AN EXPLORATORY BIOMECHANICAL ANALYSIS OF THE SIDE-TO-SIDE SWING PATTERNS OF THREE SKILLED SWITCH HITTERS

A Thesis

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo, California

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Kinesiology

By

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August 2011

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Committee Membership

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Side Swing Patterns of Three Skilled Switch HittersAUTHOR:Francesca Marie CastellucciDATE SUBMITTED:August 2011COMMITTEE CHAIR:Kellie Green Hall, PhDCOMMITTEE MEMBER:Camille P. O'Bryant, PhDCOMMITTEE MEMBER:Suzanne Phelan, PhD

Abstract

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Francesca Marie Castellucci

The ability to successfully switch hit, or hit a baseball from both sides of the plate, requires a great amount of practice and coordination bilaterally. This study used three-dimensional kinematic and kinetic data to examine the swing patterns of skilled switch hitters in baseball. Three male minor league and division I collegiate switch hitters participated. Subjects stood on force plates and hit baseballs off a tee while their swings were recorded with a three-dimensional optical motion capture system. Each subject performed twenty total swings, ten from the right and ten from the left. The swings were digitally analyzed and the dependent measures were compared side-to-side. The swing was broken down into specific events and temporal phase parameters were obtained. Peak vertical ground reaction force of each foot and stride length of each swing were also obtained. All variables were statistically analyzed using paired t-tests. The subjects displayed surface swing characteristics side-to-side that appeared identical and statistically there were no significant differences in the swing variables side-to-side. However, each subject had slight internal pattern differences side-to-side that are reported and discussed. Switch hitters are an excellent example of skilled practitioners that can provide insight into questions pertaining to dominance and motor control. Further research is needed with more subjects to explore side-to-side similarities and differences in well-established patterns.

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Acknowledgements

I would like to express my great appreciation to Dr. Kellie Green Hall, who was not only my committee chair for this thesis, but was a mentor to me during my tenure at Cal Poly. With Dr. Hall's guidance I have become a better researcher, writer and student. I am very grateful that she always had confidence and high expectations for this project and without her unwavering support this thesis would not have been possible.

I would also like to acknowledge and extend my appreciation to my thesis committee members, Dr. Camille P. O'Bryant and Dr. Suzanne Phelan. I am grateful for their support of this thesis as well as their suggestions throughout the process.

Lastly, I offer a heartfelt gratitude to my family and friends, especially my mother, Barbara Grossetti and my fiancé Roque Garza. Thank you both for supporting me through all my academic endeavors and always believing in me.

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Chapter 1

Introduction

Background of the Study

Striking a baseball thrown by a professional pitcher is one of the most difficult tasks in all of sports. The talented and highly paid hitters of Major League Baseball (MLB) today fail seven out of ten times, where an exceptional batting average is just over .333. In few other sports is it acceptable to fail more often than one succeeds. Moreover, the odds of a male high school baseball player reaching the major leagues are 2 in 1,000 (Leonard, 1996) and even those who make a minor league team only have a nine percent chance of making a MLB roster (Porter, 2010). Part of the great difficulty in hitting a baseball lies in the time it takes for a baseball to travel between the pitcher's hand and home plate, which is between 0.367 seconds to 0.614 seconds, depending on the velocity of the pitch (Milton, Solodkin & Small, 2008). During this short window of time, the batter's nervous system needs to perceive the direction and speed of the thrown ball, plan a response and perform the proper body movements to make it possible to strike the baseball. Because of this limited amount of time it has been suggested that the neural planning processes most likely take place concurrently with the swing itself. Interestingly, it has been suggested that it is highly unlikely professional players see the actual moment of contact between the bat and ball (Yastrzemski, 1972), which further adds to the difficulties of striking a pitched ball.

The average length of a MLB career for position players (non-pitchers) is 5.6 years; however MLB career lengths are not normally distributed. Career lengths in baseball are quite skewed with many players experiencing only one to two years, while an elite few play twenty or more years (Witnauer, Rogers & Saint Onge, 2007). The

longevity of one's career is not certain and professional athletes in all sporting realms consistently seek ways to increase their performance. In particular, baseball players have gotten stronger, baseball bats have been manufactured for optimal hitting performance and in the 1960's the skill of switch hitting evolved. Switch hitters are players who are able to bat both right-handed and left-handed. In a game situation, a switch hitter can decide to bat from one side of home plate or the other, and this decision would be based on the arm the opposing pitcher throws with. Generally if a right-handed batter is facing a left-handed pitcher or left-handed batter is facing a right-handed pitcher the ball travels into the batter which gives an advantage to the batter. Whereas when a right-handed batter faces a right-handed pitcher or left-handed batter faces a left-handed pitcher the ball moves away from the batter, making the situation somewhat more difficult and giving the pitcher more of an advantage.

Carl Yastrzemski (1972), a former professional baseball player and left-handed batter, has explained that when batters face pitchers who work from the same side of the plate the batter hits from there is a point during the pitcher's motion in which there is a "blind spot." Meaning that at a certain point the batter will lose sight of the pitcher's arm or the baseball in the pitcher's hand, which favors the pitcher and increases the reaction time of the hitter. Accordingly, the hitter will have a more difficult time seeing the pitch out of the pitcher's hand and thus have greater difficulty in obtaining relevant information about the type and velocity of the pitch. If the batter can't acquire pitch information in the short window of time they are afforded, then making proper swing decisions are close to impossible. Switch hitters do not encounter the "blind spot" because they are always able to hit from the opposite side of the plate versus pitchers.

Although switch hitting does provide benefits versus a skilled pitcher, the roster spots on MLB teams are not filled with switch hitters. In fact only one to four switch hitters appear on each MLB team. It's difficult enough to learn to hit proficiently from one side, and skilled hitting from the non-dominant side requires that much more practice.

An archival study was conducted with statistics of all Major League Baseball (MLB) players from 1871 to 1992 (Grondin, Guiard, Ivry & Koren, 1999). It was revealed that switch hitters had lower batting averages, slugging averages and home runs per at bat as compared to non-switch hitting players during this time period. Switch hitters also had a higher number of walks and strikeouts. From these statistics one would wonder if switch hitting is actually advantageous and whether or not it would be more beneficial for the hitter to focus on batting from one side of the plate. However, the ability to switch hit affords players the opportunity to be an everyday starter on teams as compared to those players who are "platooned." A platoon player is one who starts or plays only when the opposing pitcher throws with the arm opposite from the side of the plate the hitter bats from. This occurs because some players have very poor batting averages against opposing pitchers pitching from the same side they bat from. For example, a right-handed platoon position player will only play when the opposing starting pitcher is left-handed and vice versa. Switch hitters are not platooned, have a greater opportunity to play and in some cases would not be in the "big leagues" if it wasn't for their switch hitting ability (Yastrzemski, 1972).

The batting statistics of switch hitters show numerical differences from side to side. A generally recognized aspect of switch hitting is that switch hitters have a "power side" and a "control side." This is supported by the different number of home runs (power

number) and batting averages (control number) side to side that switch hitters exhibit. Furthermore a survey of skilled switch hitters found that only 40% of the respondents felt similarities when hitting on both sides of the plate (Matoso & Oakland, 1994). These similarities were only in regards to "reading a pitch, seeing the ball, bat control, and the stance" (Matoso & Oakland, 1994). To investigate this apparent discrepancy, in this study we will be analyzing timing, kinematic and kinetic measures via three-dimensional motion analysis of the swings of skilled switch hitters. Central to the biomechanics of switch hitting is the motor control concept of bilateral transfer.

Bilateral transfer is the motor control phenomenon that is based upon a person's ability to learn a particular motor skill more easily with one limb after having practiced the skill with the contralateral limb (Magill, 2007). The research in support of bilateral transfer of motor skills is well established and vast. Research in the area began in the 1930's (Cook, 1933) and has continued throughout this century (Teixeira, 2006). Bilateral transfer has been shown to occur in simple motor skills such as finger tapping (Parlow & Dewey, 1991) and pursuit rotor (Hicks, Gualtieri & Schroeder, 1983) as well as more complex motor skills such as soccer (Haaland & Hoff, 2003) and throwing (Liu & Wrisberg, 2005). There is also evidence in support of bilateral transfer in tasks with both motor and cognitive components (Parlow & Kinsbourne, 1989).

Bilateral transfer is associated with switch hitting because baseball players normally learn to bat from one side of the plate and it is not until later that they try to switch hit. This is substantiated by the survey conducted by Matoso & Oakland (1994) in which they found the average age respondents began to hit a baseball was 5 years old and the age in which respondents began switch hitting was almost 14 years of age.

Furthermore 80% of the respondents felt that their experience hitting from one side of the plate carried over to the other side. A primary goal of this study is to investigate the patterns of skilled switch hitters from each side of the plate and examine if temporal, kinematic, and/or kinetic differences exist between their swings.

Statement of Purpose

The primary purpose of this study was to compare temporal, kinematic and kinetic patterns in skilled baseball switch hitters while they hit a baseball from the right and left sides of the plate. A detailed biomechanical analysis of the swing characteristics of switch hitters may have implications for skill acquisition, coaching and training.

Significance

Few studies have examined switch hitters, and no studies to our knowledge, have collected temporal or biomechanical data to examine side-to-side patterns of skilled switch hitters in baseball. The mechanical aspects of a hitter's swing take place so quickly that it is difficult to visually determine characteristic differences from side-to-side. A three-dimensional biomechanical approach can lead to a better understanding of the similarities and differences of a hitter's swing from each side of the plate. This could allow coaches and trainers to implement specific practice that focuses on aspects of the swing that are superior on one side, trying to enhance these characteristics on the other side of the plate.

Research Hypotheses

Temporal Parameters.

It was hypothesized that:

- 1. The switch hitters' dominant side would exhibit a significantly quicker phase duration during the swing events of max knee to foot down (stride component 2).
- 2. There would be no other significant temporal phase differences side-to-side.
- The switch hitters' dominant side would have a significantly faster total swing duration.

Kinetic Parameters.

It was hypothesized that:

- 1. There would be a significantly greater peak ground reaction force for the front leg of the dominant side as compared to the front leg of the non-dominant side.
- 2. There would be no significant difference side-to-side for the peak ground reaction force of the back foot.

Kinematic Parameters.

It was hypothesized that:

 Skilled switch hitters will have no significant difference in stride length side-toside.

Definition of Terms

The following terms are defined as used in this study.

<u>Asymmetric Transfer</u>: When bilateral transfer occurs more readily from one side of the body to the other (e.g. more transfer occurs when the dominant side is practiced first) (Magill, 2007).

<u>Bat Quickness</u>: The time it takes to move the bat head from the launch position to contact with the ball, measured in seconds (Lund & Heefner, 2005).

<u>Bilateral Transfer</u>: The ability to learn a particular motor skill more easily with one side of the body after having learned the skill with the opposite side (Magill, 2007).

<u>Handedness</u>: The preference of using one hand over the other for unimanual tasks, also known as hand preference (Heilman, 2008).

<u>Kinetic Link Principle</u>: States that one body segment will transfer forces to the next adjacent body segment when the motion is optimally executed (Szymanski & DeRenne, 2010).

<u>Stride Length:</u> The step taken by the hitter in the direction of the pitcher, which begins as the lead foot leaves the ground and ends when it returns back to the ground (Lund & Heefner, 2005).

<u>Switch Hitting/Switch Hitter</u>: The ability to bat from either side of the plate in baseball (Yastrzemski 1972).

<u>Symmetric Transfer</u>: When the amount of bilateral transfer is similar regardless of what side of the body was used first (Magill, 2007).

Delimitations

This study was delimited to the following parameters.

- 1. Participants were required to have at least three years of switch hitting experience at either the minor league or Division I collegiate level.
- 2. Participants were NCAA Division I or professional baseball players.
- 3. Participants were between the ages of 18-28 years old.
- 4. All participants were male.

Assumptions

This study was based on the following assumptions.

- 1. All subjects were motivated to perform to the best of their ability.
- 2. All subjects were honest about their switch hitting experience.

Limitations

This study was limited by the following factors.

- Hitters swung at a baseball resting on a batting tee, instead of hitting a pitched ball. This was due to our space and safety considerations in the motion analysis laboratory.
- 2. The number of subjects (n = 3) who participated in the study. There was difficulty in recruiting switch hitters who were able to report to the laboratory.
- 3. All subjects were right-hand dominant.
- 4. All subjects were male.
- Additional kinematic data such as angular velocities and displacements were not obtained.

Chapter 2

Review of Literature

Introduction

The ability to successfully switch hit in baseball requires amazing skill and coordination bilaterally. An examination of this skill requires researchers to consider the components of the swing, bilateral transfer and the interconnectedness of the hemispheres via the corpus callosum. The following review of literature examines hitting in baseball, bilateral transfer and the role of the corpus callosum. The first objective of this review is to discuss switch hitting in baseball and present the literature that has examined the biomechanics of striking a baseball. Secondly, the motor learning concept of bilateral transfer, the different motor contexts that have been show to produce bilateral transfer and proposed explanations of this learning phenomenon. Lastly, evidence of information transfer via the corpus callosum will be discussed.

Hitting in Baseball

The baseball swing has been examined empirically using kinematics and kinetics (Escamilla et al., 2009a; Katsumata, 2007; Welch, Banks, Cook & Draovitch, 1995), electromyography (Shaffer, Jobe, Pink & Perry, 1993) and physics (Cross, 2009). Research has revealed many interesting aspects of the swing, but many questions remain. Research findings support the notion that the baseball swing is an example of the kinetic link principle (Escamilla et al., 2009a; Shaffer et al., 1993; Szymanski & DeRenne, 2010; Welch et al., 1995). The kinetic link principle states that larger base segments transfer momentum to smaller adjacent body segments when the action is optimally performed. In

the situation of striking a baseball, the lower extremity is active in the initiation stage of a swing, the momentum is then transferred through the trunk as it rotates and then through the upper extremity and hands then lastly through the bat (Welch et al., 1995).

The batter has an extremely small time window to use flight information of the pitch to organize their swing motion and the most proficient batters have the greatest bat quickness (Lund & Heefner, 2005; Yastrzemski, 1972). Bat quickness is defined as the time it takes to move the bat head from the "launch position" to contact with the ball (Lund & Heefner, 2005). As bat quickness improves, this allows the batter to have a longer time to observe the oncoming pitch and make a swing decision. Once a swing is initiated it cannot be stopped due to the velocity and time constraints of hitting (Yastrzemski, 1972) therefore it is valuable to gain extra time in decision making in order to increase the chances of making the correct decision as whether to swing or not to swing.

Another important aspect of the swing is the coordination between all four limbs and both sides of the body. Many human motor activities involve the coordination of both hands and hitting a baseball is no different. Depending on the side of the plate the batter hits from, each hand and limb have certain roles in completing the task. Of interest is the concept of handedness in relation to throwing and batting preference in the game of baseball. The authors of the statistical study of all Major League Baseball (MLB) players from 1871-1992 (Grondin et al., 1999) defined hand preference as the players' throwing hand and found that 60% of left-handed batters threw with their right hand. Heilman (2008) suggests that there are asymmetries inherent in the game of baseball and these could play a role in the statistic of throwing versus batting preference. Asymmetries in

the game include the advantage left-handed batters have in terms of being closer to first base (a shorter distance to get to the base can increase one's chances of being safe) as well as the fact that most pitchers are right-handed and as previously discussed, batters have greater success when they see a ball coming into them rather than moving away from them. However defensively, certain positions such as shortstop and second base are favorable to play as a right-handed thrower. Additional findings showed that 90% of players with left-handedness (a great preference for using the left hand) bat from the left side, while only 70% of right-handed players bat from the right. Furthermore, related to the asymmetries of the game, Matoso and Oakland (1994) found that 55% of switch hitting respondents preferred hitting with their non-dominant side, 20% preferred their dominant side and 25% had no preference at all.

Since the 1990's, three kinematic hitting studies have been conducted and have served to describe and define the baseball swing (Welch et al., 1995; Escamilla et al., 2009a & 2009b). Welch et al. (1995) investigated the swing mechanics through kinematic and kinetic measures. The purpose of the study was to preliminarily investigate the swing mechanics through the use of three-dimensional motion analysis. Kinematic and kinetic data for seven skilled batters (minor and/or major league experience) was obtained. The subjects were fitted with reflective markers bilaterally on the shoulder, elbow, wrist, hip, thigh, knee, shank, ankle and foot. Markers were also placed on the subject at the cervical and lumbar regions of the spine (one at each level). Additionally, markers were attached to the bat and ball. Subjects took swings from a tee and the tee was adjusted to the subject's preferred position and height. Movement of the reflective markers was captured by six cameras with sampling frequencies of 200 frames per second. The researchers used

global and body/joint reference frames to calculate linear and angular displacements and velocities.

Welch et al. (1995) chose three events of the swing for reference and as "key mechanical transitions." The first event was the instant the front foot left the ground and began to stride (i.e. foot off). The second event was when the front foot re-contacted the ground; this ended the hitter's leg stride and began the closed kinetic link of energy transfer. The last event defined was bat-ball contact. Individual data for each subject was produced by the average of their three "best" swings. Welch et al. (1995) found the average stride length of the subjects to be 85 cm \pm 12 cm (mean \pm standard deviation). Maximum ground reaction force was not reported and instead the research group reported the force applied at each of the mechanical transitions previously discussed. Overall, results from this study provide insight into studying hitting parameters within and between individual batters.

Escamilla et al. (2009a & 2009b) conducted two kinematic analyses on baseball hitting kinematics. One study (Escamilla et al., 2009a) investigated age level and hitting kinematics, while the other study (Escamilla et al., 2009b) investigated the effects of bat grip on hitting kinematics. Although the purpose of these studies is not of fundamental importance to the current study, the kinematic methodology and how the group defined the events and phases of the swing are significant. Also, a strength of the studies was that hitters took "normal" batting practice against a pitching machine and this was captured by video cameras and later analyzed.

The research group positioned two synchronized, genlocked 120-Hz video cameras to view the batter. The cameras were positioned so each camera's optical axis

formed a 45 degree angle to the sagittal plane of the hitter. Each camera was approximately 8-m from the hitter, the cameras were perpendicular to each other and the hitter was as large as possible in the camera's viewing screen. To analyze the data in both studies, the researchers employed a calibration frame to provide real-world units within the captured video. The motion analysis was manually digitized by the researchers and a spatial model was created specifically for batting. The spatial model included the top of the head, joint centers of the ankles, knees, hips, elbows and shoulders, the centers of the mid toes and the proximal and distal ends of the bat. All of the points included in the spatial model were seen in both camera views. The researchers manually digitized four swings per subject.

Unlike Welch et al. (1995), Escamilla et al. (2009a & 2009b) defined the swing by four events and three phases. The first two events, lead foot off ground and lead foot contact with the ground were similar between the studies but Escamilla et al. (2009a & 2009b) defined the third event in the swing as "hands started to move forward." The final event, bat-ball contact was also similar between the studies. Escamilla et al. (2009a & 2009b) also defined three phases within the swing. The phases included stride, transition and bat acceleration. The stride phase is the time duration between lead foot off ground to lead foot contact with the ground. The transition phase is the time duration between lead foot contact with the ground to hands began forward and the bat acceleration phase is defined as the duration between hands began forward and bat-ball contact.

Mechanics of the baseball swing have also been described by Lund and Heefner (2005). They described five phases of the swing; stance, wind-up, pre-swing, swing and follow through. The stance phase is "the manner in which a hitter stands in the batters'

box" (Lund & Heefner, 2005). The authors decided it was important to include this phase because of its possible effects on the other four phases of the swing. The stance phase is central to the batter's timing and improper timing will hinder the rest of the swing. The wind-up phase is synonymous with the phase Escamilla et al. (2009a) described as the stride phase, while the pre-swing phase is equivalent to the transition phase (Escamilla et al., 2009a). The swing phase (Lund & Heefner, 2005) and bat acceleration phase (Escamilla et al., 2009a) are also synonymous. Additionally, Lund and Heefner (2005) defined a batter's follow-through as the action of the bat and body post-contact. However they suggested that "follow-through is largely a matter of personal preference" and does not affect the ability of the batter to strike the ball.

The current research question being investigated parallels a prior study conducted by Hall, Matoso and Marzilli (1996). Hall et al. (1996) examined the phasing or the relative timing of skilled switch hitters swing patterns, side to side. The swing patterns of three skilled switch hitters by using the relative timing of each swing component. The hitters were all semi-professional or professional baseball players ages 21, 22, and 34 years with 12, 14, and 24 years respectively of switch hitting experience. The subjects were fitted with reflectors and a whiffle ball was suspended from the ceiling at a comfortable height for each hitter. Subjects performed 20 swings total; five from the right then five from the left which was repeated after a 1-minute rest between each set. The swing components were divided into six segments consisting of the time from heel off to toe off to maximum knee flexion to toe down to bat-ball contact. The relative timing of each component was determined by dividing the duration of each component by the overall time for the swing (e.g. Terzuolo & Viviani, 1979). The relative times side to side

were then analyzed using dependent t-tests and no significant differences were found for any of the component parts except for the segment from max knee to toe down. During this segment the dominant side was found to be significantly faster, having a shorter relative time duration. Also for all three batters the bat speed was significantly faster on the dominant side compared to the non-dominant side. The patterns side to side were visually identical with characteristics of the swings appearing very consistent. The batters however reported that the swings "felt" different or that they "saw the ball better from one side" or "had more power on my dominant side." The findings support a general pattern of behavior that can be essentially inverted and produced on the other side. However, no kinematic data was available for this study therefore only relative timing data was reported.

In a follow-up laboratory study, Coker (2004) examined the question of whether there is bilateral symmetry in general patterns side to side using a laboratory coincident timing task. Even though all subjects were novices in the striking task, the study revealed some important performance characteristics. Coker (2004) specifically examined the subject's accuracy and perception of performance accuracy (subjects were asked if they perceived a difference in performance between limbs) for each limb in a ballistic striking task. All subjects were right handed individuals with no prior experience on the experimental task. The experimental apparatus consisted of a hinged wooden barrier mounted on a tabletop. A stimulus runway was situated in direct line with the barrier and interfaced with an anticipation timer. The participants' task was to perform a single arm striking motion with a padded implement to displace the wooden barrier in coincidence with the final light from the stimulus runway. Participants were seated parallel to the

runway and the light pattern would approach the subject from the left for the right hand and from the right for the left hand. The three stimulus velocities (3-mph, 6-mph, and 9mph) were randomly presented throughout 60 total trials per hand (counterbalanced, 20 trials per velocity) and the initial limb used was randomized among participants. Knowledge of results was given about the direction and magnitude of the timing error following each trial.

Dependent measures for this experiment were: initiation time, movement time, response accuracy, response bias, and response consistency. For each dependent measure a 2 x 3 (limb x speed) analysis of variance (ANOVA) with repeated measures by block was performed. Results showed response initiation was significantly faster for the 9-mph stimulus speed followed by the slower speeds, respectively. Movement time results were also significant, with the fastest stimulus producing the fastest participant movement times. Coker (2004) found that 67% of participants perceived to perform better with their preferred limb, 13% indicated their non-preferred limb and 20% did not perceive a difference between limbs. Response accuracy, defined as the absolute error in coincident timing, was significantly better for a subject's preferred limb than the non-preferred limb. However, response bias and response consistency was not significantly different between limbs. With the exception of response accuracy, results showed that the participants' temporal proficiency and speed of limb movement for the ballistic coincident timing task was analogous for the preferred and non-preferred hand. Eighty percent of subjects perceived a performance asymmetry between limbs; however this was not substantiated by the actual performance findings.

Bilateral Transfer

Bilateral transfer is a well-documented phenomenon that demonstrates a person's ability to learn a particular motor skill more easily with one limb after they have already learned it with the contralateral limb (Magill, 2007). Research investigating bilateral transfer was popular in the early to mid part of the 20th century and much of this research used the terms "cross-education or "cross-transfer." T.W. Cook established a solid foundation of evidence for bilateral transfer during this time, publishing five articles that strongly supported bilateral transfer for motor skills (Cook, 1933; & Cook, 1936). In the literature today, bilateral transfer is the predominant term used but more specific terms such as "intermanual transfer," "interlimb transfer," "bimanual skill transfer," "cross-modal transfer," and "interhemispheric transfer" also appear throughout the literature. Current researchers have focused on specific motor learning contexts and the direction in which bilateral transfer occurs.

There are three main models that exist in the literature which attempt to explain bilateral transfer effects. All three models are predicated on the assumption that bilateral transfer effects show greater asymmetric directional transfer. The callosal access model assumes that neural representations, or motor programs, are formed in the dominant hemisphere irrespective of the limb used during motor skill acquisition. This would mean that for right-handed individuals the left hemisphere would store the programs and subsequently the right side of the body (dominant side) would have direct access to the program (Taylor & Heilman, 1980). The non-dominant limb would only have "indirect" access to the program, which would be through information transfer across the corpus callosum. This model suggests that bilateral transfer is expected in the context of motor

skill acquisition and should be greater when the non-dominant limb practices the motor skill and transfers to the dominant limb.

The other two models researchers use to explain bilateral transfer propose that practicing and learning the skill with the dominant limb and transferring to the nondominant limb will have greater transfer effects. The premise of the cross activation model is based upon the hypothesis that motor skill learning generates two motor programs, one stored in each hemisphere. The "superior" program is stored in the dominant motor cortex, while the non-dominant motor area will get a copy of the program (Schulze et al., 2002). The copy of the inferior program is only updated when the dominant program is, and in order for this to occur the dominant limb must be the practiced limb. Practicing with the non-dominant limb will not improve the motor program and therefore skill transfer is not expected in the dominant limb. The proficiency model contends that the more dominant limb is able to "learn more elements" of the motor skill during training and therefore is better adept at skill transfer to the nondominant limb than the reverse situation.

Haaland and Hoff (2003) investigated the effects of bilateral transfer on motor performance in competitive soccer players. Specifically the study examined the effects of non-dominant leg training on soccer specific tasks and on general foot-tapping tasks. The researchers hypothesized that training the non-dominant leg would enhance soccer specific and general skills in both the non-dominant and dominant legs.

Participants were male competitive soccer players ranging in age from 15-21 years old and based on self-reports were all right-handed and right-footed. The researchers matched participants by age group and randomly assigned the participants

into the experimental or control group. The experiment was a pre-test post-test design with an eight-week intervention consisting of left, non-preferred leg training in soccer specific drills. The pre- and post-tests consisted of three soccer specific performance tasks and two standardized foot-tapping tasks. The dependent measures of the study were the performance scores for each leg on each of the five tests. Both groups followed their normal soccer training schedules but the experimental group increased their volume of training with the left, non-preferred leg. This training consisted of general and "technical" soccer related skill practice and was not directly related to the tests used in the experiment. Overall the groups did not statistically differ in total training time over the eight-week training period but the experimental group self-reported 705-min of training using the left leg, whereas the control group reported 73-min.

The researchers found significant performance improvements in the experimental groups' dominant and non-dominant legs on all five tests. The control group did not significantly improve with either leg on any of the measures. It is suggested that the level of skill on the non-dominant side might limit the level of skill in the dominant side, which the authors propose might be the basis for the improvement on the right side after left side practice. Haaland and Hoff (2003) suggest that the findings from this study can be interpreted according to both predominant motor control theories. They suggest that perhaps there is support from a motor program perspective. This is based on the foundation that training improves one's abstract memory representation for a specific motor program and this program is available to the right and left sides. From a dynamical systems approach the researchers suggest that perception-action coupling is key. The

and the environment, hence enhancing performance. In general, the findings from this study suggest that non-dominant limb training can increase skill on both sides. This shows preliminary support for the callosal access model however because the nondominant limb was the only practiced limb the results are not conclusive.

Teixeira (2000) investigated the bilateral transfer of perceptual and motor components in movement control through two experiments. Teixeira classified the first experiment as having a strong perceptual and weak motor component while the second experiment had the opposite organization. The task for the first experiment was a basic anticipation timing apparatus which involved pressing a control knob coincidentally with the arrival of the last light on the runway. The lighting of LEDs from the end farthest from the participant to the end closest to the participant would produce the perception of a luminous motion stimulus. The finger press is a simple motion but is a perceptually challenging task when in a narrow temporal window. The experiment consisted of 60 practice trials and 5 transfer trials. Participants were randomly assigned to practice with either their preferred or non-preferred hand. After the 60 acquisition trials participants were engaged in a cognitive task for 10-min. This was followed by a transfer test in which the participants performed the same task but with the hand opposite to that of practice.

Participants showed an improvement in performance throughout the acquisition trials and the transfer tests showed statistical significance for both groups. There was no difference in the level of transfer between groups, indicating symmetric transfer of learning occurred. Based on the symmetric bilateral transfer findings, Teixeira (2000) suggests that temporal motor functions are relatively independent of the effector system

involved. A high level of performance on the first transfer trials was noted, indicating that the structure of control of the contralateral hand was very efficient.

The second experiment tested the transfer of learning in a task with weak perceptual and strong effector components. The task chosen here involved controlling a cursor through a linear runway to a specified target position. The movement to perform this task consisted of a wrist flexion and to have an accurate performance it was necessary to have fine motor control. Bilateral transfer was found to occur for this task as well but results showed an asymmetric transfer of learning with significant transfer occurring between the preferred to non-preferred hand but not vice versa. The authors suggest that the non-symmetric transfer may have occurred due to the specific task demands and the organization of the brain. There is a lack of neural interhemispheric projections in the brain between the motor and sensory areas of the hands and a prior study employing a force-control task measuring bilateral transfer did not show any positive transfer from practiced to non-practiced hand in either direction (Teixeira, 1993). A possible explanation for the transfer that occurred in the current study is that the preferred hand was able to learn certain "task characteristics" which aided in the nonpreferred hand's transfer tests. In contrast, the subject's who practiced with their nonpreferred hand were not able to learn the "task characteristics" and therefore the preferred limb did not have an advantage, supporting the proficiency model.

The results of this series of experiments (Teixeira, 2000) demonstrate that timing and force components are capable of being transferred from the practiced to nonpracticed limb but it was also shown that bilateral transfer occurred in qualitatively different ways for the two tasks. The different directions of transfer for the perceptual and

force component tasks (symmetric vs. asymmetric) suggest that bilateral transfer may be dependent on the main components involved in motor control for the given task.

Teixeira (2006) followed up his earlier study by investigating the intermanual transfer of learning in timing tasks with different levels of motor complexity. The apparatus for both tasks was a typical anticipation timing apparatus consisting of an electronic trackway with light-emitting diodes (LEDs) arranged in a straight line across the trackway. In the current experiment participants stood throughout the tasks and the goal for each task was to time the action of hitting a stationary tennis ball with the arrival of the LEDs at the end of the track (closest to the participant). The tennis "hemiball" had a force transducer inside and was attached to a computer for recording purposes. The simple task consisted of tapping the tennis hemiball with a wrist flexion in synchrony with the arrival of the light stimulus. The complex task was similar but instead of a wrist flexion motion, the subjects were given badminton racquets and asked to synchronize a "forehand drive" with the end of the stimulus lights. The action of the "forehand drive" was biphasic, with a backward preparatory motion followed by a forward driving movement to hit the tennis hemiball. Both auditory and visual feedback was given to the participants.

Subjects were randomly assigned to one of four experimental groups in a 2 x 2 design of practice side (preferred vs. non-preferred) and task complexity (simple vs. complex). The experiment was comprised of a pre-test, acquisition phase, post-test and transfer test. The pre-test, acquisition phase and post-test consisted of 50, 250 x 2, and 50 trials, respectively, of the task that the participants had been assigned to. For example if the participant was assigned to the preferred-simple group they would perform the

"simple" task with their preferred hand for all three experimental phases. The transfer test consisted of 50 trials using the opposite side and different task complexity as had been used for the prior three phases of the experiment. At the end of the acquisition phase performance of the four groups did not significantly differ from one another. Based on this finding, Teixeira (2006) suggests that the complex task with a non-preferred hand did not limit the participants' temporal accuracy and therefore he concluded that temporal accuracy is limited by a timing component that is effector independent.

The main findings regarding learning showed there was a significant improvement in performance in the transfer task across all groups as compared to the pretest data. The performance improvements varied between 16% and 30%. Furthermore, the direction of transfer (preferred to non-preferred vs. non-preferred to preferred) was not significant, meaning the task produced symmetric intermanual transfer of learning. This finding suggests that learning was non-specific to the effector system used during acquisition because during transfer participants used the non-practiced limb. Additionally performance on the transfer task was temporally biased by the practiced task; those who transferred to the complex task had a trend of delayed responses, while those who transferred to the simple task had a directional trend towards early responses.

Schulze, Luders and Jancke (2002) investigated the bilateral transfer effects of a four-week training program on a pegboard task. The purpose of the study was to identify: whether symmetric or asymmetric bilateral training effects would occur, if practice effects would be more profound for unimanual or bilateral training, and if task difficulty would influence practice effects. Past research has not specifically controlled for task difficulty, but the current study, similar to Teixeira (2006), manipulated the difficulty of

the motor tasks. The specific experimental task required subjects to place pegs of the appropriate diameter into the eight holes of a peg board. The experimenters controlled movement difficulty by randomly changing the diameter of the holes throughout the practice sessions.

Subjects were randomly assigned to one of three experimental groups differentiated by the hand used during practice. One group only practiced with their dominant hand, another practiced with their non-dominant hand and the last group practiced with both hands. The dependent variable measured was the time for peg placement into all eight holes of the pegboard. Before commencing the practice trials, experimenters measured dominant and non-dominant hand performance as well as bimanual performance. Subjects had eight practice sessions with each lasting 15-min.

Schulze et al. (2002) found significant practice effects for both the trained and untrained hand with task difficulty having no significant influence on the practice effect. The results also indicate that there was a weak trend for the preferred hand to benefit more from non-preferred hand training than the reverse, but there was no significant finding of asymmetric transfer. From this finding, the authors suggest that interhemispheric transfer occurred in both directions. Additionally, bimanual movements benefitted from both bimanual and unimanual practice and this same finding occurred for unimanual movements but to a lesser extent.

Similar to Schulze et al. (2002), Vangheluwe et al. (2004) investigated the transfer effects of interlimb coordination, or bimanual movements. The experiment consisted of the participants simultaneously tracing a line with the left hand while tracing a star with the right (or the opposite, with participants being counterbalanced). An

electronic metronome was used to pace the participants' tracing frequency; they were to draw a complete line back and forth between each auditory cue. Results indicated that bilateral transfer of coordination occurred, which is in accordance with the previous unimanual transfer research presented.

Liu and Wrisberg (2005) investigated the extent and persistence of bilateral transfer on throwing accuracy in four different age groups of children (6, 8, 10 and 12 year olds). The throwing task required the participants to use a "basketball hook shot" to project a "Koosh" ball over head toward a target on the floor. This novel task was selected to reduce the possibility of previous experience. The children were randomly assigned to a control group or an experimental group within their specific age group.

The experiment consisted of a pretest, practice phase, immediate posttest transfer and delayed transfer test with the use of hand counterbalanced across age and gender. The pretest consisted of ten trials of the throwing task for all participants. During the practice phase the experimental group practiced the task with the hand opposite that which was used during the pretest while the control group performed a non-task relevant balancing activity. The experimental group's practice trials lasted until an age-level criterion was successfully reached (based on the researcher group's pilot study), so the amount of practice was based on an individual's scores during their practice session. For the immediate and delayed transfer tests, all participants performed 10 trials of the throwing task with the hand used during the pretest (opposite hand from practice).

Results showed that there were no significant differences among groups on the pretest but significantly higher throwing accuracy was displayed by all experimental groups on both transfer tests. This is an important finding because it suggests that

bilateral transfer isn't limited to the adult population. Also of importance is that the bilateral transfer gains were shown to persist for at least 24 hours, but the authors suggest further research should be undertaken to understand the persistence of learning. The current study also found that bilateral transfer was symmetrical, that is, the same extent of transfer occurred between preferred to non-preferred limb as it did for non-preferred to preferred limb. However, the authors suggest that symmetric transfer of learning may have occurred in this situation because of the novelty and complexity of the task; negating the usual advantage of preferred limb practice.

In contrast, Parlow and Kinsbourne (1989) found an asymmetric transfer of learning in their study which investigated the effects of handedness (right hand dominant vs. left hand dominant) on bilateral transfer of training in a writing task. Four experimental groups were formed with subjects within each handedness group being randomly assigned to one of the groups. The groups were right-right, right-left, left-right, and left-left; the first side indicating the hand used during practice, with the second one indicating the hand used in the test phase. The task was to print the uppercase letters of the alphabet in an inverted-reversed orientation as quickly as possible. The dependent measures were the number of letters printed correctly as well as the number of letters incorrectly printed. Results showed that opposite hand training significantly benefitted the participants' non-preferred hand more than their preferred hand, meaning that bilateral transfer occurred with dominant hand practice and not significantly with nondominant hand practice. Therefore it was concluded that this task revealed an asymmetric transfer of learning between hands.

Hicks, Frank and Kinsbourne (1982) investigated the central mechanism involved in bimanual skill transfer with a dual-task experiment. All participants were right handed and typed less than 35 words per minute, as there would be greater possibilities of transfer for novices as compared to experts. The dual experimental task included a typing task with one hand, while the other hand either grasped a table leg or was free. Participants were randomly assigned to either the experimental (table leg grasping) or control group (free hand) in combination with left-to-right or right-to-left training to testing sequences. The dependent measures were the total number of characters typed and number of errors made in each trial.

Results showed that transfer of skill only occurred for the control groups, those participants who had one hand free while practicing the typing task with the other hand. Participants who were engaged in the experimental dual-task did not show bimanual transfer. The authors attribute this finding to the motor overflow theory which postulates that during training of one limb programming occurs that will subsequently be available to the other limb. Thus the non-trained limb would have an advantage upon undertaking the task. But if the other limb is not free and instead engaged in another task this prohibits the overflow availability. Motor overflow has been demonstrated through the use of electromyography (EMG) (Magill, 2007). When one limb performs a skill/task EMG activity occurs in all four limbs and it has been suggested that the central nervous system has "forwarded commands to those muscles" (Magill, 2007), therefore performance information has been obtained by all limbs without even taking part in the motor activity.

Parlow and Dewey (1991) followed up the Hicks et al. (1982) study by further examining the temporal locus of transfer of training. The study also addressed the cross

activation versus callosal access theory. The same experimental dual-task procedure was used as was used in the study by Hicks et al. (1982). The primary task was sequential tapping on a type writer and the subjects were also involved in a concurrent unrelated task. Two separate experiments were reported in this study. The primary task did not change between experiments but the secondary task differed. The secondary task for the first experiment consisted of the subjects maintaining a constant sub-maximal grip with the unused hand. The sub-maximal grip was confirmed visually by water displacement in a tube. The secondary task of the second experiment was the same table-leg-squeezing task as Hicks et al. (1982). Subjects were randomly assigned to practice with their dominant or non-dominant hand. There was also random assignment of practice conditions. The conditions included performing the secondary task during training but not during testing, performing the secondary task during testing but not during practice, performing the secondary task during both training and testing and not performing the secondary task during any phase of the experiment.

Unlike Hicks et al. (1982), Parlow and Dewey (1991) found that performing an unrelated secondary task during training did not affect bilateral transfer of performance to the untrained hand. These results were substantiated in both experiments of the study. This study also found an asymmetrical transfer benefit with the non-dominant hand benefitting more from transfer than the dominant hand. As suggested by Parlow and Kinsbourne (1989), the motor representation formed in the dominant hemisphere may be the criterion as compared to motor representation formed in the non-dominant hemisphere, possibly accounting for the asymmetrical transfer.
Hicks, Gualtieri and Schroeder (1983) investigated the extent of bilateral transfer for movement patterns that were the same as practiced versus ones that were the mirror image of what was practiced. To test this they had participants use a rotary pursuit apparatus and the dependent measure was time-on-target. The subject's task for this apparatus was to follow a rotating light with a photocell tipped stylus. The direction of rotation was either clockwise or counterclockwise, randomly assigned, and each trial lasted 30-seconds. Subjects were also randomly assigned to either 5 or 25 practice trials. The subjects switched hands for the testing phase.

The testing phase consisted of a retention test with the light rotating in the same direction as was practiced and a transfer test with the light rotating opposite as was practiced (mirror image). Results showed that participants' had a significant amount of transfer between hands for both test phase conditions (same as practice and mirror image). It was also found that for the transfer test, bilateral transfer of training was more profound for those with 25 practice trials as compared to those with only 5 practice trials. The authors suggest that motor components that are task-specific allow for bilateral transfer of skill and this is likely mediated by interhemispheric transfer across the corpus callosum.

Weeks, Wallace and Anderson (2003) investigated bilateral transfer of training with an upper limb prosthetic simulator. The simulator was designed to mimic a prosthetic device for an upper-extremity amputation. Because of the complexity of the task, the researchers' were interested in the extent to which bilateral transfer would occur and the direction of transfer. Subjects were non-amputees who were free from known upper-extremity problems that could influence performance. This was a pre-test, post-test

randomized groups design with three experimental groups. The groups consisted of a control group, preferred arm practice group and a non-preferred arm practice group. For the pre- and post-tests the practice groups used the opposite arm of which they practiced with, while the control group used the arm that was used during the pre-test.

The prosthetic simulator was attached to the subject and the subject performed three manipulation tasks. The first task required the subjects to move the prosthetic towards a "toggle switch", grasp and flip the switch upwards. The second task required "fine aiming," in which the subject had to grip a stylus and place it into a small hole. While the third task was a "prehension" task which required the subject to grip an item and transport it to a specified location. The two variables of interest were initiation time and movement time.

Results were significant in finding positive bilateral transfer of learning gains for both practice conditions in terms of initiation time. The immediate transfer test did not show a significant difference between the practice groups and the control group in movement time. However, a delayed (24-hr) retention test showed significant gains in movement time for the two practice groups as compared to the control group. The authors attribute this to the plasticity of the central nervous system and the time it needs for "consolidation of memory." The temporal variables of initiation and movement time showed a symmetric transfer, which was unexpected by the authors because of the majority of evidence in favor of asymmetric transfer (Magill, 2007). The authors did note however that movement accuracy in one of the tasks was significantly influenced by asymmetric transfer. Preferred to non-preferred transfer was more beneficial in regards to the amount of errors made on the post-test task. From their research, the authors

concluded that generalization of skill in this situation was flexible and seemed to be effector independent. They suggested that it was likely that the memory representation formed during practice consisted of strategy/abstract information relating to control rather than specifics.

Koeneke, Battista, Jancke, and Peters (2009) used finger tapping as a motor task to examine intermanual bilateral transfer effects. The experimental task of finger tapping was considered intermediate in difficulty and lacking a cognitive element. This was a 2week study in which the participants were randomly assigned to practice finger tapping with either their right or left middle fingers or a control group. Pre- and post-tests were completed in the lab but the training sessions were completed at the participants' homes. The participants followed a tapping software program provided by the researchers for their practice sessions.

Post-test analysis not only found significant improvement in the trained finger which was expected but also found training effects in all fingers of both untrained and trained hands. The authors did not find an asymmetry of transfer effects – improvements were similar for the untrained hand in both practice situations, thus symmetric bilateral transfer occurred. The authors suggest such a finding could be accounted for in terms of information transfer from the active to the passive hemispheres. This information would be effector independent but be task-related.

Intermanual transfer of procedural knowledge has been studied in terms of the neurophysiological mechanisms involved (Perez, Wise, Willingham, & Cohen, 2007). In this study the authors used a serial reaction-time task in which the subjects were instructed to respond to visual cues by pressing different keys on a keyboard. A

predetermined sequence of key presses is repeated without the subjects' knowledge, which results in a decreased response time. Procedural knowledge acquired in one limb has been shown to transfer to the contralateral limb (Parlow & Kinsbourne, 1989; Japikse et al., 2003). The current study focused on the effects of the serial reaction-time task on functional changes of the primary motor cortex in both hemispheres and results showed a significantly decreased interhemispheric inhibition (IHI) from the learning to the transfer hemisphere. A decreased IHI suggests that a greater amount of information could be transferred between the hemispheres, which supports the notion of bilateral transfer occurring in a cognitive setting.

The neurophysiological mechanisms associated with intermanual transfer of learning were also investigated by Camus, Ragert, Vandermeeren, and Cohen (2009). This experimental task was a precisional pinch force task in which the subjects' goal was to modulate the pinch force between their thumb and index finger in order to displace a cursor to sequentially reach five different targets displayed on a computer screen. Speed and accuracy of motor performance were the dependent measures of interest. Transcranial magnetic stimulation (TMS) was used to determine recruitment in different regions of the brain.

The researchers found significant improvements of speed and accuracy for both the trained and untrained hand. Results also showed a significant decrease in IHI, supporting the previous research of Perez et al. (2007). The primary motor cortex was found to be active in both hemispheres while training with one hand. Therefore the researchers suggest that the interactions/communication between the two cerebral

hemispheres contributes to the intermanual transfer of procedural knowledge, independent of the effector used.

Bilateral transfer has also been evaluated in relation to locomotion (Bhatt & Pai, 2008; Erni & Dietz, 2001; van Hedel, Bierdermann, Erni & Dietz, 2002; Prokop, Berger, Zijlstra & Dietz, 1995). Findings are mixed in this research area with studies showing both positive interlimb transfer (Bhatt & Pai, 2008; Erni & Dietz, 2001; van Hedel et al., 2002) and no significant transfer (Anstis, 1995; Prokop et al., 1995).

Anstis (1995) did not find bilateral transfer between limbs with a treadmill hopping task. Participants hopped on a slow moving treadmill with their preferred leg for 30s and with their eyes closed. After the 30s the participant immediately dismounted the treadmill and began to hop in place for 30s, also with their eyes closed. Participants were randomly assigned to ground hop with either the preferred or non-preferred leg. The transfer test for the preferred leg group showed that the participant inadvertently hopped forward an average of 118cm. This did not occur for the non-preferred leg group during transfer. The authors suggest that this task has an effector dependent quality and there are parts in the nervous system that separately control each leg.

Prokop et al. (1995) used a split belt treadmill to examine the adaptation and learning processes during human locomotion. Participants began the experiment with a slow symmetric gait but after a warm-up period they were switched to split belt locomotion with one leg at a different pace than the other in order to keep up with the treadmill belt. Electromyographic (EMG) and adaptational patterns were recorded during the treadmill tasks. On the first trial, all participants took between 12-15 strides before they adapted to the novel conditions and EMG activity paralleled this finding. By the end

of practice adaptation was seen in 1-3 strides by all participants. The transfer phase was a mirror condition with the slow and fast sides inverted. Upon transfer, the participants' averaged 12-15 strides to adapt. The EMG and adaptability parameters of the task were learned but did not show bilateral transfer of performance. The researchers concluded that there is side specific information processing and control occurring during this task, thus the learned effect could not be transferred to the opposite side.

Bhatt and Pai (2008) found bilateral transfer of gait stability following exposure to slips. The primary purpose of this study was to determine if immediate transfer to the untrained side would occur after repeated slip exposure training on the contralateral side. The authors also wanted to see if there would be long-last effects of training on gait stability. Participants walked at a self-selected pace on a split surface movable platform (similar to treadmill walking). Participants were aware that "slips" might be induced but were not told when or on what side the slip would be, however during practice the "slips" only occurred on one side. With practice, participants became well adapted to the training conditions. Immediate and latent transfer were analyzed and the transfer condition included one unexpected "slip" on the non-practiced side. Results indicated that immediate transfer of gait control and stability occurred. Latent transfer effects were also found, which showed even greater gait stability on the non-practiced side than the immediate transfer trial. The authors suggest that the results demonstrate the ability of the central nervous system to generalize acquired skill information from one limb and use it contralaterally; therefore bilateral transfer was shown to occur in this situation.

Erni and Dietz (2001) found that adaptation and cross-modal transfer of a new locomotor skill occurs after obstacle avoidance (stepping over an obstacle) practice. Van

Hedel et al. (2002) furthered this research by investigating obstacle avoidance transfer to the mirror condition. EMG activity and joint angle trajectories were recorded. The authors found that transfer to the mirror condition did occur and this transfer was symmetric, favoring neither side. EMG adaptive changes occurred for the trained side and upon transfer the non-trained side had similar EMG activity recordings. Results suggest that the observed bilateral transfer of learning effects are mediated at a high level of locomotor control and are thus effector independent.

Bilateral transfer has also been shown to occur in mirror-drawing tasks (Bhushan, Dwivedi, Mishra, & Mandal, 2000; Kumar & Mandal, 2005), which are highly cognitive in nature. Both research groups used "an electronic version of the mirror-drawing apparatus" in which the participants were instructed to trace a star pattern while looking at the mirror image of the star in the mirror in front of them. Bhushan et al. (2000) specifically examined the bilateral transfer in left-, mixed- and right-handed participants. In this study the non-preferred hand for all participants was their training hand and the preferred hand was the hand used for the pre- and post-tests. Bilateral transfer occurred for all groups but for the mixed-handed participants bilateral transfer was minimal and not statistically significant. The authors attribute the difference between mixed-handed participants and those with a strong hand preference to eye-hand coordination. They suggest that the mirror-drawing task causes interference with eye-hand coordination because of the mirror inverting the image and mixed-handers are less affected by the interference because of their lack of bias for handedness. Therefore it follows that rightand left-handed participants need more time to "undo" their prior learning because of the high level of task interference.

Kumar and Mandal (2005) using the same mirror-drawing task added to the previous research. The sample population was strictly right-and left-handers thus differing from Bhushan et al. (2000). Another difference was that subjects were randomly assigned to either preferred practice to non-preferred transfer or non-preferred practice to preferred transfer. Kumar and Mandal (2005) found asymmetric bilateral transfer with greater transfer from non-preferred to preferred side.

Magill (2007) suggests that bilateral transfer predominantly occurs in an asymmetric manner, meaning that there is greater transfer from either dominant to non-dominant or non-dominant to dominant limb. Also suggested is that bilateral transfer occurs to a greater degree when the practiced limb is the dominant limb and motor training is transferred to the non-dominant limb. Throughout this literature search I have found mixed results in regards to the directional nature of bilateral transfer. Almost an equal number of studies reviewed show that in some situations symmetric transfer occurs, while in others asymmetric transfer is predominate. However, the preponderance of evidence does suggest that bilateral transfer occurs to a greater degree in the direction of dominant to non-dominant limb. Further analysis is warranted to investigate the possible trends in different skill acquisition situations.

Corpus Callosum

One of the main structural components of the brain is the cerebrum, which consists of two cerebral hemispheres connected by a sheet of nerve fibers known as the corpus callosum (Magill, 2007). The human cerebral cortex has a wide variety of functions including but not limited to: the control of movement, coordination, memory, sensory-association and speech. The functions of the cerebrum are represented on both

hemispheres of the brain but they aren't represented equally on both sides. There is cerebral dominance in the brain, meaning one brain hemisphere will play a more active role in executing a specific function than the other hemisphere (Siegel & Sapru, 2011, p.485). An important example of cerebral dominance in motor control is a person's "handedness." The term "handedness" represents a person's preference for the use of one hand over the other, which is also associated with dominance of the opposite cerebral hemisphere (Siegel & Sapru, 2011, p. G-16). Therefore almost all right-handed individuals have left hemispheres that have cerebral dominance for handedness, but this doesn't follow for left-handers. It has also been shown that people can easily learn how to use the hand associated with the non-dominant hemisphere as effectively as the other hand, suggesting that there is "cross talk" between the two hemispheres (Siegel & Sapru, 2011, p.487).

The corpus callosum is the major brain structure involved in transfer of information from one hemisphere of the brain to the other. Roger Sperry and Ronald Meyers were the first to demonstrate the significance of the corpus callosum in interhemispheric transfer (Doron & Gazzaniga, 2008). Their introductory research was mainly based on animals in which they surgically cut the corpus callosum, but it paved the way for experiments with human acallosal patients and patients whose corpus callosum have been surgically cut. Ultimately the foundation that Sperry and Meyers set has led to our understanding of hemispheric dominance and lateralization of function.

Normal individuals show a clear pattern of brain lateralization; however atypical laterality is prevalent in those with intellectual disability (Mohan, Singh, & Mandal, 2001). Atypical laterality is the lack of a clear pattern of lateralization and evidence for

this has been established through studies on handedness. Hicks and Kinsbourne (1978) found that non-right-handedness is significantly more common for those with intellectual disability than for the general population (as cited in Mohan et al., 2001). The literature has not yet been consistent as to why individuals with intellectual disability have atypical cerebral dominance but Mohan et al. (2001) suggest that the occurrence could be due to a lowered level of bilateral organization. They go on to define lowered bilateral organization as a reduced ability of interhemispheric transfer of a motor skill from one side of the body to the contralateral side. In addition there is a reduced ability to perform tasks simultaneously that are controlled by the same hemispheric side.

Mohan et al. (2001) used the same mirror drawing task and procedures as previously reported (Bhushan, Dwivedi, Mishra, & Mandal, 2000; Kumar & Mandal, 2005) but in their study individuals with intellectual disability were compared to a group of right-handed, age-matched controls. The research group hypothesized that those with intellectual disability would have a lower level of bilateral organization as compared to a control group. Bilateral organization as defined by the study is a reduced ability to interhemispherically transfer a motor skill from one side of the body to the other. The results were as expected in that individuals with intellectual disability made significantly more errors and had significantly less bilateral transfer than the control group. Participants with intellectual disability did exhibit some bilateral transfer but it was to a very small extent, which the authors believe supports their hypothesis of a reduced level of bilateral organization.

Interhemispheric communication has also been assessed using split-brain patient "JW" (Criscimagna-Hemminger, Donchin, Gazzaniga, & Shadmehr, 2002). "JW" is a

right-handed adult male who was treated for his epilepsy by resection of the corpus callosum. He exhibits the "typical" split-brain phenomena but otherwise he is neurologically intact. The study assessed the bilateral transfer of reaching movements in neurologically intact subjects as well as "JW." The behavioral task was a curl-field motor learning paradigm as described by Shadmehr and Brashers-Krug (1997) (as cited by Criscimagna-Hemminger et al., 2002). In brief, the participants' objective was to use a "robotic manipulandum" to make point-to-point reaching movements in a force field. The researchers found significant bilateral transfer for the neurologically intact group in that learned dynamics of the reaching movements generalized from dominant to nondominant arm. Surprisingly "JW" also showed the learned dynamic of the reaching movement from dominant to non-dominant arm; therefore in this situation transfer of information cannot be attributed to the corpus callosum. This supports the crossactivation model; for right-handers learning dynamics with the dominant hand is represented in the left hemisphere and may be used for either right- or left-handed tasks. Whereas learning with the non-dominant arm facilitates storage in the non-dominant hemisphere and this information isn't available for the dominant arm in the future.

The Cross Finger Localization Task (CFLT) has been validated as a test of callosal function, as it requires interhemispheric transfer of sensory information across the corpus callosum (Chaim et al., 2010). Briefly, in the task an experimenter, who cannot be seen by the subject, touches one of the subject's fingertips and the subject must then identify which fingertip is touched. The subject identifies which fingertip they believe was touched using either the thumb of the same hand or the thumb of the opposite hand, giving two experimental conditions. Callosal transfer is only needed in the crossed

condition (opposite thumb). Chaim et al. (2010) also acquired MRI data of the subject's corpus callosum volume. Among their findings, the researchers attained a significant positive correlation between performance on the crossed CFLT condition and corpus callosum volumes. However they note that this relationship was only found in a group diagnosed with clinical psychosis and they did not find the same relationship for a control group. Because of this it cannot be concluded that there is a direct relationship between corpus callosum volume and interhemispheric transfer in the general population. The authors do suggest that there is a relationship between structure and function but additional research should be done to build upon their work.

The cerebral hemispheres, connected by the corpus callosum are the main structures of the brain and play an important role in motor control. Although the two hemispheres perform different roles, it is imperative that the hemispheres function together in order to smoothly coordinate limbs. The nerve fibers that make up the corpus callosum play a significant role in the "cross talk" that occurs between the two hemispheres, which is necessary for the bilateral transfer of information to occur from one side of the body to the other.

Summary

The mechanics of swinging a baseball bat, the motor control theory of bilateral transfer and the interconnectedness of the two cerebral hemispheres were discussed throughout this review of literature. Although there is a paucity of studies analyzing the baseball swing in three-dimensions, researchers who have investigated the swing agree that the swing can be broken down into specific events (Escamilla et al., 2009a; Lund & Heefner, 2005; Shaffer et al., 1993; Welch et al., 1995;). These events are common

components of all players' swings and were used in the current study to obtain temporal phase parameters. The examination of swing patterns of skilled switch hitters assesses the result of years of bilateral transfer. There is overwhelming research evidence in support of the bilateral transfer of motor skills from a practiced limb to a non-practiced limb, and an intact corpus callosum allows bilateral transfer to occur.

Chapter 3

Methods and Procedures

Overview

The purpose of this study was to determine if skilled switch hitters have the same temporal, kinematic and/or kinetic hitting patterns when batting from the right versus left sides. A counter-balanced within subjects design was used.

Subjects

Six skilled switch hitters were recruited and agreed to participate in this study however due to injury and illness three subjects were not able to participate in the data collection process. Thus, participants in this study were three male switch hitters. The average subject age was $21.3 \pm .6$ years, average height was 70.3 ± 1.2 inches and weight was 80.3 ± 5.7 kilograms. Written informed consent was obtained for each subject before instructions were given or data collection took place. The study was approved by the Human Subjects Committee of California Polytechnic State University, San Luis Obispo.

Subject one was 22 years of age with 17 years of switch hitting experience. His highest current level of baseball participation was high Class-A, which is a minor league subdivision of Major League Baseball (MLB). His overall batting average was .250 from the right side and .280 from the left side.

Subject two was 21 years of age with eight years of switch hitting experience. His highest current level of participation was NCAA Division I collegiate baseball. Overall, his batting average from the right was .280 and from the left was .320.

Subject three was 21 years of age with three years of switch hitting experience. His highest current level of participation was NCAA Division I collegiate baseball. Subject three possessed a .306 batting average on the right side and a .265 batting average on the left.

Procedures

Subjects were recruited and arrangements were made for each subject to come to the Center for Sport Performance at Cal State Fullerton. The Center for Sport Performance is an indoor biomechanics laboratory consisting of a Qualisys threedimensional optical motion capture system (Gothenburg, Sweden). The system included high speed video cameras as well as force plates embedded in the ground. Prior to data collection subjects completed a background inventory that included questions related to switch hitting experience, batting average, and type of baseball bat used. Hand and eye dominance were assessed following the methods devised by a modified Edinburgh handedness inventory (Oldfield, 1971) and Crovitz and Zener (1962), respectively. Subjects also completed a Physical Activity Readiness Questionnaire (PAR-Q). See appendix A for background inventory and hand-dominance assessment.

After completing all necessary paperwork, subjects performed a self-selected warm-up. All subjects used a combination of stretching, dynamic warm-up activities and swinging in the air during their warm-up time. Once the subjects felt they were ready, they were allowed to take warm-up swings off the tee from both sides. We allowed the subjects to take as many warm-up swings as they needed, however we asked the subjects to hit a consistent number from each side. After warming up, the subjects were randomly assigned to which side they would be hitting from first, right or left.

Biomechanical Analysis

Subjects were asked to come to the lab wearing shorts and a short-sleeve t-shirt. Retro-reflective markers were placed on the subject, bat and baseball. The specific marker locations on the subjects are based on the full-body three-dimensional model created by the research biomechanists at Fullerton using C-Motion, Inc. Visual 3D Movement Analysis software (Rockville, MD). Retro-reflective markers were fixed to plates, creating rigid body marker clusters. These clusters were positioned bilaterally on the dorsal aspect of the subject's foot, and laterally on the shank, thigh, forearm, and upper arm. A single rigid body cluster was positioned on the sacrum of the subject and the subjects wore a hat with retro reflective markers attached. Each rigid body cluster consisted of four retro-reflective markers, except for the foot which had three. Additionally, calibration markers were placed bilaterally on the first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral condyles, greater trochanter, middle iliac crest, acromioclavicular joint, medial and lateral humeral epicondyles, and styloid processes of the radius and ulna.

Retro-reflective markers were also placed on the handle of the bat, at the end of the barrel of the bat, and on the side of the baseball located away from the hitter. Once all markers were positioned, a calibration pose was recorded. The calibration pose was a snap spot that acted as the three-dimensional calibration model for each subject. For the calibration pose subjects stood in the location where they would subsequently be hitting and were asked to stand in an anatomical position holding the bat vertically with one hand. Once the cameras took the calibration pose, the calibration markers were taken off leaving just the rigid body markers on the subject.

A baseball was placed on a hitting tee at a height according to each subjects' individual preference and such as to be located in the middle of the strike zone. Subjects were told to swing full and hard and as if they were "hitting a line drive up the middle." Each subject performed 20 total swings. As previously stated, subjects were randomly assigned to the side that they would be hitting from first. Once this was assigned, subjects took three extra practice swings on the assigned side before data collection took place. This was so the subject could sense how it would feel to swing with the rigid body clusters attached. After the extra swings, we recorded five swings from the first side then the subjects switched sides of the plate. To be consistent, the subjects took three practice swings on the second side, which were followed by five recorded swings. Subjects were then given a one minute break and the swing sequence would be repeated, however the subjects were not given the three extra swings per side.

Movement of the hitter, bat and ball was captured by a nine camera Qualisys Oqus 300 (Gothenburg, Sweden) high-speed motion analysis system with the cameras arranged specifically for capturing three-dimensional movement. The cameras sampled at 240 frames per second. Additionally, the hitter stood with each foot on a separate Advanced Mechanical Technology, Inc. (AMTI) force platform. The force platforms sampled at 1200 Hz and simultaneous collection and synchronization of the kinematic and kinetic data occurred. A 64-channel analog interface was used for synchronization. Real-time marker position and force data were captured.

Visual 3D software (C-Motion, Inc., Rockville, MD) was used to process all swings. Raw data was filtered through the software via a 6th order, low-pass, Butterworth

filter with a 6 Hz cut-off frequency. Temporal swing events, stride length and ground reaction forces were calculated with the software as well.

Events of the Swing

The hitter's swing was defined by six events and four phases, which are the temporal parameters of the study (Escamilla et al., 2009a; Hall et al., 1996; Lund & Heefner, 2005). The events included balance point, front foot off ground (foot-off), maximum knee flexion (max knee), front foot re-contact with the ground (foot recontact), hands start forward (hands forward), and bat-ball contact (contact). The swing phases included stance, stride, pre-swing and bat acceleration. The balance point was defined as the point at which the subject's ground reaction forces were evenly distributed between both feet. This occurs in the moment just before the subject's weight begins to shift towards their back leg and marks the beginning of the stance phase. Foot-off was defined as the first frame in which the front foot was no longer in contact with the ground. This frame also signified the end of the stance phase and the beginning of the stride phase. There was two separate components within the stride phase. Max knee was the point between toe off and foot re-contact at which there was maximum flexion of the knee, which occurred at the point of maximum knee height. This was precisely before the knee changed direction and began to move towards the ground. Foot-off to max knee is the first temporal component of the stride phase (stride 1). Foot re-contact was defined as the first frame in which the front foot was back on the ground. This frame also represented the end of the stride phase and therefore the second temporal component of the stride phase of the swing was the time duration of max knee to foot down (stride 2). Hands forward represented the first frame in which both hands started to move forward

towards the baseball tee (positive x-direction). The pre-swing phase thus corresponded to the time duration between foot re-contact and hands forward. The final event was contact and was defined as the first frame of bat-ball contact. The final phase of the swing, bat acceleration, represented the time duration between hands forward and contact. The entire swing duration was defined by balance point to contact.

Dependent Measures

The dependent measures of the study include temporal, kinematic and kinetic parameters. Dependent measures in regards to timing include: total swing duration; relative timing of each event in the swing consisting of balance point, foot-off, max knee, foot re-contact, hands forward and contact. The linear displacement parameter of stride length was measured as the distance between where foot-off occurred and where foot recontact occurred. The kinetic measure of peak vertical ground reaction force was also found for both feet.

Statistical Analysis

The swing was divided into six events and four phases. Each event was digitally marked and the duration of the events of the swing were recorded. The relative time of each event and phase of the swing were calculated by dividing the duration of each component by the total swing duration (Terzuolo & Viviani, 1979). All swings were analyzed unless they were uncharacteristic of the subject's other swings. If this occurred the entire swing was considered an outlier and was not used in the analysis. After the outliers had been determined, all representative swings on each side of the plate were averaged for each variable. This produced a right side mean and a left side mean for each subject on each variable. The differences between sides for each subject were calculated

by subtracting the mean numerical values of the non-dominant side from the mean values of the dominant side. Paired T-Tests were then used to analyze the mean differences of all variables and all statistics were performed with Minitab 16 statistical software (State College, PA, USA). A Pearson correlation was run to determine the relationship between the variables of maximum ground reaction force of the front foot and the phase of max knee to foot down.

Chapter 4

Results

Overview

The purpose of this study was to investigate the temporal and biomechanical aspects of a switch hitter's swing from both sides of the plate. Specifically, the swing was broken down into six events and the relative timing of the phases of those events were recorded as used as the temporal measures of the study. The total duration of the swing was also recorded as a temporal variable. The biomechanical dependent measures were maximum ground reaction force (GRF) of each foot during the swing and stride length of the front foot. Two subjects were randomized to swing on the right side first, while one subject was randomized to the left side. All subjects took twenty swings, ten swings from each side of the plate. However, each subject had a small number of swings that were deemed outliers because they were not representative of the rest of their swings and thus were not included in the statistical analyses. Subject one had four total outliers, two from each side of the plate. Subject two had one outlier, which was a right-handed swing. Lastly, subject three had two outliers both from the right-side of the plate.

All swing variables included in the statistical analyses were averaged for each side of the plate for each subject. The mean differences for each variable were then obtained for all subjects and these differences were directly used in the statistical analysis. In the following paragraphs descriptive measures have been reported that were obtained from the background inventory questionnaire. Also reported are temporal measures including relative and absolute timing of the swing phases and differences from

side-to-side, along with ground reaction force data and stride length. Paired T-Tests were conducted for all temporal and biomechanical variables.

Descriptive Results

Subject one, a 22 year old high Class A baseball player with a batting average of .250 from the right side and .280 from the left side has been a switch hitter for 17 years. He began hitting baseballs at age three and started switch hitting shortly thereafter at the age of five. He batted from the right side of the plate first and began switch hitting in games just one year after he first started practicing to bat on the left side. Subject one "strongly agreed" with the statement: "at a younger age I felt more ambidextrous than my peers." He followed this choice up by noting that he taught himself to throw left-handed at the age of 10 and that he feels more comfortable kicking with his left foot as compared to his right. However, his Edinburgh Handedness Inventory results suggest a very strong right-hand preference. His results showed a laterality index score of 100, which put him in the 10th right decile – the farthest right-handed preference grouping possible. His eye dominance assessment revealed that he was right-eye dominant.

Subject one spends approximately the same amount of batting practice time working on his swing from both sides of the plate. As reported previously, he has a 30point difference in his batting averages with his left side being the statistically higher number of the two sides. This difference seems to agree with his answer of "somewhat agree" to the question "now that I have experience as a switch hitter, I prefer to swing from one side over the other." He attributed having more consistency and comfort from the left side to the fact that he has been on that side more often during games (because of the disparity between the numbers of right- and left-handed pitchers in the game of

baseball). Additionally subject one stated that there are fewer times in which he would rather face a left-handed pitcher as compared to the reverse scenario.

Subject two began his baseball career at age five. He batted solely from the right side of the plate until the age of 13 when he began switch hitting, which gave him a total of eight years of experience switch hitting. Although he has practiced switch hitting for eight years, he has only switch hit in game situations during his collegiate career. The results of the Handedness Inventory show that subject two has a very strong right-hand preference. His laterality index was 100, putting him at the 10th right handed decile. In accordance with the handedness assessment, subject two "strongly disagreed" to the statement "at a younger age I felt more ambidextrous than my peers." He stated that as a youth he would only use his right-hand or foot to perform activities and that there are no activities he specifically performs with his non-dominant side. Subject two was also right-eye dominant.

Similar to subject one, subject two shows a forty point difference in batting average from the right to left sides of the plate, with the left side being greater .320 versus .280 on the right. However, he "strongly disagrees" with the statement "now that I have experience...I prefer to swing from one side over the other." He stated that he feel the same "comfort" level from both sides, and interestingly during batting practice he dedicates approximately 75% of his time working on his left side swing while 25% goes to working on his right side swing.

Subject three has been playing baseball since he was six years of age. Similar to the other subjects, he also began batting from the right side of the plate, is right-eye dominant and has a strong right-handed preference with a laterality score of 100. Subject

three has switch hit for two years during game situations and has a .306 batting average from the right side and .256 average from the left. He "somewhat disagrees" with the statement "at a younger age I felt more ambidextrous than my peers," stating that he really doesn't feel comfortable doing anything "lefty except hitting." He also noted that he can kick a soccer ball with both feet but in general feels that he has poor motor skills on both sides in this realm. During batting practice his time spent on each side is broken up as 40% on the right and 60% on the left. Subject three also "somewhat disagreed" to the side preference statement. He said "it all depends on feel" – and it really varies as to why and when he'll feel better on one side versus the other.

Regarding the background inventory question of "why did you start switch hitting," all subjects responded with statements about the benefits of being a switch hitter. Subjects one and two discussed the advantages of seeing the pitch early, seeing the pitch come out of the pitchers hand and how every pitch moves towards them instead of breaking away. Subject one also noted that switch hitting wouldn't subject him to being a platoon player. A platoon player, as discussed earlier is a player who only plays against pitchers who throw with the opposite arm as to the side of the plate they hit on. These players are not everyday starters, so switch hitting allows some players to play every day. Subject three answered in a similar manner, stating that switch hitting added to his skill set as a baseball player, ultimately making him a greater asset

Temporal Parameters

The balance point is the first event of the swing, which was determined as the point when the subject's ground reaction forces were evenly distributed between both feet. The second event of the swing is foot-off, the instant when the subject's front foot

comes off the ground. The time duration from the subject's balance point to foot-off was known as the stance phase and was used as the first temporal variable of the swing. For the stance phase, the difference between the subject's temporal parameters from the right and left sides was not found to be statistically significant (p = 0.314). The third event of the swing was the point during the subject's stride in which their knee was at a point of maximum flexion. The second phase of the swing was then the duration of foot-off to maximum knee (max knee) and is known as the first component of the stride phase. The first component of the stride phase was not statistically significant (p = 0.160). Front foot re-contact with the ground (foot re-contact) was considered the fourth event of the swing. Therefore the third phase of the swing was the timing of maximum knee to foot recontact, known as the second component of the stride phase. Statistical analysis for this temporal parameter was not statistically significant (p = 0.694). The pre-swing phase is the time duration of foot re-contact and the fifth event of the swing, known as hands forward. The pre-swing phase difference between sides was not found to be statistically significant (p = 0.203). The bat acceleration phase is marked by the instant the hands move forward and terminates when contact between the bat and the ball occurs. This phase was not found to be statistically significant (p = 0.524). Individual subject temporal characteristics for each swing phase can be found in Tables 1-3. Negative differences correspond to the dominant side having a quicker relative/absolute swing phase duration.

Total swing duration consisted of the time period between the subject's balance point and bat-ball contact. Total swing duration was not found to be significantly different from the right versus left sides (p = 0.549). Individual total swing duration data

may be seen in Tables 1-3 and Figure 1. P-values for all temporal variables are shown in

Table 4.

Table 1

Subject One's Relative (Rel.) and Absolute (Abs.) Temporal Phases During the Swing on Each Side of the Plate

Phase	Stance		Stride 1		Stride 2		Pre-Swing		Bat Acceleration		Total
	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	
Subject	0.279s	0.307s	0.135s	0.140s	0.175s	0.186s	0.219s	0.242s	0.194s	0.209s	1.09s
1 RH	<u>+</u> 0.033s	<u>+</u> 0.063s	<u>+</u> 0.026s	<u>+</u> 0.034s	<u>+</u> 0.114s	<u>+</u> 0.118s	<u>+</u> 0.125s	<u>+</u> 0.145s	<u>+</u> 0.020s	<u>+</u> 0.01s	<u>+</u> 0.09s
% of											
RH	27.9%		13.5%		17.5%		21.9%		19.4%		
swing											
Subject	0.348s	0.376s	0.118s	.126s	0.238s	0.251s	0.116s	0.124s	0.180s	0.192s	1.069s
1 LH	<u>+</u> 0.058s	<u>+</u> 0.09s	<u>+</u> 0.031s	<u>+</u> 0.034s	<u>+</u> 0.089s	<u>+</u> 0.088s	<u>+</u> 0.080s	<u>+</u> 0.09s	<u>+</u> 0.015s	<u>+</u> 0.006s	+0.09s
% of											
LH	34.8%		11.8%		23.8%		11.6%		18%		
swing											
Diff.	-0.069s	-0.069s	0.017s	0.014s	-0.063s	-0.065s	0.103s	0.118s	0.014s	0.017s	0.021

Note. Values are in means \pm standard deviation; S = Seconds, RH = Right handed swing, LH = Left handed swing, Diff. = temporal difference between the right-handed and left-handed swings.

Table 2

Subject Two's Relative (Rel.) and Absolute (Abs.) Temporal Phases During the Swing on Each Side of the Plate

Phase	Stance		Stride 1		Stride 2		Pre-Swing		Bat Acceleration		Total
	Rel.	Abs.									
Subject 2 RH	0.357s <u>+</u> 0.018s	0.386s <u>+</u> 0.023s	0.036s <u>+</u> 0.008s	0.039s <u>+</u> 0.008s	0.140s <u>+</u> 0.009s	0.152s <u>+</u> 0.01s	0.295s <u>+</u> 0.018s	0.319s <u>+</u> 0.022s	0.171s <u>+</u> 0.006s	0.185s <u>+</u> 0.006s	1.08 <u>+</u> 0.03s
% of RH swing	35.7%		3.6%		14%		29.5%		17.1%		
Subject 2 LH	0.462s <u>+</u> 0.013s	0.515s <u>+</u> 0.027s	0.029s <u>+</u> 0.006s	0.032s <u>+</u> 0.007s	0.058s <u>+</u> 0.006s	0.064s <u>+</u> 0.007s	0.294s <u>+</u> 0.014s	0.327s <u>+</u> 0.019s	0.158s <u>+</u> 0.008s	0.175s <u>+</u> 0.008s	1.11s <u>+</u> 0.04s
% of LH swing	46.2%		2.9%		5.8%		29.4%		15.8%		
Diff.	-0.105s	-0.129s	0.007s	0.007s	0.082s	0.088s	0.001s	-0.008s	0.013s	0.01s	-0.03s

Note. Values are in means \pm standard deviation; S = Seconds, RH = Right handed swing, LH = Left handed swing, Diff. = temporal difference between the right-handed and left-handed swings.

Table 3

Subject Three's Relative (Rel.) and Absolute (Abs.) Temporal Phases During the Swing on Each Side of the Plate

Phase	Stance		Stride 1		Stride 2		Pre-Swing		Bat Acceleration		Total
	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	
Subject	0.343s	0.388s	0.091s	0.099s	0.244s	0.270s	0.155s	0.17s	0.168s	0.186s	1.15s
3 RH	<u>+</u> 0.066s	<u>+</u> 0.113s	<u>+</u> 0.016s	<u>+</u> 0.012s	<u>+</u> 0.025s	<u>+</u> 0.029s	<u>+</u> 0.032s	<u>+</u> 0.021s	<u>+</u> 0.016s	<u>+</u> 0.008s	<u>+0.12s</u>
% of											
RH	34.3%		9.1%		24.4%		15.5%		16.8%		
swing											
Subject	0.320s	0.333s	0.049s	0.051s	0.337s	0.348s	0.094s	0.098s	0.199s	0.205s	1.03s
3 LH	<u>+0.037s</u>	<u>+</u> 0.055s	<u>+0.013s</u>	<u>+0.014s</u>	<u>+</u> 0.026s	<u>+</u> 0.023s	<u>+</u> 0.028s	<u>+</u> 0.031s	<u>+</u> 0.05s	<u>+0.012s</u>	<u>+</u> 0.06s
% of											
LH	32%		4.9%		33.7%		9.4%		19.9%		
swing											
Diff.	0.023s	0.055s	0.042s	0.048s	-0.093s	-0.078s	0.061s	0.072s	-0.031s	-0.019s	0.12s

Note. Values are in means \pm standard deviation; S = Seconds, RH = Right handed swing, LH = Left handed swing, Diff. = temporal difference between the right-handed and left-handed swings.

Table 4

P-values of all temporal parameters of the swing from Paired T-tests

Stance Stride 1		Stride 2	Pre-Swing	Bat	Total Swing	
			Acceleration		Duration	
p = 0.314	p = 0.160	p = 0.694	p = 0.210	p = 0.524	p = 0.549	



Figure 1. Total swing duration. This figure illustrates each subject's total swing duration, the timing from the balance point to bat-ball contact, on each side of the plate. Values are in means; S = Seconds.

Maximum Ground Reaction Force

For maximum ground reaction force (N) of the front foot, the difference between sides was not found to be statistically significant (p = 0.328). Individual subject differences between the right and left sides are shown in Figure 2. Maximum GRF of the back foot was also not found to be statistically significant (p = 0.736). Individual subject results are shown in Figure 2.1.

A Pearson correlation was run between the right and left side differences of the variables of maximum ground reaction force (N) of the front foot and time duration of the phase of max knee to foot down. A strong negative correlation between these variables was found (correlation = -0.770).



Figure 2. Maximum ground reaction force of the front foot. This figure illustrates each subject's maximum GRF for the front foot when swinging from both sides of the plate. Values are in means; N = Newtons.





Stride Length

Stride length was the distance measure from where the front foot leaves the ground to where it comes back into contact with the ground. Individual stride lengths from each side of the plate are shown in Figure 3. All subjects possessed a greater stride length on their dominant side, however this variable was not found to be statistically significant (p = 0.248).



Figure 3. Stride length. This figure illustrates each subject's stride length on the right and left sides of the plate. Values are in means; cm = centimeters.

Chapter 5

Discussion

The baseball swing is a highly ballistic and compact action. In order for a batter to make contact with a pitched ball they must perceive the pitched ball, make a timely decision to swing or not and act on this decision. Even with a proficient perception-action coupling by the batter, there is a high likelihood that the bat will not make contact with the pitched ball. College and professional baseball players are highly skilled with years of practice and game experience as batters as well as in their respective positions on the baseball field (first base, second base, center field, etc). To be proficient at switch hitting at either the college or professional level requires years of practice and bilateral coordination. Due to the crossing over of neurological activity, practice on one side of the body creates slight activation in the opposite side, thus practicing on one side influences the pattern the opposite side will adopt (Magill, 2007). Motor control theories suggest that activities that are performed on either side of the body by highly skilled individuals should produce similar motor patterns side-to-side (Schmidt, 1985). However, little research has been conducted to support or refute this proposition.

The main goal of this study was to temporally and biomechanically analyze switch hitters' swing components on each side of the plate. The current study, modeled after the switch hitting study by Hall et al. (1996), adds to the previous research by incorporating kinetic data as well as using slightly different events to break down the swing (Escamilla et al., 2009a; Lund & Heefner, 2005). Based on this previous research (Hall et al., 1996), it was hypothesized that the batters would have similar relative timing of the phases of the swing except for the second component of the stride phase (max knee

to foot down). This phase was expected to have a shorter duration on the subjects' dominant side. Also hypothesized to be quicker on the subjects' dominant side was the total swing duration. All other temporal variables were not hypothesized to be significantly different side-to-side. Regarding ground reaction forces, it was hypothesized that the front foot on the subjects' dominant side would have a greater maximum ground reaction force and that the back foot would not show significant differences side-to-side. Stride length was not expected to be significantly different from one side to the other.

Findings from this study failed to support the hypothesized differences between swing components on the right versus left side of the plate. Specifically, the statistical analyses failed to support our hypotheses regarding a faster phase from max knee to foot down, a faster overall duration of the swing on the dominant side and a greater force production on the dominant side. Although these differences were not statistically significant, interesting trends were noted and discussion follows. The hypotheses regarding all other phases of the swing, ground reaction force of the back foot and stride length were supported because no significant differences were found between sides. Moreover, the p-values obtained in this study were often close to .5 indicating a random finding which does support the notion that the patterns are indeed very similar side-toside as suggested by motor control theories. During data collection, the researchers observed the subjects' swing and, after data was collected, the researchers re-examined video of the swings, noting that the surface motor patterns of all 3 subjects were quite identical looking side-to-side. Visually the subjects' pre-swing maneuvers (e.g. bat waggle and body movements) all the way to their follow-through post-bat-ball contact were matching.

The three-dimensional video and force plate data brought to light some interesting individual swing characteristics. Typically switch hitters have a dominant side and the dominant side is thought to sum greater force during the swing than the non-dominant side. This has generally been found in skilled switch hitters (Hall et al., 1996). However, that was not the case for subject two in this study. Subject two, along with the other two subjects in this study, was right-side dominant. He stayed in his stance phase longer on his non-dominant side (left), signifying that he was slower to begin running off the kinetic link of the swing. However, once he began his motion with front foot-off all phases of the swing on his non-dominant side were quicker. Most notably, subject two's stride two phase (max knee to foot re-contact) as well as his bat acceleration phase were faster on his left side. A quicker stride two phase, coupled with a greater maximum ground reaction force (32.3 N greater on non-dominant side) suggest that he was able to sum more force on his left side. The faster bat acceleration on his non-dominant side suggested that he also had a longer window to observe the flight of the pitch on that side, hence improving his ability to make correct swing decisions. These characteristics were unusual for a right-side dominant player compared to other switch hitters from previous research (Hall et al., 1996) and the other subjects in this study.

Interestingly, subject one, having 17 years of switch hitting experience and subject three, with just three years of switch hitting experience were more temporally and kinetically alike, compared to subject two who had eight years of switch hitting experience. Subjects one and three summed more force on their dominant sides by 219.3 N and 92.7 N, respectively. These two subjects also had a quicker duration of max knee to foot down, which was correlated to the ability to sum a greater force on that specific

side. Also important to note, both subjects one and three had a much quicker pre-swing phase on their non-dominant sides. In relation to the motion of the batter during this phase, it can be thought of as rotation of the torso, which is an important preparatory step before bat acceleration. Subjects one and three also had a longer mean total swing duration on their dominant sides while subject two had a shorter mean total swing duration on his dominant side. These findings were similar to the findings of previous research on skilled switch hitters as well (Hall et al., 1996).

The baseball swing is a series of sequential movements and is considered a classic example of the kinetic link principle (Szymanski & DeRenne, 2010). Although previous kinematic and kinetic baseball hitting studies (Escamilla et al., 2009a; Escamilla et al., 2009b; and Welch et al., 1995) have defined the start of the swing at foot-off, the current researchers, with the use of force plates, were able to recognize a novel event of the swing, the balance point. The balance point was inherent in all subjects' swings just before they began shifting their weight towards their back foot in preparation for foot-off. The stance phase (balance point to foot-off) of the swing is an important mechanical aspect of the swing, and is part of the preparatory part of each swing. This first segment begins the kinetic chain of events creating the swing pattern. Typically, past research has started examining the swing at toe-off, but with the use of force platforms, the balance point and subtle weight shifts are very apparent. Future research should examine how the duration of this first phase and subsequent weight shifts affect the total swing pattern in order to better understand side-to-side differences.

Recommendations

Ericsson, Krampe and Tesch-Romer (1993) suggest that elite/expert level performance is the product of a minimum of ten years of maximal, effortful deliberate practice. The subjects in the current study had seventeen, eight and three years of switch hitting experience and thus it can be suggested that perhaps not all three switch hitters have reached their optimal level of batting efficiency on each side. For a well-learned skill, such as hitting in baseball the motor patterns of expert switch hitters are expected to be relatively the same side-to-side (Schmidt, 1985). Statistically, significant differences were not found in this study supporting the notion that the patterns were similar side-toside. However, it was quite difficult to find significant differences with the small sample size included here, especially when one of the subject's components was quite different than the other skilled switch hitters examined. The trends discussed above (more force production on the dominant side, faster speed during the max knee to foot down component, and faster bat acceleration on the dominant side) did emerge and may have reached significance with more subjects. Many more subjects need to be examined to determine how individuals organize their patterns side to side in this unique skill of switch hitting.

Also the ability to include additional kinematic dependent measures such as segmental angular velocities and angular displacement parameters at each event of the swing would be very helpful and provide further clues to the control issues. The kinematic models developed for this study proved to be problematic and unreliable and thus the only dependable kinematic measure available was stride length. Future research studies should try to include the kinematic variables discussed in order to strengthen the

temporal results and further examine the trends that continue to appear in this type of study.

Conclusions

The three skilled switch hitters in this study demonstrated that well-established swing patterns, at least by all appearances, are close to identical. The preparation and overall movements on the surface cannot be distinguished. Although bilateral transfer could not be directly quantified because the subjects were not taking part in a novel skill, the swing similarities side-to-side suggest these patterns are the result of a strong crossover effect. Clearly the crossing over of neurological information via the corpus callosum has facilitated the development of similar swing patterns side-to-side for these individuals. By examining highly practiced individuals, the creation of a kinetic link and how the components of the swing interconnect to produce force can give us clues to how dominance influences patterns side-to-side. The proficiency and skill developed by the subjects on either side provide insight into larger and more theoretical motor control questions. The switch hitters examined here were highly skilled individuals and although their swings look indistinguishable from side-to-side, the small internal differences that emerged under examination that create more comfort and/or strength on one side versus the other appear to be more individualized than previously thought (Hall et al., 1996). Many more subjects and perhaps other well-established motor patterns, particularly those that require force production, need to be examined before firm conclusions can be drawn.
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Appendix A

Informed Consent Form

INFORMED CONSENT TO PARTICIPATE IN RESEARCH STUDYING THE A BIOMECHANICAL ANALYSIS OF THE SIDE-TO-SIDE SWING PATTERNS OF SKILLED SWITCH HITTERS

A research project on switch hitting is being conducted by Francesca Castellucci, a Masters student in the Department of Kinesiology at Cal Poly, San Luis Obispo under the supervision of faculty advisor, Dr. Kellie Green Hall. Dr. Scott Lynn from the Department of Kinesiology at Cal State Fullerton will also act in an advisory role. The purpose of the study is to determine if skilled switch hitters in baseball have similar temporal events of the swing, kinematic patterns and/or kinetic patterns side-to-side while hitting a baseball. Participants will take swings off of a baseball tee while motion capture cameras and force plates record the swings.

You are being asked to take part in this study because you are 18-28 years old, are in good health, and are an experienced switch hitter. If you decide to participate, it will require a time commitment of approximately one total hour. Further, you will be asked to come to the Center for Sport Performance at Cal State Fullerton. You will fill out a background inventory questionnaire and your hand and eye dominance will be determined. Following the paperwork, you will be fitted with retro-reflective markers for video data capture. You will then take 20 swings off a tee. Please be aware that your participation in this study is strictly voluntary. You may discontinue your participation at any time without consequence.

All possible attempts will be made to minimize the risks involved with the current research. Trained Kinesiology faculty and graduate students will conduct all laboratory procedures with your well-being as their first priority. All procedures will be explained and demonstrated until you are comfortable with your participation in the study. Although highly unlikely because of your experience hitting a baseball off a tee, the possible risks associated with participation in this study include musculoskeletal injury. Musculoskeletal injury may include, but is not limited to: muscle soreness, muscle strains, ligament sprains, tendon injuries and bone injuries. If you should experience any injuries or emotional distress please contact your personal doctor for treatment. You will be responsible for the costs of any treatment due to injuries sustained during this research.

Your confidentiality will be protected during the duration of this research project. All paperwork and assessment data from the study will be treated as confidential. Your name and all measures affiliated with your participation in this study will be kept confidential. Information stored on a computer database will be password protected and only the primary investigator will have direct access to it. You will be identified by participant ID on any written documents you fill-out, such as questionnaires.

By taking part in this study, we hope that you will learn valuable biomechanical information about your swing that will be beneficial with your batting and baseball training in the future.

If you have questions regarding this study or would like to be informed of the results when the study is completed, please feel free to contact Francesca Castellucci at (650)302-6573 or by email at fcastell@calpoly.edu. If you have questions or concerns regarding the manner in which the study is conducted, you may contact Dr. Steve Davis, Chair of the Cal Poly Human Subjects Committee, at (805)756-2754, sdavis@calpoly.edu, or Dr. Susan Opava, Dean of Research and Graduate Programs, at (805)756-1508, sopava@calpoly.edu.

I have read this consent form and I agree to take part in the research. I have had an opportunity to ask questions and all of my questions have been answered to my satisfaction. By signing this consent form, I willingly agree to participate in this study.

Signature of Volunteer

Date

Printed name of Volunteer

Email address

I have explained the research to the subject and answered all of his questions. I believe that he understands the information described in this consent form and freely consents to participate. I have fully explained to the above volunteer the nature and purpose, procedures, and possible risks of the research study.

Signature of Researcher

Date

Appendix B

BACKGROUND	INVENTORY
0, 10110 0110	

Name:_____

The following questions are general questions. Please answer all questions honestly and to the best of your ability.

1. What is your age? _____

2. What is your weight?_____; height?_____;

3. What type (brand) and size (length and ounces) of bat do you hit with? ______

The following are questions related to your switch hitting experience. Please answer all questions honestly and to the best of your ability.

- 1. At what age did you start hitting?
- 2. What side of the plate did you bat from first? ______
- 3. At what age did you start switch hitting? ______

4. How many years have you been switch hitting?_____

- 5. Are there any activities that you specifically perform with only your non-dominant side?
- 6. Please circle your answer to the following statement below: "At a younger age I felt more ambidextrous than my peers."

2	3	4	5	6	7				
Disagree	Somewhat	Neither agree	Somewhat	Agree	Strongly Agree				
	Disagree	or disagree	Agree						
Please explain why you chose this response:									
ć	2 Disagree xplain why	2 3 Disagree Somewhat Disagree xplain why you chose th	2 3 4 Disagree Somewhat Neither agree Disagree or disagree explain why you chose this response:	2 3 4 5 Disagree Somewhat Neither agree Somewhat Disagree or disagree Agree	23456DisagreeSomewhatNeither agreeSomewhatAgreeDisagreeor disagreeAgreeexplain why you chose this response:				

7. Do you consider yourself ambidextrous in any activity/activities other than batting?

8.	How mar	ny years did	you practice s	witch hitting befo	ore you hit in	a game s	situation?
9.	What is y	our batting	average from	the right side?			
10.	What is y	our batting	average from	the left side?			
11.	1. Why did you start switch hitting?						
12.	During a dedicate	batting pra- to your:	ctice session, a	approximately ho	w much time	(percent	age) do you
	C	ominant Si	de	Non-domin	ant Side		
13.	Please circle your answer to the following statement below: "Now that I have experience as a switch hitter, I prefer to swing from one side over the other."						
	1	2	3	4	5	6	7
	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	StronglyAgree
	Please explain why you chose this response:						

Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns.

Activity	Right-Hand Preference	Left-Hand Preference
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife		
7. Hammer		
8. Tennis Racket		
9. Striking Match		
10. Dealing Cards		

Right / Left Eye Dominant