control theory contends that in fine movement tasks the adjustments are made at the distal extremities, with the larger proximal segments showing more powerful, stable behavior (Soechting, 1984). The data collected in this study do not consistently follow this trend. The noise (as depicted by the standard deviation values) observed in the trials tended to increase as the segments were more distally located, then decreased at the left bat-forearm joint.

The highest variation was noted about the left shoulder and elbow joints. The displacements about the left bat-forearm joint exhibited remarkable consistency in all three batting conditions, possibly reflecting a consequence of the absolute bat positional constraint in order to direct the ball to the different field areas.

Conversely, the same-field outside-pitch hits displayed a different tendency. Indeed, all joint displacement patterns were more consistent than those of the proximal segments (hip and shoulder). In this case, the more stable patterns may be consequent to the more stringent spatial constraints imposed on the subject by the pitch location (outside), combined with the specific task of projecting the ball to the same-field area. To make adequate contact with the outside pitch in this condition, the subject had to more fully extend the left elbow and increase the angle about the left bat-forearm joint, reaching out to make adequate contact. The task of batting an outside pitch to the same-field may thus have minimized the available strategies to achieve optimal impact with the ball, hence the greater consistency in the movement pattern.

The performance criterion for the batting task of interest involved swinging the bat around into the contact zone in the appropriate spatial orientation, in order to achieve optimal transfer of momentum. Given the high number of musculoskeletal degrees of freedom inherent to the batter-bat system (movement of the legs, hips, trunk, and about the shoulder, elbow, and wrist joints), there are numerous potential strategies allowing the performance of this motor task. Motor control research however suggests that skilled behavior is

characterized by a reduction in the degrees of freedom to perform the task in order to reduce movement error and augment consistency (Bernstein, 1967; Gallivan, 1988; Hasan, Enoka and Stuart, 1985). The results of this study corroborate this trend, as the data indicated that the modifications made for opposite-field hitting involved the control of the adduction about the left wrist, and of the amount of shoulder and hip rotation. Similarly, the subject adjusted for pitches aimed at different pitch locations primarily through a significantly different pattern about the left elbow joint.

While statistical significance was not obtained for comparisons between the two same-field hits with regards to the effects of pitch location on the displacements about the left shoulder joint, a mean difference of 16.4° was calculated (Table 3). The statistical comparison was affected by the high variability noted for the displacements characteristic of the same-field inside-pitch condition (SD: 22.0°), as compared to the same-field outside-pitch (3.9°). The relatively large variations recorded for the displacements about the left shoulder and elbow joints in the opposite-field and same-field inside-pitch hits may in fact reflect the subject's decision to reduce the number of degrees of freedom to the two articulations, in order to perform necessary adjustments for the various environmental constraints. Consequently, the greater variability noted about the left elbow and shoulder joints may reflect their role in achieving the required bat position in a variety of ways, allowing the subject to make adjustments to the specific situation, or to correct earlier movement errors. It is also possible that the higher standard

deviations reflect the degree of difficulty presented by those two types of field-hits.

Further adjustments may also have been made by the subject in order to make adequate contact with the pitch aimed on the outside part of the plate. The high-speed camera's perspective did not allow the quantification of front knee and trunk flexion (toward the ball) upon contact with the outside pitches. As the direction of the batting strides appears to have been held relatively constant, the latter two movements may represent the remaining degrees of freedom afforded to the batter-bat system. Their potential contribution to hitting in general, and specifically to the adjustments for different pitch location will require further investigation.

5.3 Conclusions

The limitations, delimitations and methodology of the current study must be kept in mind when interpreting the results. Based on the results, evidence has been presented to support the following conclusions:

1. The bat positional characteristics for opposite-field hitting require restriction of the angular displacement at the left bat-forearm joint, as well as the amount of hip and shoulder rotation.
2. Adjustments for different pitch location require distinct movement patterns about the left elbow joint when batting to

the same-field, resulting in significantly less extension at contact of the ball aimed on the inside part of home plate.

5.4 Implications of the study

The study identified the involvement of the hip and shoulder segments in same and opposite-field hitting. Their displacements were stable, and their amplitudes were distinct between the two field-hit types. Coaches should instruct their athletes to control the amount and velocity of rotation of these segments. Difficulties in projecting the ball to the opposite-field may result from too much or premature trunk rotation toward the ball. Furthermore, control of displacements about the front wrist, elbow and shoulder joints were shown to be important for hitting to the various fields.

Consideration should be given to the effects of pitch location on the mechanics of hitting, and to the instructions to be given to the athletes. Distinct movement patterns were identified about the front (left) elbow and shoulder joints. Thus, the differences existing between same and opposite-field hitting will vary according to the pitch location. Similarly, it was shown that even when projecting the ball in the same direction, the displacement patterns about the front elbow and possibly the front shoulder will be distinctly different.

5.5 Recommendations for Future Research

A large difference was noted for the displacements about the left shoulder joint in the two same-field hit conditions. However this difference was not found to be statistically significant. Investigation

of the exact contribution of the left shoulder segment in making adjustments for pitches aimed at different locations within the strike zone is required. Further, the involvement of trunk and front knee flexion to batting in general and specifically in adjusting to pitches aimed at different parts of the plate merits examination. It seems logical that such movements may assist in contacting pitches aimed at the outside part of the strike zone. Finally, accurate measurement of batters stance and stride during the performance of different types of hits may also be indicated.

The exact contribution of the right arm segments to batting in general and specifically to same and opposite-field hitting has yet to be studied. However, due to the fact that the right arm closes the loop of the batter-bat system, it seems reasonable to assume that the displacement patterns of the right arm would be closely related to those discussed for the left arm.

Little is known about the batter's adjustments for hitting pitches aimed at different heights within the strike zone. To this author's knowledge, Shapiro (1974) conducted the only study examining the effects of pitch height on hip and shoulder rotation. Upon consideration of the existing motor control literature and the limited time afforded to batters to effectuate the necessary adjustments for pitch heights, it would seem reasonable to expect that additional, more precise modifications occur at the level of the elbow and wrist joint. Indeed, motor control research indicates that the fine adjustments during performance of motor tasks are executed at the distal extremities (Soechting, 1984). Moreover, the persistent

attempts made by pitchers to make their pitches deviate from the normal ball trajectory succeed in producing various deflections in the ball's path. These different types of pitches and trajectories require batters to make last split-second adjustments to their swings, in order to optimally orient their bat for contact. Such adjustments are unlikely to be made proximally.

Investigating batter's performance in live competitive situations is difficult. However, future research concerning same and opposite-field hitting should consider removing as many experimental constraints or limitations as possible from the methodology. Finally, while the movements of interest in this study occurred primarily in the horizontal plane, the utilization of three dimensional cinematography offers the advantage of integrated analysis of the batting swings. Such cinematographical methodology will help provide additional insight in the mechanics of hitting.

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APPENDICES

APPENDIX A

SUBJECT'S INFORMED CONSENT FORM FOR PARTICIPATION (Part 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 from the experiment 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. 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, weight, and segmental lengths. You will be asked to wear your game shoes, uniform pants, and a light-colored short-sleeved shirt.

You will be asked to sign a release statement authorizing the taking of the measurements and photographing of yourself, and the subsequent use of the data for report purposes. Opportunities will be afforded to you to view the films and to examine the final documents describing the experimental techniques and obtained results. If you so desire, the experimenter will summarize the results of the study and explain their implications. Your identity will not be revealed when the data are reported.

You will be filmed as you attempt to hit 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 four series of 12 trials, alternating between left and right field, for a total of 48 trials.

At least four investigators will be present at the data collection session and will answer all inquiries you may have concerning the procedures. You will be encouraged to wear a batting helmet for all trials and every attempt will be made to minimize any harmful effects.

INFORMED CONSENT FORM FOR USE OF HUMAN SUBJECTS (Part 2)

Date: __/__/__

NAME OF SUBJECT: _____

I hereby give consent to Marc P. Gélinas to perform and supervise the following investigational procedure or treatment:

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

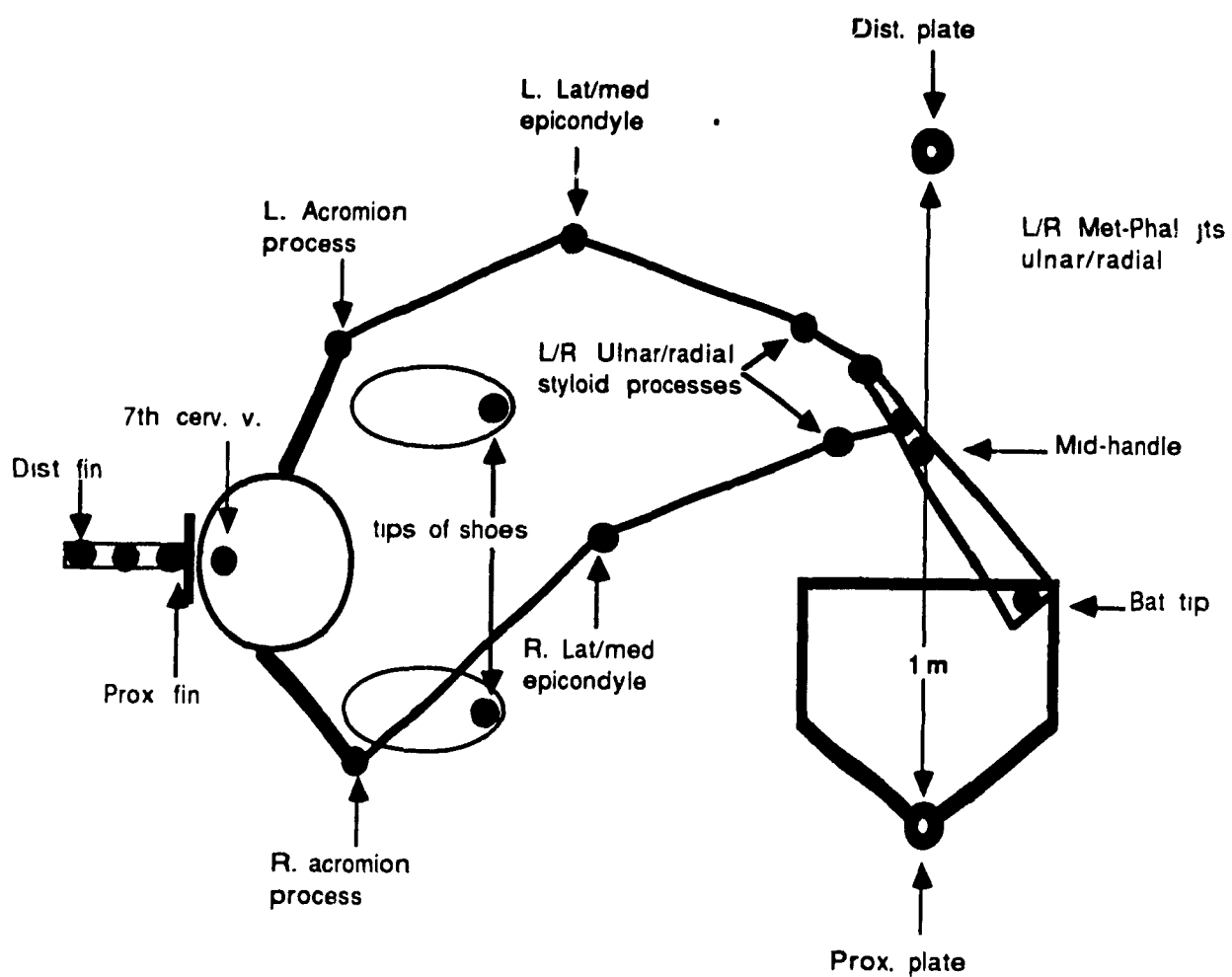
I have seen a clear explanation and understand the nature and purpose of the procedure or treatment; possible appropriate alternative procedures that would be advantageous to me; and the attendant discomforts or risks involved and the possibility of complications which might arise. I have seen a clear 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 the initial paragraph above.

Signature: _____

Witness: _____

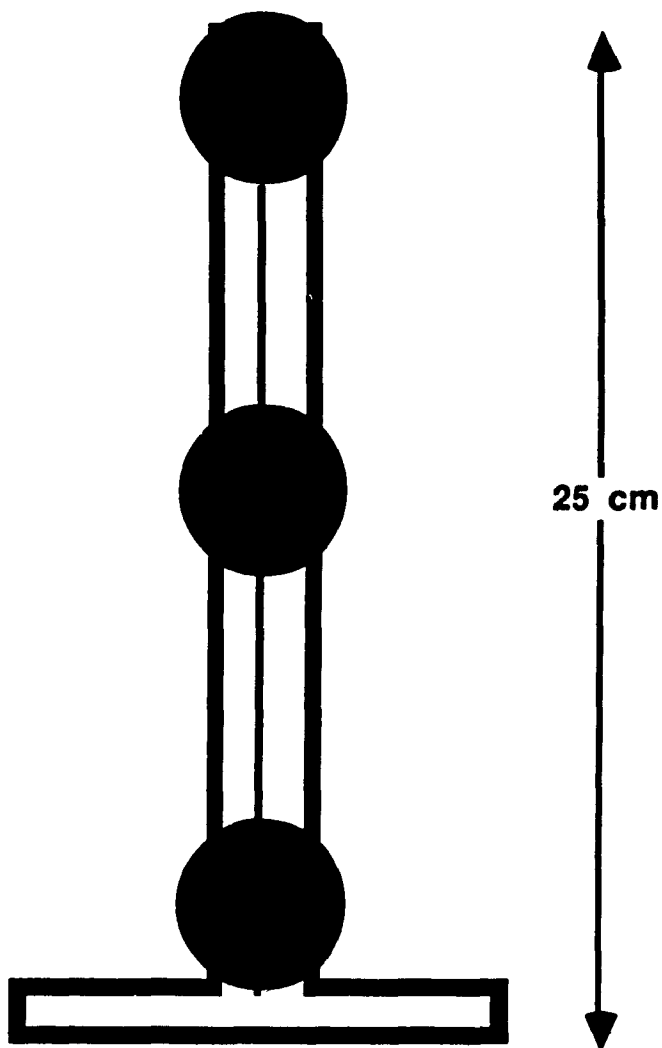
APPENDIX B

MARKER LOCATIONS



APPENDIX C

FIN USED IN DEFINING THE HIP SEGMENT



APPENDIX D

TRIAL EVALUATION SHEET

Identification code order: A TComment codes

A: Field-hit condition

1. same-field hit

2. opposite-field hit

T= Trial number

OK: proper field

F : fly ball

FB: foul ball

P : Pop-up

G : ground ball

L : line drive

V : velocity (mph)

LEFT FIELD

11 _____
 12 _____
 13 _____
 14 _____
 15 _____
 16 _____
 17 _____
 18 _____
 19 _____
 110 _____

LEFT FIELD

111 _____
 112 _____
 113 _____
 114 _____
 115 _____
 116 _____
 117 _____
 118 _____
 119 _____
 120 _____

RIGHT FIELD

21 _____
 22 _____
 23 _____
 24 _____
 25 _____
 26 _____
 27 _____
 28 _____
 29 _____
 210 _____

RIGHT FIELD

211 _____
 212 _____
 213 _____
 214 _____
 215 _____
 216 _____
 217 _____
 218 _____
 219 _____
 220 _____

APPENDIX E

PITCH LOCATION DATA SHEET

Subject name: _____

Date: _____

STRIKE ZONE

LEGEND

A= field hit condition

1. same-field

2. opposite-field

B= pitch location

1. inside

2. outside

T= trial number

ORDER: A B T

Note:

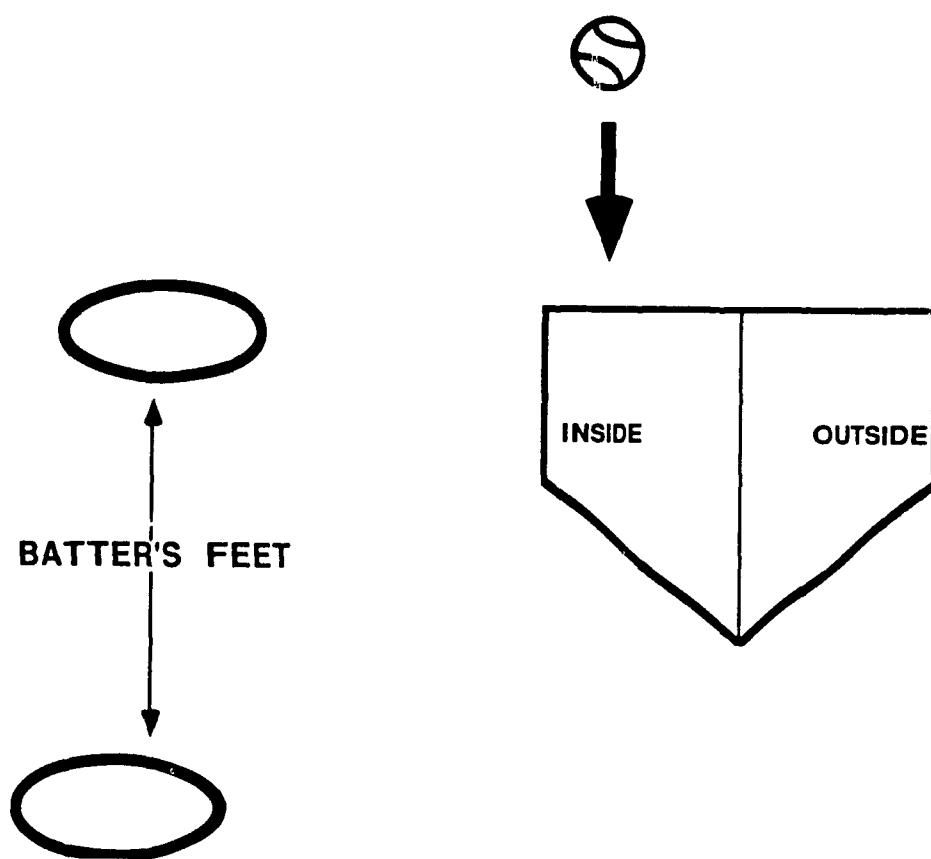
Record each trial by
inscribing the above
listed numbers in the
end location box.

Check your position:

Behind mound ☐Behind plate ☐

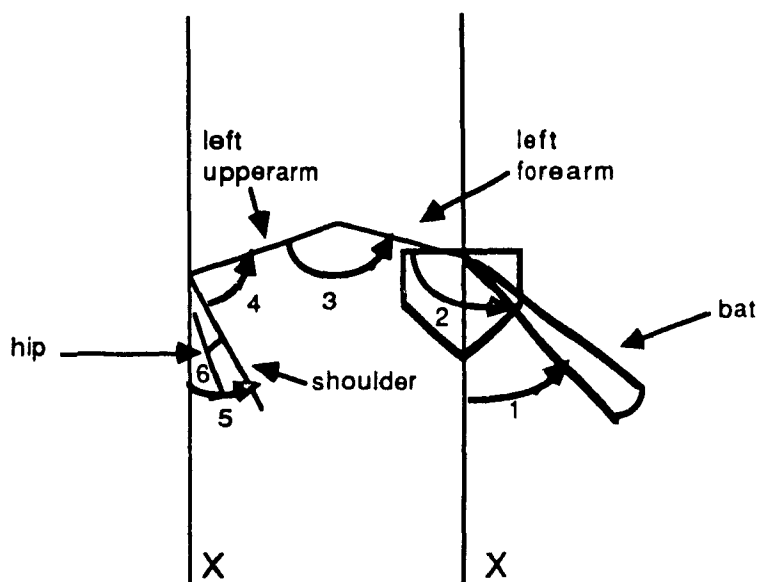
APPENDIX F

DIFFERENT PITCH LOCATIONS



APPENDIX G

VARIABLES MEASURED AT CONTACT, IN HORIZONTAL PLANE



1. Bat angular displacement
2. Displacement about the left forearm joint (wrist)
3. Displacement about the left elbow joint
4. Displacement about the left shoulder joint
5. Shoulder rotation
6. Hip rotation