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Sequential swing patterns in the developing baseball player

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**SEQUENTIAL SWING PATTERN IN THE
DEVELOPING BASEBALL PLAYER**

A Thesis

Presented to

**The Faculty of the Department of Human Performance
San Jose State University**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Arts**

by

Jill Leslie Kronick

December 1999

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ABSTRACT

SEQUENTIAL SWING PATTERN IN THE DEVELOPING BASEBALL PLAYER

by Jill Leslie Kronick

The difference in swinging styles of baseball players with differing levels of experience was investigated. Four groups of subjects were asked to hit a tennis ball from a tee 5 times. Average scores were used to find efficiency based on a scale of 1-8 (Appendix E). Subjects in group 4 (16-18 years-old, 10 + years experience) scored significantly ($p < .001$) higher (5.60 points) than subjects in groups 1 (7-9 y, 1-3 y experience, 4.00 points), 2 (10-12y, 4-6 y experience, 4.20 points) and 3 (13-15 y, 7-9 y experience, 4.05 points). In addition, the more experience a player had the more able he was to transfer his momentum from distal segments to proximal segments. However, players at all levels still needed to learn how to maximize hand speed. It is recommended that future studies employ more advanced subjects, and equipment and investigate female subjects.

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CHAPTER I - INTRODUCTION

Baseball is “America’s pastime.” Fans of the game enjoy the whole experience, especially when the players produce an exciting game. Ballparks fill with cheers for powerful hitting, hard and fast pitching, and spectacular plays on the field. In the 1998 Major League season, for example, many records were broken in all aspects of the game. Examples include Kerry Wood striking out a record 20 batters in one game, Roger Clemens winning the American League’s first triple crown (most strikeouts, most wins, and lowest earned run average), and David Wells pitching a perfect game. However, it was the home run race between Mark McGwire and Sammy Sosa that brought many fans back to the ballparks in 1998, recapturing the joy of the game after the players’ strike of 1994 caused attendance to drop. This record-breaking year increased baseball’s popularity and showed that fans enjoy home run hitting, strike-out pitching, and run-stopping defense when watching a baseball game, especially when it is produced by “their” team (Verducci, 1998).

Pete Rose once said, “hitting a baseball is the hardest thing to do in all sport. Think about it, you’ve got a round ball, a round bat and the object is to hit it square” (Maikovich, 1984, p. 112). Pitching, batting, and fielding all play an integral part in the game of baseball, and it is important to understand as much as possible about each aspect. This investigation will focus on the swinging styles of baseball players. Swinging styles of baseball players are typically individualized to that particular player’s needs. However, all players need specific characteristics in their swings to make them biomechanically effective.

Significance of study

Coaches and former players have written many articles on how to swing the bat efficiently (Bubalo, 1981a; Bubalo, 1981b; Ellis, 1977; Garhammer, 1983; Johnson, 1980; Lau, Glossbrenner, LaRussa, & Salzberg, 1980; Lefebvre, 1983; Murphy, 1991;

Thomas, 1981; Weems, 1979; Weiskopf, 1979; White & Prevo, 1991). However, this information is based on experience, not scientific inquiry. The former players and coaches gather their information through observations made throughout their careers as coaches and players. Many of these articles advocate a specific style of swinging, a style that produces results that score runs. The authors discuss the optimal positioning of the body and the optimal place to hit the ball in specific situations. They also indicate that adjustments to the stance, stride, and swing may be necessary to correct the common problems that players develop when swinging a bat. This information will be discussed in detail in Chapter II.

Cinematographic analysis of baseball and softball swings has led to revelations of what successful and unsuccessful hitters do in their swings (Conard, 1965; Hirano, 1987; Marino, 1989; McIntyre & Pfautsch, 1982; Messier & Owen, 1984, 1985, 1986; Pecci, 1986; Race, 1961; Shaffer, Jobe, Pink & Perry, 1993; Shapiro, 1979; Welch, Banks, Cook & Draovitch, 1995). Video analysis has been used to determine where, in relation to the plate, the batter should swing. Stance, arm and bat position in relation to the body, and the ground reaction forces a batter encounters when swinging at the ball have also been investigated (Marino, 1989; Messier & Owen, 1984, 1985, 1986; Pecci, 1986). Research has also shown that sequential action of body segments from the more distal segments (thighs, hips) to the more proximal segments (elbows, wrists, and even bat) influences the efficiency of a swing. As players achieve a higher skill level, their sequential pattern becomes more efficient (Conard, 1965; Hirano, 1987; McIntyre & Pfautsch, 1982; Race, 1961; Shapiro, 1979; Welch, et al., 1995). However, the findings from the above studies are on a small number of subjects.

The above studies (observational and scientific) focused on the professional player. Observation and research have shown what comprises an efficient striking pattern and what influences the development of such a pattern in youth, which will be

described further in Chapter II (Jones-Morton, 1991; Loovis & Butterfield, 1995; Southard, 1984). However, research on the development of efficient skills in the younger baseball player is lacking. If a child learns an inefficient pattern and practices this pattern, improvement will be harder to elicit. In addition, the child must be encouraged to practice the efficient swing after learning the pattern (Loovis & Butterfield, 1995). Also, learning an efficient pattern may help a youngster extend his/her career because inefficient patterns lead to more injuries (Welch et al., 1995).

In addition to the shortcomings already discussed, new techniques have been developed to analyze movement. New technology has been developed that uses motion sensors and a transmitter that sends signals to a computer. These signals show the subject's orientation on the computer screen. This system will be discussed further in Chapter III, but it consists of four steps. First, the researcher sets up a biomechanical model that will be used by determining how many sensors to use and what body segment each sensor will represent. Second, specific information can be entered into the computer to determine the parameters of motion that the researcher wishes to study. Third, the researcher defines special events, such as ball contact. Finally, specific calculations necessary to the study are determined. The program can then be stored for future use. Once the subject has completed all trials and the motions are saved, the program calculates the desired parameters and stores them for printing tables and graphs for each subject and each trial (Skill Technologies ©, Inc., 1995).

Previous researchers have suggested what future studies should examine in reference to the baseball swing. Welch et al., (1995) suggested that future studies investigate the interaction of the body segments (hips, shoulders, arms, wrists, and bat) in the kinetic link of the baseball swing. Pecci (1986) recommended studying baseball players of differing skill levels. Shapiro (1979) indicated that future studies should incorporate more subjects at different skill levels with various styles of swinging. He

also suggested exploring the contributions of various body segments to the motion of the bat and the acceleration patterns of the batter.

Purpose of study

The purpose of this study was to analyze the swinging kinematics of baseball players with various levels of experience. The efficiency of each subject was determined through motion analysis of five swings of the bat. There were four groups of subjects determined by age and experience level. Group 1 consisted of 7-9 year-olds with 1-3 years of experience. Group 2 consisted of 10-12 year-olds with 4-6 years of experience. Group 3 consisted of 13-15 year-olds with 7-9 years of experience. Finally, group 4 consisted of 16-18 year-olds with more than 10 years of experience.

Null Hypotheses

1. No statistically significant difference in efficiency will be found among baseball players at different levels of experience.
2. No statistically significant difference in hip rotation speed will be found among baseball players at different levels of experience.
3. No statistically significant difference in shoulder rotation speed will be found among baseball players at different levels of experience.
4. No statistically significant difference in hand speed will be found among baseball players at different levels of experience.

Operational Definitions

Ball contact

The final stage of the swing when the bat makes initial contact with the ball and the batter begins to follow through (Welch, et al., 1995).

Experience

For the purposes of this study, experience is defined as consistent baseball practice and play resulting in enhanced knowledge and skills. (Guralnik, 1983).

Foot down

The fourth phase of the swing, or the instant the front foot makes full contact with the ground and energy transfer begins (Welch, et al., 1995).

Foot off

Stage two of a swing, or, in a right-handed batter, the “instant the left (front) foot broke contact with the ground and began the stride” (Welch, et al., 1995, p. 196).

Stance

The first phase of swinging, defined by Hay (1985) as the “position adopted by a batter as he waits for a pitcher to release the ball” (p. 208).

Stride

The third phase of the swing, defined by Race (1961) as the “difference between the distances of the forward foot from the rear foot in the batter’s stance and in the position wherein contact was made” (p. 397).

Swing efficiency

The segmental action produced by the batter to “accelerate the end point or sweet spot of the implement so that it is traveling at optimum or maximum speed at the time of impact with the object” (Kriegbaum, 1996, p. 75).

Wrist cocking

Abduction of the wrist leading to an increase in wrist angle (McIntyre & Pfautsch, 1982).

Wrist uncocking

Adduction of the wrist usually occurring at ball contact (McIntyre & Pfautsch, 1982).

Delimitations

All subjects used for this study were male baseball players, ages 7 – 18, with at least one year of experience in league play. Subjects were solicited from local baseball

clubs and teams. Both right-handed and left-handed players were recruited since the computer program and sensors being used for the study do not require a specific dominant side.

Limitations

Differing levels of experience and maturation existed. Not all subjects in a group had the same amount of practice time or the same coach. Finally, within a group, the subjects had different swinging styles and abilities.

The accuracy of the measurement depended on the researcher and the equipment. Calibrating the equipment to ensure reliability was not available, but since the program was based on a well developed golf analysis, it was assumed to be reliable. All subjects were tested using a batting tee, a wooden bat and a tennis ball. The subjects selected the height of the tee based on preference.

In addition, the researcher assumed that all subjects gave their best efforts and the environmental conditions remained stable throughout testing. All subjects may not be similarly motivated to swing their best, but the investigator encouraged all subjects equally. Finally, seven trials were recorded but only five were averaged for results.

Summary

This study examined the swinging styles and kinematics of four groups of baseball players. The efficiency of five swings were analyzed to determine variables that discriminate among levels of experience. Former players and coaches offer advice to players on how to efficiently swing a baseball bat, but their information comes from remembering how the successful hitters hit the ball, not from experimental research (Bubalo, 1981a, 1981b; Ellis, 1977; Garhammer, 1983; Johnson, 1980; Lau, et al., 1980; Lefebvre, 1983; Murphy, 1991; Thomas, 1981; Weems, 1979; Weiskopf, 1979; White & Prevo, 1991). Some experimental research on baseball batting has been conducted, but most of this research used small subject pools and was done before today's technological

advances (Conard, 1965; Hirano, 1987; Marino, 1989; McIntyre & Pfautsch, 1982; Messier & Owen, 1984, 1985, 1986; Pecci, 1986; Race, 1961; Shaffer, et al., 1993; Shapiro, 1979; Welch, et al., 1995).

CHAPTER II- REVIEW OF LITERATURE

Introduction

The purpose of this study was to analyze swinging efficiency among baseball players with different levels of experience. This literature review will discuss the information that pertains to the baseball swing, or other striking tasks.

Coaches and former players have written many articles that include tips on how to swing the bat efficiently (Bubalo, 1981a; Ellis, 1977; Garhammer, 1983; Johnson, 1980; Lau, et al., 1980; Lefebvre, 1983; Murphy, 1991; Thomas, 1981; Weems, 1979; Weiskopf, 1979; White & Prevo, 1991). This information includes how to move the body throughout the stance, swing and follow through. All of this advice will be discussed, from head to toe, so a picture of efficient body movement during a baseball swing is unveiled. Differences of opinion among former players and coaches concerning bodily motions will also be discussed, starting with the head, continuing on to the hands and wrists, arms, shoulders, hips, legs and feet. Finally, in this portion of the chapter, the weight shift will be discussed.

From the experimental research, first the baseball swing will be discussed in relation to the sequential pattern of the motion (Breen, 1967; Conard, 1965; Hirano, 1987; Race, 1961; Welch, et al., 1995). Then, other aspects of the baseball swing will be reviewed, including forces that the players encounter while swinging, head movement and velocities and accelerations produced by baseballers hitting the ball (Marino, 1989; McIntyre & Pfautsch, 1982; Pecci, 1986; Shaffer, et al., 1993; Shapiro, 1979). The second aspect of experimental research covered will be related to sequential patterns of motions used in other striking skills (Fujimoto-Kanatani, 1996; Koslow, 1994; Messier & Owen, 1984, 1985, 1986; Roswal, 1974; Takahashi, Elliot & Noffal, 1996; Zafiroglu, 1994). In addition, the basic development of a striking skill and an investigation into

when young children develop a mature swing will be considered (Jones-Morton, 1991; Loovis & Butterfield, 1995; Southard, 1984).

Suggestions from Coaches and Players

The head

During the entire sequence of swinging, the action of the head helps to determine if and how effectively the ball will be hit. After all, the head includes the eyes, and the eyes see the ball; thus, “the bat will go where the eyes are focused” (Murphy, 1991, p.72). Thomas (1981) suggested that the batter should keep his head on a level plane because this allows the player to more accurately judge the distance of the ball. Other authors agreed with this suggestion (Bubalo, 1981b; Johnson, 1980; Lau, et al., 1980; Murphy, 1991; White & Prevo, 1991). However, Breen (1967) stated that the head must adjust to the pitch in both angle and direction so that the batter can focus on the ball for as long as possible. By decreasing the angle between the flight of the ball and his/her own line of vision, a batter will be able to see the ball better, and thus is in a better position to hit the ball. The batter must be able to adjust this angle when the pitch changes from an outside pitch to an inside pitch (Breen, 1967).

The hands and wrists

Because the hands and wrists are the last segment to act in the pattern of the swing they are important throughout the entire swinging process. They are vital in the grip, the stance, and the swing. First, the grip is crucial in making the batter comfortable and relaxed before the swing. The grip should lead to a comfortable and flexible swing. The bat should be held where the palms end and fingers begin, and choking up on the bat allows for a more manageable swing (Lau et al., 1980). By lining up the middle knuckles of the top hand between the last and middle knuckles of the bottom hand a player will have a natural grip which leads to greater speed and ability to bring his top hand through on a larger variety of pitches (Thomas, 1981). Other authors agreed that the bat should

be held firmly, but not tightly, at the base of the fingers to achieve a more relaxed swing (Bubalo, 1981a; Murphy 1991).

Keeping the hands back (above the shoulders and behind the ears) during the stance leads to a smoother transition to the launching position and generates rhythm for the swing (Thomas, 1981). If the hands are held above the shoulders, the swing is more tense, and if they are held too far away from the body, the bat will be slowed. Batters should hold their hands in a position that leads to initiation and production of a swing as quickly as possible. If the hands are dropped below the pre-swing position instead of being cocked back, uppercutting may develop leading to more pop-ups, missing high pitches and getting crowded close to the body on inside pitches (Bubalo, 1981a).

For the launching position, or the position adopted by the player just before the pitch is released, the hands should be back with the bottom hand near the armpit of the player and the top hand near the rear tip of the shoulder (Lau et al., 1980). During the swing itself, the hands should lead the bat head, and the wrists will whip the bat into the ball (Bubalo, 1981a; Lau, et al., 1980; Murphy, 1991). The body should always be kept in a straight line; thus, the hands must adjust for the pitch. By letting the hands control the bat speed, the player can have a more balanced swing (Johnson, 1980). At contact, the palm of the top hand should be facing up and the palm of the bottom hand should be directed down (Murphy, 1991).

Whether the wrists should be uncocked (one hand comes off the bat) or rolled (both hands stay on the bat) at the end of the swing is subject to controversy (Hay, 1985). However, wrist extension and flexion help maintain the position of the bat and the fluidity of its motion (Garhammer, 1983). Weiskopf (1979) advocated popping the wrists during the swing, which is uncocking the wrists to allow for an increase in bat speed at contact. Ellis (1977) agreed, stating that "This snap is essential for all hitters." (p. 63).

The arms

The elbows and arms are the next segments to be used in the swing. During the stance, the front arm should be flexed slightly at the elbow. A straight front arm leads to tension which reduces the bat speed. An overflexed arm puts the hands in front of the rear shoulder leading to a swing that is late and less powerful (Thomas, 1981). In addition, a straight front arm can lead to a long bat arc which makes the swing less effective (Johnson, 1980). However, others believed that during the swing the lead arm should be completely extended so that the batter can hit through the ball (Hay, 1985; Lau et al., 1980). Murphy (1991) advocated a front arm that is about 80 percent extended and a back arm in a "V" position, in which the elbow is between 90 and 100 degrees flexed, during the swing. The rear elbow should be at a 45 degree angle with the body to allow the hitter to attack quickly and effectively (Thomas, 1981). A back elbow that is flexed 90 degrees restricts the hand movement and encourages holding the bat deep in the palm of the top hand (Bubalo, 1981a). Positioning the arms close to the body allows the batter a free, full swing and protection against those pitchers who throw inside (Murphy, 1991).

Weems (1979) discussed reasons for raising and lowering the rear elbow, depending on the player's ability. Raising the rear elbow extends the rear wrist, which increases the contractile potential of the hand and forearm allowing a greater range and force of motion as the bat begins to accelerate. It also places the bat firmer into the groove between the thumb and the index finger. This allows the bat to move in the same plane as the hand during wrist flexion, leading to greater velocity and force of the bat. By lowering the elbow, the player loses the potential of the wrist joint in the rear arm. However, a lowered elbow leads to a greater striking position, barrel velocity, and a longer bat path with greater acceleration. This position is better for batters with a slow swing. By changing the positioning of the elbow, the entire swing can change. Raising the elbow produces greater bat velocity and swing force, but the batter must begin his

swing earlier. It also decreases the player's ability to hit the ball towards the opposite field. In contrast, lowering the elbow leads to a faster swing and thus a greater decision time and helps in altering the direction that the ball is hit (Weems, 1979).

The shoulders

The shoulders also contribute to the baseball swing. During the stance, if the front shoulder is higher than the rear shoulder, swinging up at the ball may result (Bubalo, 1981b; Ellis, 1977; Johnson, 1980). In the stride, the elbow is abducted for conservation of momentum (Garhammer, 1983). Through the swing, the front shoulder should remain closed and pointed at the pitcher as long as possible (Murphy, 1991). An efficient swing is evidenced by the shoulders rotating on a level plane (Ellis, 1977).

The hips

The muscles of the hip begin the sequential pattern of the swing. In a powerful swing, the larger muscles generate the power while the smaller muscles lead to control and precision (White & Prevo, 1991). During the approach to the swing, the hip joint of the striding leg extends, abducts and is externally rotated (Garhammer, 1983). At the instant of contact, the hips should be abruptly rotated outward to generate more power (Lau et al, 1980). Without the hip action, less power can be achieved in the swing, and the force of the hip rotation twists the entire body (Ellis, 1977). Motionless hips lead to an ineffective arm swing (Johnson, 1980).

The legs

The flexion of the back leg may vary with the pitch. A low pitch indicates slight flexion while a high pitch leads to a straighter rear leg. However, excessive flexion must be avoided because it will lead to a delayed weight shift, a slow bat and the bat head dropping, which all make the swing less efficient (Thomas, 1981). Slight flexion of the knee can lead to greater power and explosion during the swing (Bubalo, 1981b). As the

player nears the launching position, the stride leg will extend and the rear leg will push through slight knee and hip extension and slight plantar flexion (Garhammer, 1983).

The feet

The positioning of the feet is the foundation for the swing. The further the batter positions his feet from the pitcher, the longer he will have to decide if and how he will swing. Also, he will have a greater chance that the ball will be out of reach. However, if his feet are too close, the inside pitch will be hard to hit. In addition, the distance between the batter's feet is important. In general, the feet should be slightly greater than shoulder distance apart, and a taller player can afford to have a greater distance between his feet. During the stride, the player must lift his front foot and advance it a short distance forward in the direction of the pitcher (Hay, 1985). A smaller step leads to a reduced chance of error and less motion of the head. This allows for greater ball vision and is advocated by many writers (Bubalo, 1981a; Hay, 1985; Lau, et al., 1980; Murphy, 1991; Thomas, 1981). Striding toward the plate leads to an inability to fully rotate the hips; thus, less bat velocity is generated through the strike zone (Johnson, 1980; Thomas, 1981). The distance, direction and height of the stride should remain consistent for all pitches, as seen in the more successful hitters (Bubalo, 1981b).

The weight shift

A rear foot to front foot weight shift is also imperative for a powerful swing. The rear foot should be in a position parallel to the front of the plate with the weight concentrated on the inside of the foot. If the back toe is pointed toward the catcher the pivot of the foot is restricted and the rotation of the hips will be limited (Thomas, 1981). The proper weight shift begins with the weight concentrated on the rear foot and leg and ends with the batter swinging from a firm, rigid front foot and leg. In addition, the stride should be toward the pitcher, and the front foot should pointing straight ahead. If the toe

is not pointed straight ahead, the hips will rotate too soon leading to less power in the swing (Bubalo, 1981b; Ellis, 1977; Lau, et al., 1980; Murphy, 1991).

Sequential Action in a Baseball Swing

Five studies have investigated segments of the sequential action of the baseball swing (Breen, 1967; Conard, 1965; Hirano, 1987; Race, 1961; and Welch, et al., 1995). In 1961, Race conducted a cinematographical analysis of a baseball swing using a 16-mm camera during batting practice to scrutinize swinging mechanics. He captured data on 17 subjects with a mean batting average of .297. He analyzed effective motions that led to the ball traveling a distance of at least 370 feet (against the fence) or line drives which were “very sharply (hit) with a relatively flat trajectory” (p.395). He found that for 15 of 17 subjects, the hands and wrists traveled the fastest at a mean velocity of 192.7 in/s. All subjects employed the hands and the wrists in the fastest manner when compared to the hips’ rotation, and the movement of the foot in the batter’s stride. At a mean velocity of 35.2 in/s, the movement of the foot in the stride was slower than the hands and wrists, and hips. The mean hip velocity was 95.3 in/s. In addition, he found that the mean distance of the pitched ball, when hit, was 20.3 to 27.4 feet from home plate (at speeds ranging from .43 s to .58 s, respectively) (Race, 1961).

Race also determined that the player must lean backward, extend his front knee and his rear hip and swing the body counter to the bat path to counteract the propelling bat. The front knee of the subjects did not fully extend at contact. In addition, the rear wrist or forearm must be supinated to provide for a level swing, and the elbow must be in proximity of the body when it nears 90 degrees of flexion. As for the player’s head, it experienced an average change of –6.5 percent of body height in stance, indicating that it was lowered for all but one subject. During stance, he found that the subjects’ hands were a mean of 22.8 inches from central axis of rotation of the body, and the wrists were extended a mean of 19.6 degrees. He concluded that to accomplish an effective baseball

swing, motion is initiated by dramatic hip rotation and finished by quick and powerful wrist (Race, 1961).

Conard (1965) examined the actions of skilled, semi-skilled and non-skilled baseball players swinging a bat. There were five subjects per group. This study revealed five consistencies among major body segmental movement. First, the pelvis was the first segment to move. The rotation of the pelvis was followed by the forearms and, finally, the wrists. After contact, in 65 of 75 trials, the pelvis rotated backward. She found that the non-skilled players tended to rotate the pelvis too far backwards whereas the skilled and semi-skilled players more consistently started the pelvis rotation in the correct position. In addition, the skilled and semi-skilled batters had a more consistent arm placement at the starting position (Conard, 1965).

Conard (1965) found some other differences when comparing her three skill groups. More wrist action and wrist velocity came with increasing skill level, showing that the more skill the batter had, the more control he had of the bat. Thus, the batter does not have to swing as hard. Compared to the forearm and the pelvis, the wrist angular velocity was also found to be the greatest. In addition, the forearm had greater angular velocity than the pelvis. This shows that the more distal the segment of the chain (wrist-forearm-pelvis), the greater the velocity. According to Welch, et al. (1995), maximally “ ‘passing’ momentum to smaller adjacent segments” (p.199) contributed greatly to a player’s efficiency when swinging the bat. Conard’s (1965) findings were in agreement with this statement.

Conard (1965) also found significant differences in post-contact linear movement. The batter should move forward after contacting the ball. She found that the higher the skill of the player, the more post-contact linear movement was produced. The unskilled players even moved slightly backward after contact. Finally, she noted that the “skilled and semi-skilled batters contacted the ball at the proper point of impact more frequently

than the non-skilled batters” (p.104). The proper point of impact was defined as the point when the ball was directly over the plate (Conard, 1965).

By studying films of successful hitters, Breen (1967) determined five keys to hitting over .300. He found that the center of gravity of a successful hitter followed a level plane. Also, their heads adjusted to the pitch so that they could get the longest and best look at the flight of the ball. The greater bat speed was accomplished by the lead forearm straightening immediately. In addition, the stride length of these players was similar regardless of the pitch type. Finally, after contact, “the upper body position is in the same direction as the flight of the ball, thus putting the weight on the front foot” (Breen, 1967, p. 26).

Using five skilled and two unskilled Japanese college baseball players (all right handed), Hirano (1987) examined the mechanics of hip rotation with the purpose of understanding the kinematics of swinging a bat. First, examining the linear and angular velocity of the player’s center of gravity, he found that all subjects had similar angular velocity, though linear velocity varied. The skilled subjects elicited constant linear velocity after the front foot contacted the ground in the stride and then linear velocity rapidly increased just prior to contact with the ball. However, the linear velocity of the unskilled players gradually increased following the foot’s contact with the ground. Hirano (1987) concluded that this gradual increase in linear velocity after foot contact was due to “misuse of hip rotation” (p.27). This also led to the skilled subjects showing greater maximal kinetic energy during the swing, meaning that the unskilled subjects produced insufficient work necessary for energy transfer from the body to the bat (Hirano, 1987).

Hirano (1987) also examined hip, shoulder and elbow displacements during the swinging sequence. He found that the unskilled subjects had an earlier increase in angular velocity and a lower maximal angular velocity in hip angle displacement. The

unskilled subjects also had an earlier increase in hip angle displacement with respect to the angle of the bat. He also found that unskilled subjects tended to begin their swing with horizontal shoulder flexion and elbow extension of the left arm which made it difficult to increase the linear velocity in the distal segments. This increase in velocity is important in the last part of the swing because it allows the bat to travel fast enough to contact the ball. Finally, he concluded that this slowing of the segments of the left arm was due to early hip rotation with respect to the bat which led to the lowering of the kinetic energy of the bat (Hirano, 1987).

Using 23 reflective markers for each of seven right-handed batters, Welch et al. (1995) studied the biomechanics of a baseball hitter. In addition to the video analysis, two force plates were used to determine force data. The researchers found that bat speed was generated through the kinetic link in which the proximal segments transfer their momentum to the distal segments. The deceleration of the larger segments increases the velocity of the remaining segments. The right-handed hitter began his swing with clockwise rotation of the arm, shoulder and hips, which loads the link by transferring the weight to the rear foot. However, excessive clockwise rotation can reduce the efficiency, inhibiting the hitter's ability to fully incorporate all muscles into the swing. Linear and rotational components interact at foot down to determine how the kinetic link will be utilized. Proper timing of the rotation of each segment is necessary to achieve bat speed and power through successively higher rotational velocities of the segments. Momentum is sacrificed if a smaller segment reaches maximal velocity before the segment preceding it (Welch et al., 1995).

Phases of the Baseball Swing

Shapiro (1979) studied one subject performing three swings against live pitching. He found that in the first phase, initiated approximately 250 ms before contact, the motion of the bat "change (d) in position from a vertical to a horizontal orientation of the

long axis of the bat” (p.109). Also, the bat head was lowered so that it was slightly below the hands. In the second phase of bat action, 120 ms prior to contact, the bat was rotated quickly into the hitting area, thus generating the speed necessary to hit the ball. He also found that rotation of the hips, trunk and shoulders generated maximal angular acceleration about 59-68 ms before contact followed by a brief deceleration. Another brief acceleration followed when the right arm extended at the elbow (Shapiro, 1979).

Pecci (1986) found that long decision times and consistent time of stride were important aspects in swings that produced hits. He found that when the baseball player is first learning how to swing a bat at a ball on a tee, a consistent stride must be developed because the stride is the foundation, or structural base, of the swing. When the stride is too long, the batter has a hard time adjusting to a pitcher who can effectively change the speed of his pitch. He found that the tee was important to the batter because it taught him to understand ball locations (spatial coordination). Once the pitch was delivered, the batter needed to concentrate on the timing of the pitch (temporal coordination) (Pecci, 1986).

Stance was the independent variable of choice for Marino’s (1989) study of 10 Canadian Olympians. He studied how total movement time, swing time, linear velocity of the bat at impact, and the ground reaction forces of the back foot during swing and impact related to the three different types of stance: open, closed and square. He found that the total swing time was slightly shorter (but not significantly) with the open stance. In addition, the bat time (first movement of the bat to impact) was slightly shorter in the open stance. He found no significant differences in ground reaction forces between stances but a significant difference existed in the anteroposterior maximal force, which depended on type of stance and handedness of the subject (Marino, 1989).

Different Types of Hitting

Because a batter must be able to hit accurately to the same and opposite field, McIntyre and Pfautsch (1982) conducted a study to distinguish players with differing abilities to hit to all fields. Using 20 former or current collegiate, right-handed baseball players, the investigators videotaped the player hitting the ball to both the same and opposite fields at least three times each. When the field is divided in half from home plate to second base, a same field hit lands on the same side that the player is swinging from and an opposite field hit lands on the other side. In a right handed batter, the same field hit will land on the left side of the baseball diamond, and the opposite field hit will land on the right side of the field. No significant interactions were found between the players deemed inefficient and those deemed efficient by their coaches. However, there were significant differences between the two types of hits. Mean swing time (from initial movement to contact) was significantly shorter in the opposite field hit. Subjects also adjusted their stance depending on the type of hit. The researchers found that the distal head of the third metacarpal of the left hand preceded the tip of the bat at ball contact in the opposite field hit, but was behind the bat in the same field hit. Also, in the opposite field hit, the mean angular displacements of the bat, left forearm and left hand were significantly less, and at contact the mean angular velocities of these points were significantly higher. In the same field hit, the left elbow joint became more fully extended. In conclusion, the researchers determined that the batter adjusted the amount of extension at the left elbow joint and angle of left wrist joint so that the bat would reach appropriate orientation at contact (McIntyre & Pfautsch, 1982).

Muscular Action in the Baseball Swing

A study by Shaffer et al. (1993) investigated the muscle activity involved in a baseball swing. Seeking to understand mechanics, optimize swinging performance, and design sport-specific training, conditioning and rehabilitation programs, the researchers

studied 18 professional baseball players hitting six pitched fastballs. The investigators found that swinging was a “coordinated transfer of muscle activity from lower extremity to trunk and finally to upper extremity” (p. 293). The power of the swing was due to the uncoiling of the pelvis, trunk and upper extremities on a stable base, of which the hamstrings and lower gluteus maximus contribute significantly. The triceps and upper extremity muscles appeared to be stabilizers in the positioning of the arm for swinging. Finally, the researchers concluded that abdominal and back conditioning was necessary because these muscles (erector spinae and obliques) were highly active throughout the entire swing (Shaffer, et al., 1993).

Softball Studies

Messier and Owen (1984, 1985, 1986) researched the softball swing. In 1984, they used 3D cinematography to determine the bat dynamics during the swing of eight subjects. They found that there was a rapid increase in bat velocity directed away from the body 200 ms prior to ball contact. The researchers also determined that there was a small increase in rotation of the bat about its long axis. At 120 ms before contact, there was a rapid increase in bat velocity toward the ball. Until 87 ms prior to contact, the bat experienced downward motion. Then, the bat showed an increase in upward velocity until contact. However, the researchers found that the maximum bat velocity was experienced 32 ms before contact, and the bat was actually decreasing in velocity at the time of contact (Messier & Owen 1984).

In a subsequent study, Messier and Owen (1985) used cinematography and a force platform to study ground reaction forces exerted and lower body kinematics during the stride and swing of seven female softball players. Vertical forces exerted by the rear foot experienced a mean decrease of 55 percent, and this resulted in a weight shift toward the front leg. The researchers also found that the rear knee flexed an average of 2.30 radians at contact, indicating proper weight transfer. In addition, the mediolateral forces

indicated movement toward the ball and were maximal just prior to contact. The anteroposterior forces revealed a right foot / left foot balance that rotated the hips and upper body counterclockwise (Messier & Owen, 1985).

In a third study, Messier and Owen (1986) investigated the different directions of a stride on ground reaction forces and bat velocity. Again, seven softball players served as subjects. Right foot anteroposterior forces (when the “batters right foot pushed backward” p. 330) were significantly greater at contact in the closed striding technique when compared to the open striding technique. Also, maximal right foot anteroposterior forces in the closed stride were greater than both the closed and parallel striding technique. However, enhanced force production did not lead to greater bat velocity at contact. The researchers determined that players may not be able to rotate the bat to the desired position in time leading to contact before the bat reaches maximal velocity (Messier & Owen, 1986).

Other Swinging Skills

Other studies have examined sequential motion relating to swinging tasks. Since there are not many studies that investigate the baseball swing, it is helpful to understand how sequential action leads to greater consistency, efficiency and success in similar tasks. Some of the other swinging skills that have been studied include tennis, golf, badminton, and volleyball. Roswal (1974) studied two male subjects performing either the one-handed or the two-handed backhand swing in tennis. The subjects were filmed from the top, side, and front. Each subject was instructed to hit “several cross-court and down-the-line drives into designated areas” (p.77). The two-handed swing produced a higher ball velocity and greater consistency in step direction (more directly towards the ball) and led to the player contacting the ball later. However, the peak angular velocity was reached 1/40 second before contact; whereas in the one-handed swing peak angular velocity was

reached at contact. Roswal (1974) also concluded that the force of the ball was determined by abrupt wrist flexion at ball contact.

A more recent study by Takahashi et al., (1996) investigated racket speed trajectory and the roles of the lower body, trunk, upper arm, forearm and hand. The investigators analyzed successful trials of flat, topspin and topspin lob forehands of six male tennis players. Professional coaches picked the subjects on the basis that they could hit three different types of shots: a flat forehand, a topspin forehand and a topspin lob. Fourteen markers were attached to the players and three cameras filmed their actions when hitting two of each type of forehand. Ball speed was controlled by the researchers.

Takahashi, et al, (1996) found that rotational changes in ball motion led to changes in linear velocity of the center of the racket because of the “almost perpendicular racket-face angle at impact and an increase in pre- and post-impact racket trajectory” (p. 112). The researchers also determined the percentages of speed that could be attributed to each body segment. Linear speed was formed mainly by upper limb motion (90%). Racket head impact velocity in the x- direction was mainly configured of internal rotation of the upper arm (42%), horizontal flexion and abduction of the upper arm (20%), ulnar flexion (10%), trunk and lower limb rotation (10%), and palmar flexion (8%). Racket head impact velocity in the y- direction was mainly configured of internal rotation of the upper arm (44%), horizontal flexion and abduction of the upper arm (20%), palmar flexion (19%) and trunk and lower limb rotation (10%) (Takahashi, et al., 1996).

Zafiroglu (1994) studied five male golfers and one female golfer swinging a golf ball with a putter at distances of two, three and four meters. The purpose of this study was to investigate continuous and segmented putts and determine which allowed greater consistency. Zafiroglu determined that segmenting the movement allowed the subjects to consistently reproduce and control their intended pattern of movement. Segmented patterns also had decreased temporal variability but only minimally affected outcome.

Finally, he concluded that by manipulating the putt type and distance from the target, movement patterns were altered. This was indicated in different acceleration-time profiles and an increase in peak acceleration led to increased errors (Zafiroglu, 1994).

Koslow (1994) investigated 30 male beginning golfers using both the driver and eight-iron. After instruction through videotapes, lecture, demonstration and five days of class, each subject performed ten swings using each club. All swings were analyzed with a Sporttech Swing Analyzer. He focused on the weight shift of beginning golfers. The proper shift occurred when the golfer began the swing (in address position) with his weight centered, shifted his weight to his rear foot at the top of the swing and finally shifted his weight to the front foot at impact. Koslow found two kinds of weight shift problems in beginners. First, he found improper shifts, defined as proper shift at top of swing but less than 50% of the weight being shifted to front foot at impact. Second, he saw reverse shifts, when most weight is at front during top of swing and most in back at impact. With the driver, he found that 57% of subjects did not shift to the front foot and 27% showed a reverse shift at impact. With the eight-iron, he found that 50% of the subjects had improper shift at impact and 23% had reverse shift during the swing. Since a proper weight shift helps to ensure that adequate force is transferred to the ball at impact, Koslow determined that teaching golfers proper weight shift is important at the beginning levels (Koslow, 1994).

Finally, Fujimoto-Kanatani (1996) investigated the three dimensional kinematics of 13 professional golfers. Distance, intermediate, and accuracy shots were all studied. Subjects used a 1-wood for the distance shots, a 3-iron for the intermediate shots and an 8-iron for the accuracy shots. Each subject performed three shots of each type. Two cameras were used to film the action, and then the videotapes were analyzed using the Peak Performance 3D Measurement System.

Fujimoto-Kanatani (1996) found that all the shots showed similar temporal characteristics. However, subjects actually rotated their lower body for a longer time when they were using longer clubs. This body rotation was the primary driving force of the club, and it was necessary to have the correct body movement, in which maximal rotation is reached in the hip first, followed by the shoulders and the golf club, for a properly executed and effective swing. Finally, this study showed that a kinematic link was present; the maximal angular velocity was shown to be transferred from the knee to the hip to the shoulder. Also, this velocity was transferred from the left to right wrist to the clubhead (Fujimoto-Kanatani, 1996).

Development of Swinging Skills

Jones-Morton (1991) discussed the five essentials to swinging. First, the grip and the elbow should be checked. A person's dominant hand should be on the top when gripping the swinging implement. Both elbows should be away from the body and the rear elbow should be raised, almost in line with the shoulder. Second, the player should keep his/her eyes fixed on the ball. Third, stride and weight shift are important. When striking an object a person should take a small, forward-directed step with his/her foot barely clearing the ground. This will help with striking consistency, timing and power of the swing. The fourth key to the swing is body rotation and the positioning of the straightened front leg. During a swing, a person's hips should move "upward in the direction of the weight shift" (p.29), and the front leg of the player should attain a straightened position at ball contact. Finally, the wrist action is very important to the swing. The wrists should start cocked and stay that way until the end of the swing where the wrists should be rolled, thus both hands stay on the striking implement (Jones-Morton, 1991).

Knowing the influence of age on a striking skill is also beneficial. Loovis and Butterfield (1995) studied 380 boys and 337 girls between the ages of 4 and 14 years to

determine how age, sex, balance and sport participation aid in development of a striking task. At each grade, boys outnumbered girls in their rate of mature striking patterns. A mature striking pattern was assessed using multiple tests, and the investigators were primarily looking for “horizontal swinging action of the arms and forward step of the lead foot” (Loovis & Butterfield, 1995, p. 596). By second grade, mature patterns were seen in 98% of the boys, but only in 45% of the girls. By fifth grade, the numbers of girls and boys with mature striking patterns were about equal (at 95%), but the girls showed a decline after fifth grade while the boys stayed consistent (near 100% of boys showed mature patterns). However, the researchers did find that the girls involved in softball maintained the mature pattern reached in fifth grade (Loovis & Butterfield, 1995).

Southard (1984) conducted a study that investigated how the efficiency of a striking pattern changes with time. Using 10 right-handed volunteers with inefficient striking patterns, defined as “constraint of arm, forearm and hand to exhibit similar angular velocities throughout” (p.349), he determined whether or not speed, accuracy, or both contributed more to efficiency. He found that the subjects initially constrained the limb segments to act as one during the striking motion but with practice, this motion pattern changes as relative segmental position changes and varies. The subjects eventually move to a more efficient pattern in which the distal segments lag behind adjoining proximal segments. The wrist is the first segment to vary, followed by the forearm and, eventually, the arm itself (at the shoulder). When accuracy is the goal, the arm and forearm act as one with the wrist free to vary. However, when speed is the goal, the constrained limb swings faster to achieve greater angular velocity. In the accuracy and speed condition, the angular speed was reduced for control of the action. He concluded that sacrificing velocity for accuracy is unwise because it impedes the development of an efficient striking pattern, and the greater accuracy may not be achieved with the slower pattern (Southard, 1984).

Summary

From head to toe, each segment of the body has a role in a successful baseball swing. The head is important for sight and judging distance of the ball (Bubalo, 1981b; Johnson, 1980; Lau, et al., 1980; Murphy, 1991; White & Prevo, 1991). The hands and wrists are vital for a comfortable grip, flexible swing and increase in speed at the end of the swing (Ellis, 1977; Lau, et al., 1980; Thomas, 1981; Weiskopf, 1979). The hips are responsible for bringing most of the power to the swing when they rotate forcefully (Ellis, 1977; Lau, et al., 1980; White & Prevo, 1991). Finally, the feet form the foundation for the swing, and a rear foot to front foot weight shift contributes to the power of a swing (Bubalo, 1981b; Ellis, 1977; Lau, et al., 1980; Murphy, 1991).

To accomplish an effective baseball swing, rotatory motion is initiated by dramatic hip rotation and finished by quick and powerful wrist flexion (Race, 1961). Conard (1965) also found that wrist angular velocity achieved the highest value in the swing when compared to the angular velocities of the forearm and the pelvis. Hirano (1987) found that unskilled baseball players tend to improperly rotate their hips leading to a lower bat speed at contact. Finally, proper timing is necessary to achieve bat speed and power through successively higher rotational velocities of the segments. Momentum is sacrificed if a smaller segment reaches maximal velocity before the segment preceding it (Welch, et al., 1995).

In conclusion, many aspects of the swing interact to determine whether a player will be successful. By learning the proper motions and relationships between these motions, players can improve their swings. Further studies into the stance, stride and swing of a hitter are necessary to fully understand this action. Since an efficient kinetic link can lead to faster bat speed and a more accurate swing, studying where hitters are less efficient may be necessary so that swinging can be improved before less efficient patterns become habitual.

CHAPTER III – METHODS

Introduction

The purpose of this study was to analyze swinging efficiency in baseball players with differing levels of experience. This chapter explains the methodology for the study. First, the subject pool will be described. Second, the instrument used to test the subjects will be described. Third, the procedures that will be used in the study are detailed. Finally, this chapter discusses the statistical design of the study and the data analysis.

Subjects

For the purposes of this study, four groups of subjects were examined. All subjects were selected based on their age and baseball experience. Subjects were solicited from local leagues and high school teams. All subjects were male. Both right-handed and left-handed subjects were studied. Group 1 consisted of 10, 7-9 year-old baseball players with 1-3 years of experience. Group 2 consisted of 10, 10-12 year-olds with 4-6 years of experience. Group 3 was made up of 10, 13-15 year-old baseballers with 7-9 years of experience. Finally, group 4 included 10 varsity high school players, ages 16-18, with over 10 years of experience. All subjects signed an informed consent form (see Appendix A), and for those subjects under 18 years of age, the parent/guardian signed a parental consent form (see Appendix B).

Instrumentation

The SkillTechnologies 6D Research program was used to analyze all subjects (Skill Technologies ©, Inc., 1995). This program used up to eight motion sensors to capture movement. The sensors were attached to cables which lead to a transmitter and two motion capture units. The transmitter was interfaced with a Tri-Star Pentium™ personal computer. First, the researcher determined how many sensors to use, and which body segment each sensor represented. This became the biomechanical model for the program. Setting up the correct segments allowed the system to scale and position the

model for a precise representation of the body. Then, specific information was entered into the computer to calculate the desired parameters of motion. These parameters included joint angles, special events, and specific calculations necessary for the study. The program was then stored for future use. Once the subject had completed his trial and his motions are stored, the program calculated the desired parameters and stored them for analysis and printing of tables and graphs for each subject and each trial (Skill Technologies ©, Inc., 1995). The specifics for this study are shown in later in this chapter.

Procedures

Prior to testing, a data collection sheet (see Appendix C) was completed for each subject. This sheet included personal measurements as well as player statistics. The personal measurements included age, height, and weight. The statistics recorded were years of baseball experience, hours of baseball practice per week, baseball games played, innings played per game, position played, batting average, and hits (number of each type). All of these statistics were taken from the previous baseball season.

Next, eight sensors were attached to the subject. Sensors 1 and 2 were situated on the right and left hands of the player, at the midpoint between the metacarpophalangeal joint of the middle finger and the point halfway between the styloid processes of the radius and ulna, using double stick tape. Sensors 3 and 4 were within plastic holders on velcro straps attached to the midpoints of the right and left forearms of the player. Sensor 5 was placed in the velcro shoulder harness situated at the third thoracic vertebra. Sensor 6 was placed within the hip strap which places the sensor midway between the greater trochanters of the femurs on the posterior of the player. Sensors 7 and 8 were within plastic holders on velcro straps attached to the midpoint between the medial and lateral malleoli and the patellae of the right and left legs.

Next, the subject was instructed to set the tee at his desired height and take five practice swings. This determined if the cables and sensors were hindering the swing. Any further adjustments were made to ensure a fluid swing, and all cables were secured using velcro straps. After all adjustments are made, the player was instructed to stand with his back toward the transmitter, palms forward and fingers pointed downward, and look straight ahead. This allowed the program to properly align the subject so that his head, torso, and limbs are in the correct position. After being aligned, the player stood in the batter's box that was drawn on the floor of the testing area and the tee was adjusted to the correct height, which was in the middle of the subject's strike zone. The player then took five more practice swings. For safety, a tennis ball was used. After five practice swings, the player was instructed to return to his natural stance and take seven swings that were captured by the computer. Players' data were stored for future analysis.

Data Analysis

After testing was completed, data analysis took place. Swings 1, 2, 3, 5 and 7 were analyzed. To determine swing efficiency, parameters were set to determine the sequential pattern of the subject. These parameters were rotation, rotational speed, time of maximal rotation, and time of maximal rotational speed. These parameters were measured for the segments of the hips, shoulders, arms, wrists, and hands. The values were recorded from the computer on a data collection sheet (see Appendix D). Finally, these numbers were analyzed to determine if the subject's swing followed a sequential pattern. This analysis was made on a scale of one to eight (Appendix E). The scale determined if the subject's rotational time and speed followed a sequential pattern starting with the hips and continuing to the shoulders, arms, wrists, and hands. If a sequential pattern was followed, a perfect score of 8 was achieved.

Statistical Analysis

Descriptive statistics (means, standard deviations) were used to characterize the subjects of each group. Height, weight, and baseball statistics were described. In addition, means and standard deviations for rotation, rotational speed, time of maximal rotation, and time of maximal rotational speed were calculated for each group for the hip, shoulder, arm, wrist, and hand. Then, four Kruskal-Wallis one-way analysis of variance (ANOVA) tests were performed to determine if efficiency, hip rotational speed, shoulder rotational speed, and hand speed were significantly different among groups. This non-parametric test was used because the homogeneity of variance and normality assumptions necessary to perform the one-way ANOVA were violated.

CHAPTER IV – RESULTS

Introduction

This chapter will discuss the results yielded from this study. First, it will describe the process for transforming each subject's results into comparable data. Second, results from statistical testing will be explained. This will include descriptions of the subjects and mean scores on all parameters.

Scoring of Data

Before the statistical tests were performed, a few adjustments were made to the data in Appendix C. Each subject's weight was converted from pounds to kilograms, and the subject's height was converted from inches to meters. Secondly, mean values for all parameters in Appendix D were compiled from the five trials (1, 2, 3, 5 and 7) per subject. This information was used to compare the groups on the characteristics from Appendices D and E.

Level of Significance

An α level of 0.05 was chosen for the Kruskal-Wallis one-way ANOVA by ranks to control for type I error. However, for the post-hoc test, α was set at 0.008 because the study had four groups (k) which means that six comparisons are possible ($((k(k-1)/2))$) so α must be divided by 6 (Thomas & Nelson, 1996). In addition, each ANOVA had a p value of 0.001.

Analysis of Data

Descriptions of the subjects and their baseball statistics are organized in tables I and II. In table III and IV average scores are shown for rotational speeds, hand speeds and timing parameters. In addition, completed data collection sheets are included as Appendices F, and G. Appendix H shows a sample graph printout for the same 13 year-old, left-handed subject. As depicted, the hip rotation speed and shoulder rotation speeds maximized at the same times. However, the graph also shows that the shoulder rotation speed was approximately 269 degrees / second higher.

Table I

Characteristics of Subjects

Category		Group Number				
		1	2	3	4	T
Age (years)	<u>M</u>	8.3	11.0	14.0	17.0	12.58
	<u>s</u>	0.82	0.82	0.82	0.82	3.39
Height (m)	<u>M</u>	1.46	1.63	1.75	1.91	1.69
	<u>s</u>	0.76	0.61	1.05	0.79	1.69
Weight (kg)	<u>M</u>	29.12	36.20	46.45	68.72	45.12
	<u>s</u>	6.46	4.29	13.39	9.86	17.52
Experience (y)	<u>M</u>	2.3	5.1	7.8	12.6	6.95
	<u>s</u>	0.67	0.88	0.79	1.43	3.96

Note. T= total for all subjects.

Table II

Game Statistics of Subjects

Category		Group Number				
		1	2	3	4	T
GP	<u>M</u>	16.3	26.2	25.4	66.1	33.5
	<u>s</u>	3.89	2.53	2.37	5.57	19.81
AvIP	<u>M</u>	5.15	5.40	6.50	6.55	5.98
	<u>s</u>	0.50	0.66	0.53	1.26	0.95
BA	<u>M</u>	0.580	0.508	0.314	0.306	0.427
	<u>s</u>	0.109	0.097	0.040	0.050	0.143
HP-IS	<u>M</u>	4.8	7.2	9.0	26.5	11.88
	<u>s</u>	1.87	1.99	2.00	4.55	9.10
HP-OS	<u>M</u>	1.9	1.6	3.75	19.3	6.64
	<u>s</u>	1.10	1.05	1.27	4.52	7.82
Basehits	<u>M</u>	10.0	20.8	19.3	27.1	19.3
	<u>s</u>	1.05	4.04	5.01	6.87	7.69
Doubles	<u>M</u>	4.4	3.1	5.1	8.4	5.25
	<u>s</u>	1.50	2.51	2.28	5.13	3.63
Triples	<u>M</u>	0.8	0.3	1.1	0.8	0.75
	<u>s</u>	1.03	0.48	1.45	1.61	1.21
Homeruns	<u>M</u>	0.2	1.1	0.9	2.3	1.13
	<u>s</u>	0.42	1.29	0.88	2.16	1.51

Note. T = total for all subjects; GP = games played last season;

AvIP = average number of innings played; BA = batting average;

HP-IS = hours practiced (per week) in-season; HP-OS = hours

practiced (per week) off-season. BA is always carried to three digits.

Table III

Mean Rotational and Hand Speeds

Category		Group Number				
		1	2	3	4	T
MHRS	<u>M</u>	303.88	486.05	519.00	549.98	464.73
	<u>s</u>	117.92	90.78	64.98	64.70	128.14
MSRS	<u>M</u>	378.32	550.74	665.23	733.34	581.91
	<u>s</u>	143.84	82.59	86.31	81.59	167.75
MWCS	<u>M</u>	-464.31	-652.71	-540.62	-964.39	-655.51
	<u>s</u>	82.22	126.88	156.53	93.46	223.98
MHS	<u>M</u>	293.36	411.51	548.11	687.34	485.08
	<u>s</u>	76.65	67.27	133.01	94.14	175.64
HSC	<u>M</u>	208.98	338.22	381.10	508.81	359.28
	<u>s</u>	76.00	52.06	62.21	85.01	127.60

Note. Values are in degrees per second. T = total for all subjects; MHRS = maximal hip rotation speed; MSRS = maximal shoulder rotation speed; MWCS = maximal wrist cock speed; MHS = maximal hand speed; HSC = hand speed at contact. Negative MWCS values indicate the wrist is moving in the direction of uncocking (ulnar deviation). Absolute values were used for left-handed subjects.

Table IV

Mean Swing Timing in Relation to Contact

Category		Group Number				
		1	2	3	4	T
DTMHRS	<u>M</u>	-0.13	-0.13	-0.12	-0.19	-0.14
	<u>s</u>	0.06	0.02	0.02	0.04	0.04
DTMSRS	<u>M</u>	-0.14	-0.14	-0.12	-0.17	-0.14
	<u>s</u>	0.04	0.03	0.02	0.04	0.03
DTMWCS	<u>M</u>	0.08	-0.04	-0.04	-0.11	-0.03
	<u>s</u>	0.18	0.02	0.04	0.05	0.11
DTMHS	<u>M</u>	-0.06	-0.07	-0.10	-0.10	-0.08
	<u>s</u>	0.10	0.07	0.08	0.04	0.07

Note. T = total for all subjects; DTMHRS = difference between time of maximal hip rotation speed and contact; DTMSRS = difference between time of maximal shoulder rotation speed and contact; DTMWCS = difference between time of maximal wrist cock speed and contact; DTMHS = difference between time of maximal hand speed and contact; HSC = hand speed at contact. All values are in seconds. Negative values indicate occurrence before contact.

The Kruskal-Wallis one-way ANOVA by ranks tests showed significant differences ($p < 0.001$) between groups for the parameters of maximal hip rotation speed (MHRS), maximal shoulder rotation speed (MSRS) and maximal hand speed (MHS) ($\alpha = 0.05$). Using the post-hoc test for the Kruskal-Wallis test (similar to the Scheffé), all possible pairwise comparisons were made. Tables V, VI, and VII show where statistically significant differences were found between groups.

Table V

Post-hoc tests for MHRS

Category	Group Number			
	1	2	3	4
Group 1	X	*	*	*
Group 2		X		
Group 3			X	
Group 4				X

Note: * indicates the values were significantly (statistically) lower.
 $p < 0.001$.

Table VI

Post-hoc tests for MSRS

Category	Group Number			
	1	2	3	4
Group 1	X		*	*
Group 2		X		*
Group 3			X	
Group 4				X

Note: * indicates the values were significantly (statistically) lower.
 $p < 0.001$.

Table VII

Post-hoc tests for MHS

Category	Group Number			
	1	2	3	4
Group 1	X		*	*
Group 2		X		*
Group 3			X	
Group 4				X

Note: * indicates the values were significantly (statistically) lower.
 $p < 0.001$.

The main focus of this study was how efficiency differed among groups. The post-hoc pairwise comparison ($\alpha = 0.013$) found that group 4 showed a significantly higher efficiency rating ($\bar{M} = 5.60$ points; $\underline{s} = .61$) than groups 1 ($\bar{M} = 4.00$; $\underline{s} = .58$), 2 ($\bar{M} = 4.20$; $\underline{s} = .71$) and 3 ($\bar{M} = 4.05$; $\underline{s} = .69$). The average efficiency rating for the entire group was 4.46 ($\underline{s} = .92$).

CHAPTER V: DISCUSSION , CONCLUSIONS, RECOMMENDATIONS AND

SUMMARY

Introduction

In this final chapter the results will be discussed. First, a discussion section will relate the data to the hypotheses and compare results to previous studies . Second, conclusions are drawn from the data. Finally, the weaknesses of the study are discussed and recommendations for future studies are made.

Discussion of Findings

Efficiency, defined earlier as the segmental action produced by the batter to “accelerate the end point or sweet spot of the implement so that it is traveling at optimum or maximum speed at the time of impact with the object” (Kriegbaum, 1996, p. 75), was the main focus of this study. Efficiency was determined by a rating scale (Appendix E) consisting of eight questions related to the subject’s baseball swing. The end point is the bat-ball contact; however, for the purposes of this study, the end point was the hand. This is due to the fact that the fragile sensors could not be attached to the bat. Therefore, the questions on the scale related to the timing and magnitude of the rotational speeds of the hips, shoulders, and wrist, and the speed of the top hand at contact. Results of the study show that the subjects in group 4 scored a significantly higher efficiency ($p < 0.001$) rating (5.60 of 8) compared to the other three groups. In addition, the subjects in group 2 showed better efficiency (not statistically significant) scores than those in group 3 (4.20 vs. 4.05). One reason this may be the case is that the younger subjects did not need to adjust much to use of a tee, whereas the older subjects were unaccustomed to the tee.

When the rating scale was examined in depth, other patterns became apparent. All of the subjects except one, whose numbers were equal, scored one point for question one, meaning they all had greater maximal shoulder than hip rotational speed, the first

requirement of an efficient swing. Since an efficient pattern is evidenced by a transfer of momentum from proximal to distal segments (Southard, 1984), investigating the timing of maximal hip and shoulder rotational speed is important. Question 5 accomplished this. The hips are the more proximal segment so the time of maximal hip rotational speed should precede maximal shoulder rotational speed. This was the case in 10 of 40 subjects (5 from group 4). In addition, 26 subjects reached maximal rotational speed in the hip and the shoulder at the same time. This shows that the swing pattern was more simultaneous than sequential at the start of the swing.

Question 2 asked if the wrist cock speed was greater than the shoulder rotational speed, continuing down the sequential link of the baseball swing. Out of 40 subjects, 24 scored one point, including all of group 4, six of group 1, and seven of group 2. However, only one subject in group 3 met this requirement, which might show that as a baseball player starts playing against pitching, as opposed to a pitching machine, he may need to relearn the wrist pattern in the swing. When the timing of these parameters was studied (question 6), 36 of 40 subjects were found to reach maximal shoulder rotational speed before wrist cock speed. Two subjects reached maximal levels of both parameters simultaneously. This shows that the action of the swing was becoming more sequential as proximal segments were reached, even if the transfer of momentum does not maximize the wrist cock speed fully.

Question 3 determined if the maximal hand speed was greater than the maximal wrist cock speed. Only seven subjects, two of group 4, and five of group 3, scored points for this question. A baseball player must be able to transfer the speed from the uncocking of his wrists onto his hands. This is the speed that is necessary to make the bat speed maximal (Welch, et al., 1995). Therefore, this is an aspect of the swing that needs to be improved for the player to excel at more advanced levels. In addition to their problem transferring momentum from wrist speed to hand speed, the subjects in this study,

especially in groups 1, 2, and 3, must increase their wrist speed before their hand speed is maximal (question 7). Only 10 subjects (6 from group 4), reached maximal wrist cock speed prior to maximal hand speed, and this must be reversed if the hand speed is to be transferred to the bat before contact.

Question 4 addressed the area where the subjects showed the most need for improvement. Not one subject showed maximal hand speed at contact. However, as asked in question eight, all but four of the subjects exhibited maximal hand speed prior to contact. This problem can probably be alleviated if the subjects learn to transfer the momentum from the wrist uncocking onto the hands, thus increasing the hand speed and maximizing it at contact or just prior to contact.

In addition, this study examined the differences between groups for the parameters of maximal hip rotational speed (MHRS), maximal shoulder rotational speed (MSRS), and maximal hand speed (MHS). Hirano (1987) found that unskilled players show an earlier and lower mean maximal angular velocity in the hip leading to a slower bat. The subjects in this study exhibited the latter finding. Subjects in group 1 had a significantly ($p < 0.001$) lower maximal hip rotational speed when compared to the other three groups. The rotational velocity of the hip transfers to the other segments of the body during the swing. Therefore, the lower magnitude of the MHRS will lead to lower rotational speeds in the other segments and, thus, a lesser bat speed. This was seen in the values of MSRS. Group 1 had significantly ($p < 0.001$) lower MSRS than groups 3 and 4, but not group 2. However, group 2 values were significantly ($p < 0.001$) lower than group 4. This pattern was also seen in the MHS values. Whereas the problem with group 1 began with the hips, it seems that with experience the players learn to rotate the hips, but the shoulders do not always follow.

Welch et al., (1995) found that the transfer of momentum is lost if the smaller segment reaches maximal velocity before the preceding segment. However, in this study,

many of the subjects did not follow this advice. Only 10 of 40 subjects maximized transfer of momentum from the hips to the shoulders by reaching maximal values in the hips first. In 26 of 40 subjects, the hips and shoulders maximized rotational velocity at the same time therefore not allowing the batter to achieve a full transfer of speed. Thirty-six of 40 subjects were able to reach MSRS prior to MWCS, showing that momentum transfer was maximized from the shoulders to the wrists. In the final stage of batting (in this study), the transfer of momentum from the wrists to the hands, only ten subjects were able to reach MWCS prior to MHS. This was the area that the subjects in this study needed to improve most. However, 6 of the 10 subjects were in group 4, showing that as more experience is gained, this transfer of rotational speed from the wrists to the hands was more common.

As seen previously, timing is important to a swing. Welch et al., (1995) found that the hips and shoulders reached their maximal rotational velocity approximately 0.075 s, and 0.065 s prior to contact, respectively. They also found that bat lag, their indication of hand speed, reached maximal rotational velocity at 0.02 s prior to contact. The subjects in this study reached maximal values earlier than the subjects in the Welch et al. (1995) study. MHRS occurred a mean 0.014 ($s = 0.04$) s prior to contact. MSRS was reached at approximately the same time (as MHRS), on the average. MHS, an indication of bat speed in this study, was attained at a mean of 0.08 s prior to contact. Since the subjects in the Welch et al., (1995) study were at a higher level of play, this information shows that as a player gains experience and playing time, he learns to conserve his momentum so that more rotational speed can be transferred to the bat, and thus the ball.

Conclusions

The results of this study show that as baseball players gain experience both in practice and game situations, they develop a more efficient swinging pattern. They begin

to use their hips to gain momentum and power. They can now transfer momentum onto the smaller segments of the body that will give them more precision in their swing. By transferring rotational velocity from the hips to the shoulders, wrists, and hands, the player can achieve maximal bat speed. Increased bat speed is a necessity if the player wants to continue on to higher levels. Though this study could not pinpoint exactly when this transfer occurs, it did show that more than 10 years of experience significantly increases efficiency rating. This study also found that with experience (and possibly growth), the subjects could rotate their hips faster, which leads to faster shoulder rotation and faster hands. The subjects in this study still need to enhance timing and transferring momentum to their hands in order to improve bat speed and efficiency.

Weaknesses

An obvious weakness occurred in this study in subject recruitment. Because of the timing of the study and the unwillingness of professional teams to participate, it was not possible to find subjects above the high school baseball level.

Second, metal objects interfered with accurate data collection, so all of the subjects were required to use a wooden bat. Many players at the youth league and high school level are not accustomed to wooden bats, and this may have caused some problems. In addition, wooden bats are not readily available in the lighter weights; therefore, every subject in this study used the same bat. This bat may have been too heavy for the younger subjects, although nobody complained.

Third, because the players had to use a tee and a tennis ball, their swing may not have been as efficient as it would be with live pitching. However, use of the tee and tennis ball was the only way to ensure the safety of the subjects, researchers and other people in the vicinity.

Finally, pilot testing would have helped to further determine whether or not the number of swings and position of the subject was accurate. In addition, pilot testing

would help to ensure reliability of the system and program, since calibration was not available.

Recommendations

Baseball players can benefit from this study by learning the aspects of an efficient swing. They can also use the information to learn what causes an inefficient swing. Then, the coach can use this information to help the player improve on the aspects of his swing that cause the inefficiencies. If coaches can determine the problems in an early stage, they can help players improve before the swing pattern becomes instinctive.

Future studies into the efficiency of a baseball swing may benefit from a more advanced level of subjects. Also, testing female subjects could also further the knowledge of the baseball swing. Using a portable apparatus that allows live pitching or a pitching machine may lead to the acquisition of more valid data.

Baseball players could benefit further if future studies investigate the relationship between efficiency and different types of stance and stride. Finally, a study that examines speed of the swing versus its accuracy could be useful in determining whether or not speed is the ultimate goal when swinging a bat.

Summary

The purpose of this chapter was to discuss the results, draw conclusions, and make recommendations from the data. The results showed that all subjects could transfer their momentum from the hips to the shoulders; however, the timing of this transfer was not always correct. In fact, 26 of the subjects started their swing with a simultaneous pattern, their shoulder rotation speed was higher, but it maximized at the same time as the hip rotation speed. The next step in the pattern was to transfer the momentum from the shoulders to the wrists. Results showed that group 3 (13-15 y, 7-9 y experience) scored lowest on this transfer. This could mean that when players start batting against live pitching they may need to adjust their swing pattern. In this study, the area needing the

most improvement is hand speed. Many of the problems with efficiency stem from the players' inability to maximize their hand speed.

Other conclusions were drawn based on differences between groups. First, the results showed that the less experienced a player is, the lower in the kinetic chain the problem occurs. As a player gains more experience, he is more able to transfer his momentum all the way to the hands and, thus, the bat.

Based on these results, a more efficient swing pattern comes with experience in the game. Players learn to use larger body segments to gain momentum so that the bat hits the ball precisely. Players must learn to enhance the timing of this transfer of momentum if they wish to compete at the higher levels.

The weaknesses of this study included lack of higher level subjects. In addition, use of a batting tee, wooden bat and tennis ball, although necessary, may have interfered with the subject's natural swings. Finally, lack of pilot testing led to protocol that was not thoroughly explored.

The last item included in this chapter was recommendations for future studies. It is suggested that future studies use larger subject pools, more experienced subjects, and female subjects. In addition, it would further knowledge of the baseball swing if topics such as speed v. accuracy and different stances were studied.

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Appendix A
Agreement to Participate in Research
San Jose State University

Investigator: Jill Kronick

Research Topic: Sequential Swing Pattern in the Developing Baseball Player.

You are invited to participate in a research study I am conducting for my Master's Thesis at San Jose State University. I will be analyzing the differences between beginning and more experienced baseball players in regard to the baseball swing. The results of this study will help to further understanding of the batting process. This form assures that you, the subject, knows about my research and consent to participate in this study. Please read the following and if you agree with the terms, sign this form on the bottom.

I understand that:

1. I will be asked to attach sensors to my body with double stick tape or on a velcro strap and perform a series of baseball swings to determine my batting style.
2. When participating in this study, I will not be subjected to any unusual risks, other than those minor risks that can occur when batting on a tee.
3. I will benefit by learning more about my baseball swing.
4. If the results of this study are published all subjects and their data will remain completely anonymous.
5. No formal compensation will be made to me or other participants.
6. Any questions I have can be answered by calling the investigator, Jill Kronick at (408) 723-0107, or my thesis advisor, Dr. Greg Payne at (408) 924-3028.
7. Any complaints I have can be brought to the graduate advisor, Dr. David Furst at (408) 924-3039. If I have any questions or complaints regarding research subject's right, or any research-related injuries I can contact Dr. Nabil Ibrahim, Ph. D. (Interim Associate Vice President for Graduate Studies & Research) at 924-2480.
8. My consent is being given voluntarily, without coercion. I may refuse to participate in this study or in any part of this study. My consent may be withdrawn at any time, without prejudice.
9. I have received a copy of this consent form for my files.

HAVING READ THE INFORMATION PROVIDED ABOVE, I HAVE MADE A DECISION WHETHER OR NOT I WILL PARTICIPATE. MY SIGNATURE INDICATES THAT I AM WILLING TO PARTICIPATE.

_____
 Date

_____
 Signature

_____
 Print Name Here

FOR SUBJECTS UNDER THE AGE OF 18, PLEASE HAVE PARENT OR GUARDIAN READ AND SIGN THE FOLLOWING FORM.

Appendix B
Agreement to Participate in Research
San Jose State University

Investigator: Jill Kronick

Research Topic: Sequential Swing Pattern in the Developing Baseball Player.

Your child is being invited to participate in a research study I am conducting for my Master's Thesis at San Jose State University. I will be analyzing the differences between beginning and more experienced baseball players in regard to the baseball swing. The results of this study will help to further the understanding of batting. This form assures that you, the parent, knows what is going on and consent to have your child participate in this study. Please read the following and, if you agree, sign this form on the bottom.

I understand that:

1. My child will be asked to attach sensors to his body and perform a series of baseball swings to determine his batting style.
2. When participating in this study, my child will not be subjected to any unusual risks, other than those minor risks that can occur when batting with a tee.
3. My child will benefit by learning more about his baseball swing.
4. If the results of this study are published, my son will not be identified because all results will remain completely anonymous.
5. My son will not be compensated for his participation
6. Any questions I have can be answered by calling the investigator, Jill Kronick at (408) 723-0107, or my thesis advisor, Dr. Greg Payne at (408) 924-3028.
7. Any complaints I have can be brought to the graduate advisor, Dr. David Furst at (408) 924-3039. If I have any questions or complaints regarding research subject's right, or any research-related injuries I can contact Dr. Nabil Ibrahim, Ph. D. (Interim Associate Vice President for Graduate Studies & Research) at 924-2480.
8. My consent is being given voluntarily, without coercion. My child may refuse to participate in this study or in any part of this study. My consent may be withdrawn at any time, without prejudice.
9. I have received a copy of this consent form for my files.

HAVING READ THE INFORMATION PROVIDED ABOVE, I HAVE MADE A DECISION WHETHER OR NOT MY CHILD MAY PARTICIPATE. MY SIGNATURE INDICATES THAT MY CHILD MAY PARTICIPATE AND IS WILLING TO PARTICIPATE.

_____
 Date

_____
 Parent's / Guardian's Signature

_____
 Child's Name

_____
 Relation to Child

Appendix C

Pre-testing Information

Subject ID _____

Age _____

1. Height (inches) _____

2. Weight (pounds) _____

3. Baseball Experience (years) _____

4. Position played most often _____

5. Time practiced per week (hours):

In-season _____

Off-season _____

6. Number of games played last year _____

7. Average innings played per game _____

8. End of season batting average _____

basehits _____

doubles _____

triples _____

homeruns _____

Appendix D

Testing Information

Subject ID _____

EFFICIENCY CHARACTERISTICS

1. Maximal hip rotation (degrees): _____
2. Maximal hip rotation speed (degrees / second): _____
3. Time of maximal hip rotation: _____
4. Time of maximal hip rotation speed: _____
5. Maximal shoulder rotation (degrees): _____
6. Maximal shoulder rotation speed (degrees / second): _____
7. Time of maximal shoulder rotation: _____
8. Time of maximal shoulder rotation speed: _____
9. Maximal wrist cock (degrees): _____
10. Maximal wrist cock speed (degrees / second): _____
11. Time of maximal wrist cock: _____
12. Time of maximal wrist cock speed: _____
13. Time of maximal hand speed: _____
14. Time of ball contact: _____
15. Hand speed at ball contact: _____

Appendix E

Post-testing Information

Subject ID _____

SWING EFFICIENCY VARIABLES

1. Maximal hip rotation speed less than maximal shoulder rotation speed?
YES NO
2. Maximal shoulder rotation speed less than maximal wrist cock speed?
YES NO
3. Maximal wrist cock speed less than maximal hand speed?
YES NO
4. Hand speed maximal at ball contact?
YES NO
5. Time of maximal hip rotation speed precede time of maximal shoulder rotation speed?
YES NO
6. Time of maximal shoulder rotation speed precede time of maximal wrist cock speed?
YES NO
7. Time of maximal wrist cock speed precede time of maximal hand speed?
YES NO
8. Time of maximal hand speed precede ball contact?
YES NO
9. Looking at all these variables, was the swing efficient? Rate on scale of 1 to 8, 1 being inefficient, 8 being maximal efficiency.

1   2   3   4   5   6   7   8

Appendix F

Testing InformationSubject ID 120011

EFFICIENCY CHARACTERISTICS

1. Maximal hip rotation (degrees): -82.07
2. Maximal hip rotation speed (degrees / second): -418.4
3. Time of maximal hip rotation: .33 s
4. Time of maximal hip rotation speed: .20 s
5. Maximal shoulder rotation (degrees): -90.7
6. Maximal shoulder rotation speed (degrees / second): -687.3
7. Time of maximal shoulder rotation: .37s
8. Time of maximal shoulder rotation speed: .20s
9. Maximal wrist cock (degrees): -8.0
10. Maximal wrist cock speed (degrees / second): -648.6
11. Time of maximal wrist cock: .37s
12. Time of maximal wrist cock speed: .23s
13. Time of maximal hand speed: 451.0 at .20s
14. Time of ball contact: .33s
15. Hand speed at ball contact: 385.3

Appendix G

Post-testing InformationSubject ID 120011

SWING EFFICIENCY VARIABLES

1. Maximal hip rotation speed less than maximal shoulder rotation speed?
YES   NO
2. Maximal shoulder rotation speed less than maximal wrist cock speed?
YES   NO
3. Maximal wrist cock speed less than maximal hand speed?
YES   NO
4. Hand speed maximal at ball contact?
YES   NO
5. Time of maximal hip rotation speed precede time of maximal shoulder rotation speed?
YES   NO   SAME
6. Time of maximal shoulder rotation speed precede time of maximal wrist cock speed?
YES   NO
7. Time of maximal wrist cock speed precede time of maximal hand speed?
YES   NO
8. Time of maximal hand speed precede ball contact?
YES   NO
9. Looking at all these variables, was the swing efficient? Rate on scale of 1 to 8, 1 being inefficient, 8 being maximal efficiency.
1   2   3   3.5   4   5   6   7   8

Appendix H

Sample Graph**Skill Technologies 6D-Research**

Test Name: 120011

Test Date: 7/2/1999

HipRotnSpd —
Shldrotnspd —