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Laterality in the Power Five and Group of Five Conferences in Women's College Softball

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LATERALITY IN THE POWER FIVE AND GROUP OF FIVE CONFERENCES IN WOMEN'S COLLEGE SOFTBALL

by

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DISSERTATION

Submitted in Partial Fulfillment of the
Requirements for the Degree of

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DEDICATION

This dissertation is dedicated to the memory of my parents, Glen and Doreen Nachtigal. Mom and Dad, you raised five intelligent, open-minded, and kind-hearted children. You instilled in us your hopes to leave the world a better place than you found it. You taught us that it is not whether we win or lose in sport and in life, but how we play the game. For that lesson in sportsmanship and so much more, I am grateful and lucky to have had you as my parents.

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ABSTRACT

Females in sport are under-represented in data and analysis when compared to their male counterparts. This disparity also applies to women's softball in comparison to men's baseball. To help fill this gap, this study evaluated the extent and impact of laterality in women's college softball's Power Five and Group of Five conferences from 2015-2017.

This study focused on the extent of a left-sided lateral preference in women's college softball, possible interactions between throwing hand and batting preference, to what extent the platoon effect exists in the sport, and the extent of positional bias in the sport. As one of the largest studies on the laterality of women in sport, with a sample size of over 3,000 women's college softball players, this study contributes to the understanding of the manual act of throwing and the bimanual act of batting by females.

The results from this study indicated that a left-sided lateral preference occurred more often in women's softball than in the public, with slap hitters a possible cause.

However, without a method to identify which batters in softball are slap hitters, it was difficult to draw as rich of conclusions about laterality in women's softball as those drawn for men's professional baseball. The study also provided an assessment of performance variables that could impact the way the game is played and how coaches make recruiting decisions.

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CHAPTER I. INTRODUCTION

Participants in the sport of baseball have long recognized that pitcher and batter matchups are impacted by laterality, which is the preferential use and superior functioning of one side of the body over the other (Functional Laterality, 2012). Though fastpitch softball and baseball have similar rules (O'Connor, 2013), the impact of laterality on fastpitch softball, to the researcher's knowledge, has never been studied. The scientific study of softball is in its infancy when compared to baseball (Flyger, Button, & Rishiraj, 2006). Perhaps the assumption for this lack of study or use of laterality as a strategy is a belief that an effect involving laterality does not exist in fastpitch softball. This seems probable, as demonstrated by a discussion on an online message board. Reasons presented on the site DiscussFastpitch.com ("Switch Hitter ?", 2012, December 28) for dismissing the role of laterality when batters face pitchers in fastpitch softball included:

1. Softball players do not have enough time to practice switch hitting, which is when a batter is able to hit from either the right or the left side of the plate. Also, it is argued that the benefits of switch hitting are not great enough when compared to practicing hitting from just one side of the plate. One review of switch hitting in college baseball found that three percent of batters switch hit ("Why are switch hitters", n.d.). It should be noted that females playing fastpitch softball likely have as much time to practice switch hitting as their male counterparts playing baseball.
2. In baseball, batters switch the side of the plate they hit from to maximize their effectiveness against breaking balls (e.g., curveballs and sliders) while in softball there is no point in switching the lateral preference of batters because

pitchers can throw curveballs and screwballs that break toward each side of the plate. To contradict this argument, it should be noted pitchers in baseball also throw pitches that break toward either side of the plate.

3. Because the bases are closer in softball than in baseball, there is a bigger advantage to batting left-handed in softball, which explains why in softball there are never left-handed players who bat right-handed. This study researched this claim regarding whether softball has no left-handed throwers who bat with a right-sided lateral preference.
4. If handedness were important in softball, every college team would have at least one left-handed pitcher to pitch to batters with a left-sided lateral preference as is the case in professional baseball. However, if research on handedness and lateral preference in softball has not been performed, it makes sense that, therefore, teams would not see the need for left-handed relief pitchers.

This study attempts to end some of the conjecture surrounding the role of laterality in fastpitch softball by analyzing the rosters, performance data, and situational statistics of women's college softball. College-softball rosters describe the players for each team by providing information such as each player's uniform number, first and last name, position on the field, and class (e.g., freshman, sophomore, junior, or senior). Of utility in this study was that rosters also describe each player's handedness for throwing and lateral preference for batting.

Hand preference can be assessed through questionnaires and unimanual tests (Faurie, Raymond, & Uomini, 2016). Throwing hand or arm is typically one qualifier in determining hand preference (Grondin, Guiard, Ivry, & Koren, 1999), though handedness, throwing hand, and batting lateral preference are not perfectly correlated (Loffing, Sölter, & Hagemann 2014).

Because batters use both hands when swinging a baseball or softball bat rather than just a single hand, the batter's choice of side preference is a *lateral preference* rather than an indication of handedness (Guiard, 1987). Based on a recommendation that bimanual activities, such as swinging a bat, should be described as a lateral preference rather than as handedness (Loffing et al., 2014), batters will be described in this study as hitting with a right-sided or left-sided lateral preference.

The *platoon effect* is a term from baseball that describes the impact of laterality on the outcomes of at-bats. From a strategic perspective, the importance of the platoon effect can often be identified in profession baseball when a manager introduces a relief pitcher to the game who has a different handedness than the pitcher being replaced to gain an advantage due to the batter's lateral preference. Those involved in professional baseball first noticed this phenomenon in the late 1800s, though managers utilized the platoon effect only sporadically for decades (James, 2001). In the 1940s, the Brooklyn Dodgers hired statistician Allan Roth after he presented platoon splits and other findings to general manager Branch Rickey, who had never seen how his hitters performed numerically against left-handed and right-handed pitchers (Schwarz, 2005). However, it was the proselytizing on the benefits of the platoon effect by New York Yankees manager Casey Stengel and its contribution to his success in managing five consecutive championship teams from 1949-1953 that helped the platoon effect become firmly established as a strategy in professional baseball (James, 2001).

Different theories exist for the cause of the platoon effect in baseball. It was long thought that the movement of the curveball caused batters of the same lateral preference as the pitcher's throwing hand to struggle with such a pitch (Adair, 1990). PITCHf/x is a video-tracking system installed in Major League Baseball (MLB) stadiums in 2007 to track the trajectories of pitches (Nathan, 2012). Through analysis of PITCHf/x data, pitches such as the fastball, sinker, and slurve, which combines aspects of a slider with a curveball (Urban, 2005), have been found to have more of a platoon effect than curveballs, which typically have a reverse platoon effect that favors the batter when thrown by pitchers of the same handedness as the batters' lateral preference. (Marchi, 2010, April 23). In professional baseball, Grondin et al. (1999) found that left-handed throwing fielders who batted with a left-sided lateral preference hit more home runs and had higher slugging percentages than did right-handed throwing fielders who batted with a left-sided lateral preference. Right-handed throwing fielders who batted with a left-sided lateral preference had lower rates of strikeouts than did left-handed throwing fielders who batted with a left-sided lateral preference (Grondin et al., 1999). The researchers attributed the differences in batting performances to the kinematic chain model of an asymmetrical division of labor regarding the role of each hand. Walsh (2007a), however, associated the cause of the platoon effect to an overabundance of right-handed players in baseball due to positional bias. Walsh asserted that positional bias exists because left-handed throwers rarely play catcher, third base, shortstop, and second base because baseball's design favors right-handed throwers at these positions.

Softball has a long history dating back to the 1800s (Flyger et al., 2006). Though today there are only six professional women's fastpitch softball teams (Sievers, 2017), fastpitch softball at the college level in the United States is flourishing. For the 2016-2017 season in National College Athletic Association (NCAA) women's college softball, 19,999 females participated in the sport ("Sport Sponsorship, Participation and Demographics Search," n.d.). While softball is a popular sport, most of the research performed on the sport has focused on the kinesiology of the sport's athletes rather than on aspects of how the game is played.

Purpose Statement

The purpose of this study was to examine the relationship between performance and laterality in women's college softball. Specifically, this study focused on the extent of a left-sided lateral preference in women's college softball, possible interactions between throwing hand and batting lateral preference, to what extent the platoon effect exists in the sport, and the extent of positional bias in women's college softball.

Justification for Research

Male sports receive considerable interest while the attention given to female sports pales in comparison. McCann (2015) described the lack of data and analysis available for women's sports:

> While you can easily look up all 14,260,129 at-bats in the history of Major League Baseball, I have no idea how many at-bats were taken during the five years of the Women's Professional Softball League. That league folded—along with any of the data it recorded, presumably—and now the new National Pro Fastpitch League has archives that only go back to 2004. (And it appears that they haven't been updated since 2009.)

> With such incomplete data, it's hard to draw as rich of conclusions about how women play professional softball (better, worse, faster, or slower than before?). You can glean a lot more from 85 years of data than from 5. There's not only better historical data, but there's far more data recorded for men's sports too. The PGA Tour site, for instance, lists hundreds of performance stats for each player. On the LPGA site, there are only eight. (para. 7-8)

Whereas there was research on laterality and the platoon effect in professional baseball, there was no research on these subjects in women's softball at any level, to the best of the researcher's understanding.

Another deficiency in the literature was the type of sport being considered. Prominent college athletic programs, specifically NCAA Division I men's basketball and football, typically receive the bulk of event attendance, media coverage, and sponsorship. Therefore, the type of competition considered in previous research left a gap in the literature. This gap was important to fill because of the potential that women's softball embodies for females toward equality in sports and as a contribution to the elimination of gender bias.

Research Questions

R_1 To what extent is a left-sided lateral preference found in women's college softball for the Power Five and Group of Five Conferences?

R_2: To what extent do the recorded statistics vary for players who throw right and bat left, who throw left and bat left, and who throw right and bat right in women's college softball for the Power Five and Group of Five Conferences?

R_3: To what extent does a platoon effect exist in women's college softball for the Power Five and Group of Five Conferences?

R_4: To what extent does positional bias exist in women's college softball for the Power Five and Group of Five Conferences?

Hypotheses

H_1: Batters and throwers with a left-sided lateral preference are more common in women's fastpitch softball than in the general population.

H_2: Performance differences exist between players who throw right and bat left, who throw left and bat left, and who throw right and bat right.

H_3: The platoon effect exists in women's college softball.

H_4: Positional bias exists in women's college softball.

Significance of Study

While there has been an increase in women participating in sport, female athletes still face biases (Brookshire, 2016). Costello, Bieuzen, and Bleakley (2014) studied three prominent exercise journals published between 2011 and 2013 and found that of 1,382 articles involving over six million participants, women represented only 39% of the participants. Another analysis of two exercise journals during the first five months of 2015 found that women represented 42% of the participants studied (Brookshire, 2016). Cultural reasons could be to blame since women are under-represented in the media as well, which serves the reproduction of hegemonic masculinity (Greer, Hardin, & Homan, 2009; Kian, Vincent, & Mondello, 2008; Vincent, 2004). Sport is an institution where hegemonic masculinity is confirmed (Messner, 2002; Nylund, 2007). An example of apparent bias toward female athletes is demonstrated in the wage-discrimination lawsuit by members of the United States women's national soccer team. The team generated $20 million more in revenue in 2015 than the U.S. men's team, yet the women were paid approximately 25% of what the men received ("U.S. women's team files", 2016). Individuals have long been taunted as unathletic with the expression, "You throw like a girl," (Hively & El-Alayli, 2014). By analyzing laterality, an aspect of the game that involves the same act of throwing that was once used as a taunt, this study hopes to encourage the elimination of gender bias by studying the athletes who play at the highest level of women's college fastpitch softball.

Considerably less research occurs on softball, a predominantly female sport, than on baseball, a predominantly male sport. This study helps provide a type of analysis of women's college softball that men's baseball typically receives. As described by one Division-I college-softball coach, the scientific study of softball "is in the newborn stage" (Meuchel, 2013, para. 3).

Discussion and research continues on the impact and importance of laterality on the lives of humans (Brown, Roy, Rohr, & Bryden, 2006; Christman, 2010; Flatt, 2008; Selgin, 2005). Past research on handedness and brain asymmetry has set the stage for research to better understand laterality, including areas such as genome mapping and neural imaging (Porac, 2016).

As one of the largest studies on the laterality of women in sport, with a sample size of over 3,000 women's fastpitch college softball players, this study contributes to the understanding of the manual act of throwing and the bimanual act of batting in females. Furthermore, the researcher hoped that the analysis of the platoon effect, and the effect of throwing hand and batting lateral preference on performance, could be used to make suggestions for strategies in the game of softball, both with how the game is played on the field and in areas off the field such as in recruiting. An example of the potential importance of studying laterality in softball can be found in how laterality changed professional baseball. Beginning in 1914, the utilization of the platoon effect in baseball had an "almost revolutionary impact, as opposed to evolutionary" (James, 1997, p. 46).

Assumptions

Assumptions of this study were as follows:

1. The throwing hand of softball players indicated a lateral preference.
2. The data collected by the NCAA representing game events were an accurate source of data.
3. The sample was representative of the performance of student-athletes playing college softball.
4. The data were independent and normally distributed within the population.
5. The performance of one student-athlete was not dependent upon the performance of another student-athlete.
6. The size of the population was sufficient to detect significance, if it existed.

Limitations

The potential limitations of this study included:

1. Differences existed between the talent and ability of those who play in different divisions of women's college softball. Therefore, the study may not be representative of anyone beyond the population being studied.
2. The determination of hits and errors in softball was at the discretion of each game's official scorer, so rulings on hits and errors may vary by scorer.

3. The time of the study (limited historical data).
4. Inability to identify batters who slap hit. Slap hitting is when the batter runs toward the pitcher and attempts to make contact by bunting or slapping at the ball, as opposed to batters who take a full swing (Muellar, n.d.).
5. A small population of switch hitters in college softball prevented analysis beyond descriptive statistics.
6. A small population of left-handed throwers who were right-sided batters prevented analysis beyond descriptive statistics.
7. Because the season for women's college softball involves about one-third the number of games as those played in professional baseball and because the playing careers of women's college softball players are much shorter than those in professional baseball, considerably less situational data were available for the study of softball than for baseball.
8. The throwing and batting preferences for some players were tabulated more than once because they appeared on multiple rosters between 2015-2017. Therefore, figures represent total observations.

Delimitations

1. Data represent the entire population from the college athletic conferences being studied from 2015 to 2017.
2. The results of this study were indicative of events that occurred at the time the data were recorded.
3. Team rosters and statistics were available for study.

Definition of Terms

Baseball/Fastpitch Softball Pitch Types

Changeup. A slow pitch that is thrown to contrast the speed of a fastball and is intended to disrupt a batter's timing ("Changeup (CH)," n.d.).

Curveball. A pitch slower than the fastball with a large degree of movement ("Curveball (CU)," n.d.).

Fastball. Usually the fastest and straightest pitch thrown by a pitcher ("Four-Seam Fastball (FA)," n.d.).

Screwball. A pitch with movement in the opposite direction of a curveball ("Screwball (SC)," n.d.).

Sinker. A sinker is slightly slower than a fastball and has a downward movement (Bernier, n.d.).

Slider. A pitch typically thrown faster than a curveball but with less movement ("Slider (SL)," n.d.).

Slurve. A pitch with the characteristics of both a slider and a curveball (Urban, 2005).

Baseball/Fastpitch Softball Terms and Statistics

At-Bat (AB). Official at-bats are calculated by Hits + Outs – Sacrifice Hits – Sacrifice Flies + Reached By Error ("At bat," 2017).

Batting Average. A longtime standard for measuring a batter's performance, the formula for calculating batting average is Hits / At-bats (Albert, 2003).

Defensive Earned Run Average (DERA). The average number of runs per nine innings a pitcher allows based upon the expected value of an event (Hirotsu & Wright, 2005).

Earned Run Average (ERA). A common measurement for evaluating pitchers, the formula for ERA is 9 x (ER/IP) (Albert, 2003).

Fielding Independent Pitching (FIP). A metric used to evaluate a pitcher's talent for events (home runs, walks, and strikeouts) that pitchers can control, the formula for FIP is ((13 x HR) + (3 x (BB + HBP)) – (2 x K) / IP + a constant (Nachtigal, 2014a).

Net Stolen Bases (NS). A measurement for evaluating base stealers, the formula for net stolen base is Stolen Bases – (Caught Stealing x 2) (Turkenkopf, 2009).

On-Base Percentage (OBP). A measurement of how often a batter reaches base. The formula for OBP is (Hits + Walks + Hit By Pitches) / (At-Bats + Walks + Hit By Pitches + Sacrifice Flies) (Albert, 2003).

On-Base Plus Slugging (OPS). Combing a batter's on-base percentage and slugging percentage, the formula for OPS is OBP + SLG (Albert, 2003).

PITCHf/x. Sportvision's PITCHf/x tracking system uses multiple cameras to record the trajectory of each pitch in three dimensions (Fast, 2009).

Sabermetrics. The application of scientific principles to baseball, sabermetrics is the term coined by baseball-researcher Bill James referring to the Society for American Baseball Research (SABR) and metrics (Schwarz, 2005).

Plate Appearance (PA). The total number of times a batter has the opportunity to bat, the formula for a plate appearance is At-Bats + Walks + Hit By Pitches + Sacrifice Hits + Sacrifice Flies (Albert, 2003).

Platoon Effect. A phenomenon found in baseball where batters with a left-sided or right-sided lateral preference hit better against pitchers who throw with the opposite hand (Bradbury and Drinen, 2008).

Slugging Percentage (SLG). Slugging percentage is a measurement of a batter's power., the formula for slugging percentage is ([Singles] + [Doubles x 2] + [Triples x 3] + [Home Runs x 4]) / [At-Bats] or Total Bases / At-Bats (Albert, 2003).

Weighted On-Base Average (wOBA). wOBA assigns a different linear weight to each offensive event (Panas, 2010). Although the weights can change each year, an example of the wOBA formula for MLB is (0.69 x (Walks – Intentional Walks) + 0.72 x Hit By Pitches + 0.89 x Singles + 1.27 x Doubles + 1.62 x Triples + 2.10 x Home Runs / AB+ BB – IBB +SF + HBP ("wOBA", n.d.).

Win Probability. The likelihood of a participant or team winning the game given the game's state (Albert, Glickman, Swartz, & Koning, 2017).

CHAPTER II. LITERATURE REVIEW

Research on Women's Fastpitch Softball

Physiological aspects of women's softball players have received much of the attention of researchers studying the game. The windmill throwing motion of fastpitch softball pitchers is of interest to researchers, particularly regarding the study of injuries (Corben et al., 2015; DeFranco & Schickendatz, 2008; Lear & Patel, 2016; Rojas et al., 2009; Sauers, Dykstra, Bay, Bliven, & Snyder, 2011) and kinematics (Maffet, Jobe, Pink, Brault, & Mathiyakom, 1997; Nimphius, McGuigan, Suchomel, & Newton, 2016; Oliver, 2014; Oliver & Plummer, 2011; Werner et al., 2005; Werner et al., 2006; West, Scarborough, McInnis, & Oh, 2016). Studies have also evaluated the risks and types of injuries associated with softball (Briskin, 2012; Dover, Kaminski, Meister, Powers, & Horodyski, 2003; Meyers, Brown, & Bloom, 2001; Nachtigal, Kim, Lee, Seidler, & Stocz, 2016; Nadeau, Brown, Boatman, & Houston, 1990; Rice & Cogeni, 2012; Skelton & Kesslar, 2001; Skillington, Brophy, Wright, & Smith, 2017; Stanley et al., 2011), elements of batting in softball (Koenig, Mitchell, Hannigan, & Clutter, 2004; Lino, Fukushima, & Kojima, 2014; Lund, Ficklin, Faga, & Reilly-Boccia, 2015; Wendell & Jensen, 2016), the physics of softball (Kensrud, Nathan, & Smith, 2017; Nathan, Smith, & Faber, 2011; Smith, Nathan, & Duris, 2010), and psychological components of the game (Baugh, 2002; Buning, 2016; Buning & Thompson, 2015; Clement, 2004; Kellers, 2004). To the best of the researcher's understanding, there is no research involving the extent and effect of laterality in women's softball.

A Historical Perspective of Laterality Research

Handedness, an aspect of laterality, has a long and wide-ranging history that has been extensively researched. Right-handedness was identified in the fossil record of a Homo habilis who lived 1.8 million years ago (Frayer et al., 2016). A right-sided bias existed in Neanderthals and a left-handed minority existed in prehistoric groups of humans (Porac, 2016). A study of the tools used 4,000 years ago in the Neolithic period found a six percent rate of human left-handedness in Switzerland and 19% left-handedness in Germany (Spenneman, 1984). Lateralization may not be unique to just humans since non-human species demonstrate hemispheric specialization and non-human primates have been found to have hand preference (Porac, 2016). Handedness is the most investigated aspect of lateralization (Corballis, 2014). In the academic record, a meta-analysis of literature pertaining to handedness and language lateralization found over 10,000 studies in a 40-year period (Sommer & Kahn, 2009).

Biological Theories of Handedness

A pathological model of left-handedness was presented by Satz (1972) based upon increased levels of left-handedness in the intellectually disabled and those with epilepsy. The model estimated a switch in hand preference in the event of damage to the hemisphere contralateral of the dominant hand. Research by Silva and Satz (1979) proved inconsistent with Satz's model when it showed an increase in left-handedness associated with bilateral abnormalities (Pipe, 1990).

Another pathological model of handedness was presented by Bakan, Dibb, and Reed (1973). The model suggested that deviations from the norm of right-handedness are the result of environmental factors or pregnancy and birth stress causing cerebral anoxia, a lack of oxygen, to the left hemisphere of the brain. According to McManus (1981), the research presented by Bakan et al. suggested no such link. In his critique, McManus wrote:

> There seems little doubt that birth stress is unlikely to play any role in the development of left-handedness in the majority of the population. It may be concluded safely that the incidence of left-handedness need be of no concern to obstetricians anxious to monitor the efficiency of their services. (p. 496)

A hormonal model has been proposed suggesting a correlation between high levels of prenatal testosterone and various traits, including cerebral dominance (Geschwind & Behan, 1982; Geschwind & Galabruda, 1987). This theory has been disputed, with critics citing little evidence of high levels of prenatal testosterone related to left-handedness as put forth by the authors (Berenbaum & Denburg, 1995). Empirical evidence contradicting the role of high levels of testosterone and a corresponding link with an increased incidence of left-handedness involves Klinefelter syndrome, a condition believed to be associated with low prenatal testosterone (Netley & Rovet, 1982). In a critique of this hormonal model, Bryden, McManus, and Bulman-Fleming (1994) concluded:

> All things considered, then, we find the evidence to support the Geschwind and Galaburda (1987) model lacking and would suggest that psychologists and physicians have more useful things to do than to carry out further assessments of the model. (p. 155)

The rare-trait marker model (Coren & Searleman, 1990) identifies the left-handed population as having shifted away from right-handedness. The rare traits of left-handedness are markers of neurological, physical, or genetic deficits (Coren & Searleman, 1990). Some of the problems and conditions Coren and Searleman referenced as positively correlating with left-handedness include: brain damage, epilepsy, neuroticism, drug and alcohol abuse, homosexuality, aggression, criminality, intellectual disabilities, allergies, autoimmune disorders, migraines, emotionality, birth stress, chromosomal damage, poor spatial and verbal abilities, failure in school, attempted suicide, autism, vegetarianism, sleep issues, and slow maturation. Coren and Halpern (1991) published a report showing a shorter lifespan for left-handers. A best-selling book by Coren (1992), which equated the mortality of left-handers with a lifetime of heavy smoking, was heavily criticized by laterality researchers (Porac, 2016). In a critique, Harris (1993) criticized Coren and Halpern for their methodologies and scientific reasoning:

> I do not say that a longevity effect could not be in operation as one of the factors contributing to the underrepresentation of left-handers among older age groups. However, I do say that the evidence that C & H have assembled to prove that it is in operation, much less that it is the major factor, is not convincing. The evidence for the modification explanation, which they call deficient, is instead substantial and includes a variety of special features that are difficult to reconcile with a longevity effect. The evidence provided by their own baseball and next-of-kin studies is directly contravened by other studies, including new death record data. Finally, the reports linking left-handedness to accidents, birth stress, alcoholism,

> disease, and delayed physical maturation at best are inconclusive and at worst do not support their hypothesis. (p. 229)

Genetic Theories of Laterality

Prior to the introduction of genome-wide association studies, numerous genetic theories attempted to explain the predisposition of humans toward a right-sided laterality. One reason for these theories is that the laterality of offspring is influenced by parental laterality, suggesting a genetic component to handedness (McManus & Bryden, 1992).

Genetic Models of Laterality

Two single-gene models of handedness and language lateralization in humans were developed and debated for almost half a century by competing and preeminent theorists in the field: Annett and McManus. According to Bishop (1990a), the simplicity and accuracy of these single-gene models and their ability to predict the handedness of families contributed to their popularity. The theories of Annett and McManus are two of the best known genetic models to attempt to fit family data and twin data (Coren, 1996). Annett and McManus proposed that a single gene causes both handedness and cerebral dominance, although their approaches to the role of this hypothetical gene differed slightly.

Annett (1972) advanced her right-shift model of a genetic link to handedness and cerebral lateralization. Right-shift theory proposes an RS+ allele that increases the likelihood of right-handedness and left-hemispheric development of language in the brain of humans, with an RS- allele being indifferent to the assignment of handedness (Annett, 1978). Individuals with a combination of an RS-RS- allele, according to Annett, are the most likely to become left-handed but are influenced less by genetics and more by childhood or cultural interventions. Therefore, Annett proposed that right-handedness is determined genetically but that left-handedness is not. The RS+ allele operates in dominant-recessive mode in biasing cerebral dominance but in additive mode in biasing handedness (Annett, 2003).

With her balanced polymorphism hypothesis, Annett (2002) surmised that strengths and weaknesses associated with handedness were due to the unidentified genotype and that the shift toward right-handedness is a result of language localization in the left hemisphere. Annett proposed that the RS+ gene possibly evolved when hominids diverged from apes and this gene would have been helpful with speech acquisition.

McManus (1985), meanwhile, proposed a dextral/chance theory involving a hypothetical D allele which strongly influences development of right-handedness in the body and language toward the left side of the cerebrum. He labeled the alternate allele as C which produces a chance mixture of right-handers and left-handers. McManus theorized that individuals with a DD allele were strictly right-handers, a combination of a DC allele causing a 50% right-handed and 50% left-handed mix, and a CC allele mix leading to a distribution of 25% left-handers and 75% right-handers. Therefore, according to McManus, handedness is a discrete variable (Musálek, Bryden, Tichy, & Serých, 2014). McManus suggests that rather than the continuum for handedness proposed by Annett, there are two unique handedness phenotypes (Gangestad & Yeo, 1994). To account for a higher incidence of left-handedness in males and the fact that left-handed mothers produce more left-handed children than do left-handed fathers, McManus and Bryden (1992) also advanced a sex-linked moderator gene.

McManus (2004) conceded that the similarities between his theory and Annett's are far greater than the differences. However, in *Grappling with the Hydra*, a critique of Annett's (2002) book *Handedness and Brain Asymmetry: The Right Shift Theory*, McManus compares changes to right-shift theory with the mythical, multi-headed Hydra:

> Rather like Heracles fighting the Hydra, just as one head is chopped off, so another appears, so that every year or two the theory seems to mutate and a half dozen new heads to spring forth. Although mutation might imply evolution, evolution would probably be the wrong word, for the theory is essentially creationist, change resulting only from some insight on the part of Dr. Annett. (2004, p. 139).

In response, Annett (2004) suggested that McManus's dextral/chance theory was based on her work in a manner that would intentionally make it difficult to distinguish from right-side theory. Annett concluded, "The many-headed snake says something about McManus's perception of the RS (right-shift) theory, but did he really see himself as Hercules? Words suitable for academic discourse fail me" (2004, p. 149).

Klar (1996) proposed a single-gene model similar to those of Annett and McManus but where a developmental event is the pivotal cause determining whether an individual is right-handed or left-handed. According to this theory, ambidextrous individuals are left-handed but cultural influences have taught them to use either hand (Klar, 1996). In a critique of Klar's theory, Annett (2009) wrote:

> Klar has not attempted to fit his model to other studies in the literature. A basic problem is that frequencies of left-handedness vary widely. If preference is treated as a discrete variable, then incidences are unstable

> and theories are restricted in the range of incidences to which they apply.
> (p. 75).

An X-linked, three-allele model for hand preference in handwriting and handwriting posture was proposed by McKeever (2004). The model utilized McKeever's (2000) research suggesting a maternal link as the cause for an increase in left-handed sons in left-handed parents. Criticism of McKeever's findings includes that the model was created to fit his data and that the data included an inflated number of left-handed subjects (Annett, 2009).

A two-gene, four-allele model was postulated where one gene controls language lateralization and the other gene controls handedness (Levy & Nagylaki, 1972). This theory was discredited when researchers identified conflicting test data within the study (Hudson, 1975).

Gangestad and Yeo (1994) contributed their developmental-instability model of handedness, theorizing that two or more genes have led to the increased occurrence of right-handedness. The laterality performance of individuals varies from extreme left-handedness to extreme right-handedness (Annett, 2002). Studies have shown that both left-handed and extremely right-handed individuals have a higher occurrence of developmental instabilities (Musálek et al., 2014). This model proposes that a similar genotype exists for left-handers and extreme right-handers with respect to developmental instability (Gangestad & Yeo, 1994). For example, schizophrenia is a neurodevelopmental disorder that has been associated with left-handedness or extreme right-handedness (Gualtieri, Adams, Shen, & Loisell, 1982).

The gene-cultural model of Laland, Kumm, Van Horn, and Feldman (1995) posits handedness variability arises early in childhood development and is influenced by the handedness of the parents. The probability of handedness, according to this model, is the result of natural selection (Laland et al., 1995). The credibility of this theory was questioned when it could not account for the contradictory findings of a study on the handedness of children in foster care (Musálek et al., 2014).

With her article *In Defence of the Right Shift Theory*, Annett (1996) proposed that right-shift theory and dextral/chance theory better predict the distribution of handedness in families and twins than does developmental-instability theory, and that right-shift theory does an even better job of predicting handedness than does dextral/chance theory. Gangestad and Yeo (1994) highlighted the failure of the theories of Annett and McManus to account for left-handed parents who tend to produce extremely right-handed children. McKeever, Cerone, and Chase-Carmichael (2000) challenged the predictions of both Annett's right-shift theory and Gangestad and Yeo's developmental-instability theory. The back and forth between researchers concerning their competing theories of handedness continued in academic literature until the advancement of genome-wide association studies.

Genome-Wide Association Studies

With the advent of technology capable of DNA sequencing, genome-wide association studies could determine the content of a million or more base-pair changes within the DNA sequence (Bush & Moore, 2012). Numerous researchers (Arning et al, 2013; Bloss, Delis, Salmon, Bondi, 2010; Brandler et al, 2013; Francks et al., 2002; Francks et al., 2007) recommended the testing of a specific gene or genotype to check for an association with handedness only to have a genome-wide association study show no correlation (Corballis, 2014) or have their methodology criticized (Crow, Close, Dagnall, & Priddle, 2009; Piper, 2013).

In a search of the genome alleles strongly associated with handedness, analysis excluded the genetic models of Annett and McManus (Armour, Davison, & McManus, 2013). No single gene has been identified as determining handedness and language lateralization (Schmitz, Lor, Klose, Güntürkün, & Ocklenburg, 2017). Forty or more loci have been identified for possible involvement in determining handedness (Scerri et al., 2011).

The isolated arm movements of human fetuses were found to gradually increase from 8-19 weeks (de Vries, Visser, & Prechtl, 1985). In a study of fetuses 10 weeks gestation, 87.5% of the fetuses moved their right hand more than their left (Hepper, Mccartney, & Shannon, 1998). Hepper et al. (1998) theorized that it is unlikely that laterality is under control of the brain at this age, instead proposing that a muscular or spinal determination was more likely. In 2017, Ocklenburg et al. identified marked right-left differences in the spinal cord segments of fetuses eight weeks post-conception. The study concluded that genes in the spinal cord, rather than the brain, are responsible for the beginning of human handedness (Ocklenburg et al., 2017). A weakness of this study was that the sample included only five fetuses, though this sample size was based on the effects of previous studies of fetal cortical tissue (Ocklenburg et al., 2017).

A study of gene ontology, pathway, and disease association suggests handedness and language, despite long-standing speculation that the two are related, are almost independent of each other (Schmitz et al., 2017). Researchers found that the genes involved in handedness mainly contribute to structural development and are less complex than the genes involved with language lateralization (Schmitz et al., 2017). The study's authors suggest that testosterone in the developing fetal brain could play a role in handedness, and that this might explain why males have a 1.23 odds ratio for a higher rate of left-handedness than females (Papadatou-Pastou, Martin, Munafo, & Jones, 2008).

Sport Theories of Laterality

Several theories have been advanced to explain lateral-dependent outcomes in athletic competitions. Theories to explain the performances of left-handed and right-handed athletes include innate superiority hypothesis, negative frequency-dependent selection, fighting hypothesis, and strategic advantage hypothesis.

According to innate superiority hypothesis, left-handed individuals have advantages over right-handed individuals due to more efficient neurological processes (Bisiacchi, Ripoll, Stein, Simonet, & Azémar, 1985; Geschwind & Galaburda, 1987; Gursoy, 2009; Holtzen, 2000). This innate advantage enables left-handers to be over-represented in certain sports (Grouios, 2004). Researchers have identified a lack of hemispheric lateralization in left-handed individuals (Hardyck & Petrinovich, 1977; Hécaen & Sauguet, 1971), which has been associated with left-handed athletes' innate superiority over right-handed athletes. McLean and Ciurczak (1982) theorized that left-handed athletes may benefit in bimanual sporting activities, such as hitting a baseball, due to weaker lateralization of the brain's hemispheres, giving left-handers an innate superiority over right-handers. Critical response to the methods used by McLean and Ciurczak soon followed the publishing of their theory (Hemenway, 1983). Wood and Aggleton (1989) found that while left-handers may have a slight advantage in athletics over right-handers, the effect is not strong and is inconsistent. In support of the innate superiority hypothesis, left-handers have been found to have attentional advantages (Bisiacchi et al., 1985), better visuospatial abilities (Annett, 1985; Gursoy, 2009; Holtzen, 2000), improved hand-eye coordination (Taddei, Viggiano, & Mecacci, 1991), enhanced visual perception (Goulet, Bard, & Fleury, 1989; Hagemann, 2009; Loffing, Hagemann, & Strauss, 2012; McMorris & Colenso, 1996; Schorer, Loffing, Hagemann, & Baker, 2012), faster reaction times (Dane & Erzurumluoglu, 2003), and better fine-motor skills when performing bimanual activities than right-handed athletes (Judge & Stirling, 2003). Groothuis, McManus, Schaafsma, and Geuze (2013) pointed out that the studies by Taddei et al. (1991) and Judge and Stirling (2003) had small sample sizes, and more research is needed on the innate superiority of left-handers. According to Porac (2016), speculation of left-handers having an innate superiority in sport is fiction.

Innate superiority hypothesis can be difficult to distinguish from negative frequency-dependent selection (Loffing & Hagemann, 2016). Negative frequency-dependent selection purports that when a gene or trait is rare, an organism may acquire an advantage over the rest of the population (Wright, 1969). For example, if the genetic traits of an organism are rare and lead to improved fitness, this could lead to an advantage in viability or mating (Hedrick, 2011). The opposite of negative frequency-dependent selection is frequency-dependent selection, an example of which is when a common trait keeps an organism from being singled out by a predator (Hedrick, 2011). Negative frequency-dependent selection has been used to explain a consistent minority of left-handers in the human population (Faurie & Raymond, 2005).

A factor that favors negative frequency-dependent selection over innate superiority hypothesis is the advantage that left-handed athletes have in interactive sports which does not exist in non-interactive sports (Loffing & Hagemann, 2012). Interactive sports involve interaction between opponents, either direct or indirect, while non-interactive sports feature no physical interaction between opponents (Loffing & Hagemann, 2016). If left-handers truly had better spatiomotor skills than right-handers, as suggested by innate superiority hypothesis, then left-handers should also have an advantage in non-interactive sports, such as darts or snooker (Loffing & Hagemann, 2016). Left-handers have been shown to have no such advantage in these sports (Aggleton & Wood, 1990). According to Schorer, Loffing, Hagemann, and Baker (2012), the success of training methods that help athletes anticipate left-sided movements supports the negative frequency-dependent advantage hypothesis.

Left-handed combatants gain a frequency advantage when their population is limited (Raymond, Pontier, Dufour, & Møller, 1996). The fighting hypothesis is based on the theory of negative frequency-dependent selection and assumes that the benefit of being left-handed in confrontations comes with a fitness cost of overall health risks (Porac, 2016). According to the fighting hypothesis, left-handers would see their fighting advantage decrease should their frequency increase (Faurie & Raymond, 2013). A two-part test for evaluating the fighting hypothesis in athletics is, first, compare the rate of left-handed athletes in the sport to see if they participate at a higher rate than what is found for left-handedness in the public and, second, determine if left-handed participants win more often in the sport than right-handed participants (Porac, 2016). The fighting hypothesis has been used to explain the advantage of left-handed athletes in sports involving direct confrontation such as fencing, boxing, karate, and judo (Grouios et al. 2000; Raymond et al. 1996), as well sports involving indirect interactions such as baseball (Clotfelter, 2008; Goldstein & Young, 1996).

There are reasons to question the validity of the fighting hypothesis in sport. The literature on health risks associated with left-handedness is inconsistent (Groothuis et al., 2013). Left-footed soccer players were initially found to be more aggressive and less tolerant of others (Dane & Sekertekin, 2005). The findings on aggressiveness in left-footed soccer players have been used to explain the over-representation of left-handed fighters in combat sports (Groothuis et al., 2013). However, a subsequent study with a much larger cohort found no such association between left-handedness and violence (Faurie et al., 2011). The advantage of left-handed pitchers in baseball, according to negative frequency-dependent selection and the fighting hypothesis, should be due to left-handers having an advantage when they are uncommon (Clotfelter, 2008). In contrast to this prediction, Clotfelter found no evidence that pitching performance improved based upon the rarity of left-handed or right-handed pitchers. A review of mixed martial arts matches showed that while left-handed fighters were substantially over-represented in the sport, no increase in the likelihood of winning was associated with left-handed fighters (Pollet, Stulp, & Groothuis, 2013). While the fighting hypothesis can be used to explain why left-handedness still exists from an evolutionary perspective, it fails to explain why left-handedness first appeared in humans (Mastin, 2012). Though weak evidence supports the fighting hypothesis, no strong evidence is available to dismiss it (Groothuis et al., 2013).

The strategic advantage hypothesis proposes that left-handed athletes gain an advantage due to unfamiliar strategies and patterns of attack in interactive sports (Faurie & Raymond, 2005). The strategic advantage of left-handed athletes is likely a subcomponent of frequency-dependent selection (Loffing & Hagemann, 2012). Coren (1992) noted that left-handed boxers have an advantage over right-handed boxers and attributed this advantage, in part, to the left-handed style of attack being infrequently encountered. In 1560, Italian fencing master Camillo Palladini was encouraging fencers to practice against left-handed opponents to gain familiarity with the left-handed fighting style (Harris, 2010). Fencing and baseball were also identified by Coren (1993) as giving left-handed participants a strategic advantage. Left-handed athletes have been recognized as having a strategic advantage in other indirect interactive sports including cricket, table tennis, tennis, and volleyball (Brooks, Bussiére, Jennions, & Hunt, 2004; Grouios, Tsorbatzoudis, Alexandris, & Barkoukis, 2000; Wood & Aggleton, 1989). The motor responses to left-handed attacks may be practiced less (Hagemann, 2009). Support for the strategic advantage hypothesis can be found in studies showing that sports lacking interaction, such as darts and golf, have no over-representation of left-handed players (Aggleton & Wood, 1990) while interactive sports, such as boxing and basketball, have higher participation by left-handed individuals (Grouios et al., 2000). A weakness of the strategic advantage hypothesis is that the theory lacks experimental evidence (Groothuis et al., 2013).

Laterality in Indirect-Interactive Sports

When compared to the general population, left-sided athletes have been found with greater frequency at the elite level of individual interactive sports and in team sports featuring one-on-one interactions (Loffing & Hageman, 2016). Direct interactive sports, such as boxing, fencing, and judo, involve athletes who are in close physical proximity to one another and have the highest rates of left-handedness (Grouios et al., 2000). In indirect interactive sports, such as table tennis, tennis, and volleyball, left-handedness is found at a slightly lower rate than in direct interactive sports but higher than in non-interactive sports (Grouios et al., 2000). Indirect-interactive sports are those where some form of distance prevents an athlete from directly manipulating the actions of their opponent (Loffing & Hageman, 2016). Only males have a higher proportion of left-handed participants in direct than in indirect interactive sports (Groothuis et al., 2013). Non-interactive sports, such as darts, golf, snooker, and bowling, have rates of left-handedness that more closely reflect that of the general population (Aggleton & Wood, 1990). In non-interactive competition, the participant is primarily on offense and is attempting to perform well for oneself (Deci & Olson, 1989). The overall percentage of left-handedness has been found to be 8.6% for women and 11.6% for men (McManus, 2002).

Women are under-represented in research studies appearing in sport and exercise medicine journals (Costello, Bieuzen, & Bleakley, 2014). Therefore, it would not be surprising if women were also under-represented in studies of laterality in sport. The following review of laterality studies pertains to indirect-interactive sports and, when available, places an emphasis on studies involving the laterality of female athletes.

Badminton

In an analysis of left-handedness in badminton players, 11.8% of the 17 women on the elite Danish badminton team were found to be left-handed (Raymond, Pontier, DuFour, & Møller, 1996). The study's survey noted that overall in the interactive sports surveyed, 10.7% of the females sampled were left-handed compared to 9.9% in non-interactive sports and 7.7% of the population. The study's authors concluded that the findings of male badminton players were consistent with the fighting hypothesis but that the theory applied less to females since they fight less and have a lower rate of left-handedness. The overall sample size for the study reflects a gender discrepancy, with a sample size of 13,205 male athletes and 1,1767 female athletes.

In a study utilizing the Edinburgh Handedness Inventory to measure the dominant hand of Japanese badminton players 16-45 years of age, 5.2% of the females surveyed were left-handed, one percent were ambidextrous, and 93.8% were right-handed (Demura et al., 2006). In an analysis of the combined handedness rates for males and females, the study divided the participants by experience level and found that just 2.2% of experienced badminton players were left-handed while eight percent of inexperienced players were left-handed. It should be noted that in Japan, as in many cultures, being left-handed is discouraged (McManus, 2002). Japanese schools as recently as 1970 forbade students from writing with their left hand (McManus, 2002). Only 3.1% of those surveyed from seven Japanese prefectures write with their left hand (Demura et al, 2006).

In the rankings of the best male badminton players in the world, 16% were left-handed (Lanzoni, Semprini, Di Michele, & Merni, 2013). No statistics showing the handedness of female professionals were mentioned in the study.

The use of a racket in sports such as badminton is thought to be similar to the act of throwing (Moynes, Perry, Antonelli, & Jobe, 1986; Buckley & Kerwin, 1988; Ryu, McCormick, Jobe, Moynes, & Antonelli, 1988). Demura et al. (2006) found that a combined total of 5.3% of females and males throw with their left hand.

Baseball

Although batting in baseball is typically referred to as batting left-handed or right-handed, it has been recommended that laterality researchers refer to bimanual activities, such as swinging a bat, as a lateral preference rather than by handedness (Loffing et al., 2014). When hitting with a right-sided lateral preference, the batter's left shoulder faces the pitcher and the batter's left hand is nearest to the knob of the bat with her right hand placed just above the left. When hitting with a left-sided later preference, the batter's right shoulder faces the pitcher and the batter's right hand is nearest the knob of the bat with the left hand placed just above the right. A lateral preference for an asymmetrical bimanual action, such as swinging a baseball bat, is often predicted by hand preference (Grondin et al., 1999). However, because unilateral activities correlate higher with handedness than do bilateral activities (Loffing et al., 2014), throwing in baseball or softball is referred to by the researcher as handedness while batting is referred to as a lateral preference.

Due to baseball's long history, the interest of its fans in the game's statistics, the sabermetrics movement, and the availability of data, a considerable body of non-peer reviewed and peer-reviewed research exists regarding the effect of manual and bimanual laterality on the sport. Therefore, this section is divided into non-peer reviewed and peer reviewed research.

Non-peer reviewed baseball research.

In 1871 Bob Ferguson became professional baseball's first switch hitter, meaning that he could bat with either a left-sided or right-sided lateral preference (James, 2001). This is proof of an understanding of the importance of pitcher handedness and batter lateral preference according to James, who wrote, "Why would you switch hit if you didn't think there was an advantage to batting left against a right-hander?" (p. 117).

Alternating multiple players at the same position of varying lateral preference to gain a hitting advantage was utilized in 1886 by Captain Anson, manager of the Chicago White Stockings (Nawrocki, 1995). In baseball this phenomenon is called the platoon effect, which is when batters hit better when facing pitchers who throw with the opposite hand of the lateral preference of the batter (Bradbury & Drinen, 2008). By substituting right-batting rookies Jocko Flynn or Jimmy Ryan for the left-batting Abner Dalrymple and George Gore, Anson could take advantage of the platoon effect to gain a statistical advantage (Nawrocki, 1995). On May 6, 1886, a reporter from the Chicago *Inter Ocean* newspaper documented Anson's utilization of the platoon effect:

> The team presented by Captain Anson had particular reference to the effectiveness of [Lady] Baldwin, Detroit's left-handed pitcher, and Dalrymple and Gore, both left-handed batters, were accordingly laid off, Flynn and Ryan taking care of left and center field (Nawrocki, 1995, p. 34).

In 1966, Cook published *Percentage Baseball* in which he asserted that the platooning of hitters cost teams up to 125 runs per season and the platooning of pitchers cost teams 113 runs on average per season (Schwarz, 2005). In his review of the book, Lindsey (1966) wrote: "It is written in a lively and amusing style; but, unfortunately, some of the mathematical presentations which form the heart of the book are atrocious" (p 1088). In his *1981 Baseball Abstract*, James (1981) wrote: "Cook knew everything about statistics and nothing at all about baseball--and for that reason, all of his answers are wrong, all of his methods useless." (Lederer, 2004, para. 12). James (2011) also wrote of Cook, "He disliked platooning, based apparently on the fact that he didn't have any stats on the subject." (para. 7).

In a review of MLB pitchers from 1984-1989, Shaughnessy (1989, March 31) showed that left-handed starting pitchers had better won-loss records and lower earned run averages (ERA) than did right-handed starting pitchers. Won-loss records and ERA are not the best metrics to evaluate the ability of pitchers. The won-loss records of pitchers are affected by factors that are largely out of the control of pitchers, such as how many runs offenses score for the pitchers (Baumer & Zimbalist, 2014). ERA is a better measurement of pitching ability than pitching won-loss records, although this metric also has some inherent issues (Law, 2017). ERA, a rate statistic measuring the number of runs a pitcher allows on average for every nine-innings pitched, has several shortcomings including a subjective element since errors are judged by official scorers, the performance of relief pitchers can affect the ERA of starting pitchers, and pitchers with good defense will typically give up fewer earned runs than those with poor defense (Winston, 2009).

It was thought that the break of the curveball caused batters of the same lateral preference as pitcher handedness to struggle because they swing too quickly at the curveball due to its movement away from the batter and slower speed (Adair, 2002). Speculation on the relationship between the curveball and the platoon effect continued until the introduction of PITCHf/x to MLB. PITCHf/x is a motion tracking system that uses multiple cameras to track pitch trajectory in three-dimensions (Sievert, 2014). Using PITCHf/x data and multi-level modeling, Marchi (2010, April 23) identified the pitch types of a slurve and a sinker as having the most extreme platoon splits of any pitches. Meanwhile, curveballs were shown to have a reverse platoon effect, meaning that when pitchers and hitters have the same lateral preference, it is typically not a detriment to the batter when a curveball is thrown but instead gives the batter an advantage (Marchi, 2010, April 23).

In a study comparing the platoon effect splits for the first half of the playing careers to the second half of the careers of professional baseball players, right-preference batters were found to have a coefficient of determination of .0053 for batting average, .0171 in on-base percentage, and .0302 in slugging percentage (Click, 2006). The coefficient of determination for left-preference batters for batting average, on-base percentage, and slugging percentage were .0587, .0693, and .0943, respectively (Click, 2006). While these correlations are low, according to Click they show that left-preference batters are considerably more consistent in the platoon effect than are right-preference batters.

It has been proposed that the asymmetrical nature of baseball favors left-preference batters, whose clockwise swing turns them toward first base as opposed to right-preference batters whose counter-clockwise swing turns them toward third base (McManus, 2002). Left-preference batters are also thought to gain an advantage by starting closer to first base when in the batter’s box than right-preference batters (Hertzel, 1975). Contrary to these assumptions, Walsh (2007a) found that left-preference batters in

MLB get fewer infield hits than do right-preference batters. Walsh attributed this discrepancy to left-preference batters hitting more groundballs to the right side of the infield, which is a shorter throw to first base, than most of the groundballs that right-preference batters hit, which are to the left side of the infield and farther away from first base.

Walsh associated the cause of the platoon effect with an overabundance of right-handed players in the game due to positional bias. Right-handed fielders dominate four positions in baseball: catcher, second base, shortstop, and third base. This positional bias exists because, due to the rules of the game, these positions favor a right-handed thrower. The other positions in baseball, which include first base and the outfield positions, do not favor a player by throwing hand. Walsh analyzed these positions according to the number of at-bats these positions had by lateral preference and the corresponding batting averages from 2000-2006, as shown in Table 2.1.

Table 2.1

At-Bats and Batting Average by Positions

POS	AB L	AB R	AVG L	AVG R	L Minus R
1B-OF	243,784	223,599	.276	.275	.001
C-3B-SS-2B	65,579	343,551	.269	.266	.003

Note: Grouped according to first basemen and outfielders (1B-OF), and catchers, third basemen, shortstops, and second basemen (C-3B-SS-2B), displaying total number of at-bats by left-preference batters (AB L), right-preference batters (AB R), batting average for left-preference batters (AVG L), right-preference batters (AVG R), and the differential in batting average between left-preference batters and right-preference batters (L Minus R) (Walsh, 2007a).

The batting averages for left-preference batters and right-preference batters who play first base and outfield are virtually even, as are those for left-preference batters and right-preference batters who play catcher, third base, shortstop, and second base (Walsh, 2007a). Due to an overabundance of right-handed pitchers, batters face more right-handed pitchers than left-handed pitchers. The large discrepancy in the number of at-bats for right-handed catchers, third baseman, shortstops, and third basemen skews the overall performance of batters in favor of those with a left-sided lateral preference (Walsh, 2007a). Walsh posits that the platoon effect is caused mostly by positional bias and the need to populate certain positions with right-handed throwers.

Through an analysis of the platoon splits for pitchers from 1957-2006, Walsh (2007b) determined that the average platoon split according to on-base percentage was .065. Walsh then identified pitchers with significantly higher and lower platoon splits than the average and estimated the types of pitches that each of these pitchers threw. By assigning a point system to the pitches in each pitcher's repertoire, Walsh found, "It really appears that pitchers who depend on the slider are more susceptible to having a large platoon differential, compared [with] pitchers who prefer the curveball or change up" (2007b, p. 168). Walsh also found that pitchers with the most extreme platoon splits often threw with a side-arm motion.

Platoon splits, which differ individually for pitchers and batters, correlate for players from one season to another, though more so for left-handed pitchers, right-handed pitchers, and left-preference batters than for right-preference batters (Tango, Lichtman, & Dolphin, 2007). The averages for platoon splits from 2000-2004 are shown in Table 2.2 according to on-base percentage (OBP) and weighted on-base average (wOBA). Tango et al. introduced the rate statistic wOBA, which assigns a linear weight to each batting event and is considered the best of baseball's new rate statistics (Law, 2017). Skill variations in Table 2.2 represent standard deviations.

Table 2.2

Average Platoon Splits in MLB from 2000-2004

	RHB	LHB	SHB	RHP	LHP
Average OBP	.333	.349	.344	.338	.342
OBP skill variation	.041	.040	.029	.023	.025
Average OBP platoon split	.017	.019	.002	.025	.011
Platoon skill variation	.014	.016	.022	.021	.027
Average wOBA	.335	.349	.338	.340	.342
wOBA skill variation	.046	.045	.031	.024	.025
Average wOBA platoon split	.017	.027	.001	.025	.019
Platoon skill variation	.013	.018	.025	.022	.027

(Tango et al., 2007)

The difference in hitting in Table 2.2 favors left-preference batters by .016 in OBP and .014 in wOBA. Pitchers, meanwhile, are more balanced. Using Table 2.2 for its skill-variation measurements, Tango et al. concluded that while the variation in overall skill levels is less for pitchers than for batters, variation in platoon splits are higher for pitchers than for batters. The authors attributed the higher platoon skill variation to differing pitch-type repertoires and arm angles in pitcher throwing motions.

Additional findings by Tango et al. regarding lateral preference in MLB included that switch hitters on average have almost no platoon split but have a large range in splits, pitchers who are less effective against batters of a similar lateral preference are not rare, pinch hitters should only be used against pitchers of the opposite handedness when the batter being replaced is a much poorer hitter, platooning two players of opposite lateral preference at a position is an effective strategy to increase overall scoring, and a method for neutralizing an opponent's ability to platoon is to use starting pitchers who have small platoon splits.

Tango et al. identified the top left-preference batters in the league when facing right-handed pitchers and left-handed pitchers in MLB over a three-year period. A correlation between the performance of these same top batters and their performance in the subsequent season led Tango et al. to conclude that the platoon effect reflects an inherent ability by the top batters to hit pitchers who throw with the opposite hand. This finding contradicts a study by Albert and Bennett (2003), who looked at batting performance over a four-year period and concluded that there was no relationship between a batter's ability to hit opposite-handed pitching and that same ability in the subsequent season. Albert (2017) would later admit that his previous analysis of the platoon effect was basic and seemed flawed.

Right-preference batters need about 2,000 plate appearance and left-preference batters 1,000 plate appearances for their platoon split to be considered reliable (Tango et al., 2007). The authors determined that platoon splits of right-handed pitchers become reliable around 700 plate appearances while left-handed pitchers become reliable near 450 plate appearances. Switch hitters require 600 plate appearances against left-handed pitchers before their platoon splits become reliable (Tango et al., 2007).

Inspired by Tango et al. (2007), Walsh (2007b), and Marchi (2010, April 23), Cross (2015) used PITCHf/x data to analyze pitcher arm angles and the impact on the platoon effect. Based on a ridge regression model, Cross found that from a median arm angle of 50 degrees, right-handed pitchers who throw entirely four-seam fastballs would have a platoon split of 19 points in wOBA while left-handed pitchers who throw entirely four-seam fastballs would have a platoon split of 20 points. Having established a baseline, as shown in Table 2.3, Cross then estimated the impact of changes to the pitcher's arm angle and pitch repertoire on the platoon effect.

Table 2.3

Platoon Split Changes

Adjustment	RHP Platoon Effect	LHP Platoon Effect
+10 degrees arm angle	-5.7	-6.7
+10% sinkers	+1.8	+2.3
+10% sliders	+2.2	+4.9
+10% curves	-5.1	0.0
+10% cutters	-1.3	-0.9
+10% splitters	-6.4	-0.3
+10% change-ups	-4.0	-9.1
>50% knuckleballs	-18.0	NA

Note: Changes in the platoon effect estimated by points of wOBA for right-handed pitchers (RHP) and left-handed pitchers (LHP) (Cross, 2015).

While MLB managers will add left-handed batters to their lineups when facing right-handed pitchers, Cross found that managers appear to pay little attention to the platoon splits of opposing pitchers when filling out their lineup cards.

Albert (2015) collected play-by-play data and used the R programming language to compare the platoon effect in MLB over six decades. Comparing the handedness of pitchers and the lateral preference of batters, Albert found that the percentage of right-handed pitchers has steadily increased to over 70% as of 2014, the use of right-handed pitchers in the ninth inning peaked in 2004 at over 80%, and the use of right-preference batters decreases as the game goes along with the smallest proportion of right-preference batters appearing in the ninth inning.

Albert also analyzed the platoon advantage of pitchers every ten years (see Figure 2.1).

Figure 2.1

Platoon Advantage by Pitcher Handedness

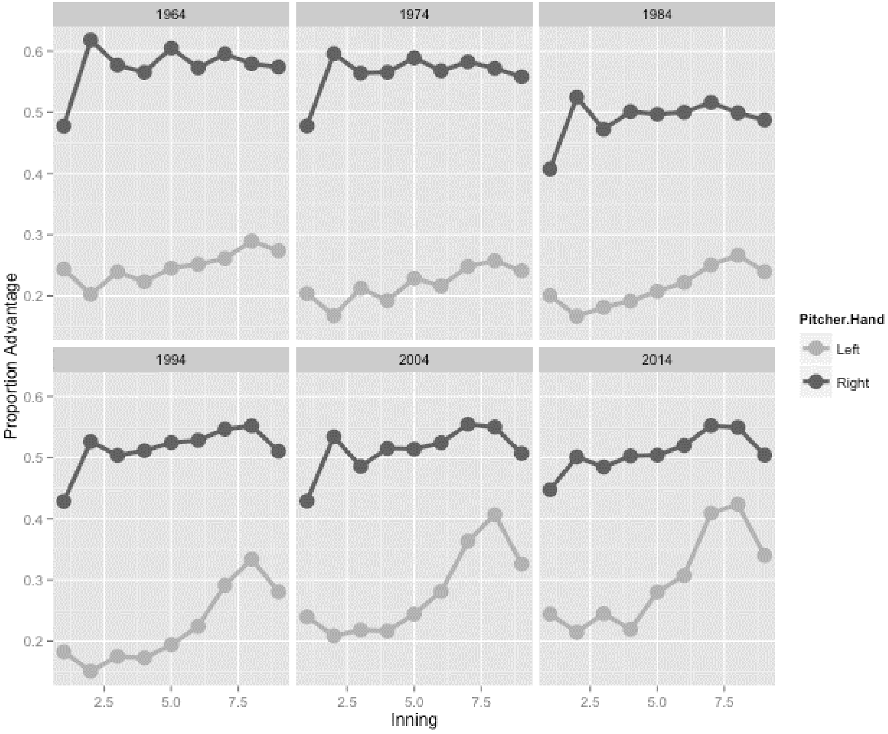


Figure 2.1: The platoon advantage for left and right-handed pitchers over the course of a nine-inning game every 10 years from 1964-2014 (Albert, 2015).

As shown in Figure 2.1, left-handed pitchers have generally reduced the platoon effect gap with right-handed pitchers since 1964, for right-handed pitchers the platoon effect has less variation as the game progresses, and left-handed pitchers gain an advantage in the platoon effect on average as a game progresses until the ninth inning (Albert, 2015).

Albert (2017) would revisit platooning by analyzing play-by-play data according to wOBA for the 2016 MLB season. The platoon advantage was calculated as a percentage of when a hitter faced a pitcher who threw with the opposite arm (Albert, 2017). Albert found that as plate appearances increase over the course of a season, the percentage of batters having the platoon advantage in batter and pitcher matchups typically decreases, as shown in Figure 2.2. The decrease is likely due to players playing full-time at their position who will therefore face pitchers of the same handedness as their batting laterality preference over the course of a season than would players who share a position.

Figure 2.2

Platoon Advantage by Plate Appearances

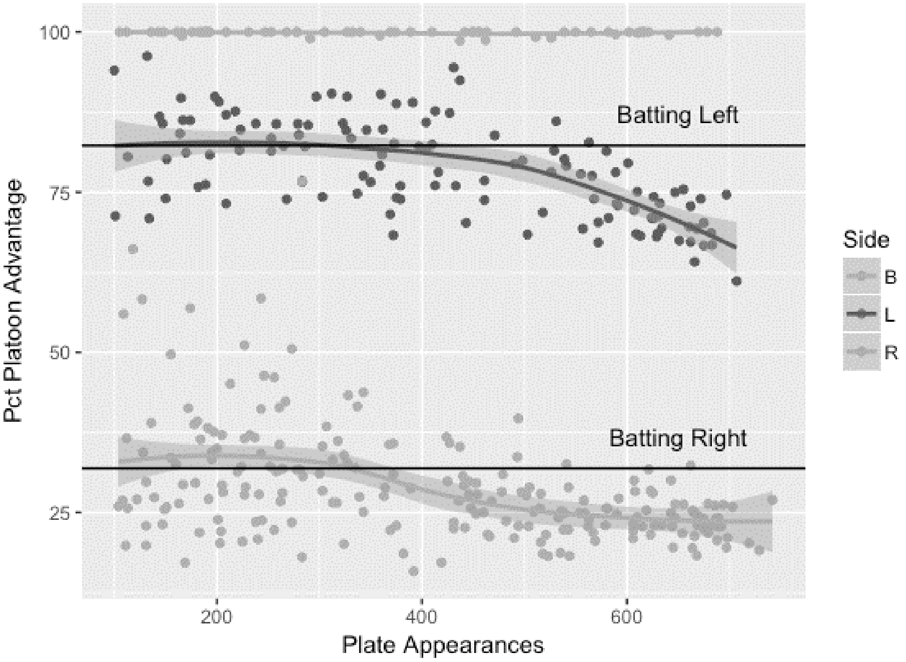


Figure 2.2: The platoon advantage for switch hitters (B), left-preference batters (L) and right-preference batters (R) by percentage in 2016 (Albert, 2017).

In Figure 2.2, Albert shows that left-preference batters have a large platoon advantage over right-preference batters. The overall platoon advantage for all batters is 53%, with switch hitters had a platoon advantage in nearly 100% of at-bats (Albert, 2017).

Using beta-binomial regression, Robinson (2017) found that MLB batters with a left-sided lateral preference get a hit about one percent more often than right-sided batters. Robinson also used a Bayes estimation to show that with between 1,000 to 10,000 at-bats, any difference between left-sided and right-sided batters will converge.

Peer reviewed baseball research.

By evaluating 12,000 at-bats in Major League Baseball (MLB) and the International League for the 1951-52 seasons, Lindsey (1959) found that batting average increased from .231 when batters faced pitchers of the same lateral preference to .263 when batters faced pitchers of the opposite lateral preference. Overall, left-preference batters hit .258 as compared to .240 for right-preference batters, which Lindsey suggested was due to a profusion (73% of the at-bats) against right-handed pitchers. Lindsey noted that slugging percentage would be a preferable metric to batting average because slugging percentage adds a weight to each type of hit while batting average treats all hits as equal, however he indicated that he used batting average because of its general use.

In a study of 28 college baseball players, eye dominance was thought to interact with hand dominance and have an impact on batting performance (Adams, 1965). Adams found that batters with the same eye dominance as batting lateral preference had a slightly higher batting average than batters with crossed-eye dominance and batting lateral preference. Contrary to the findings of Adams, a study of 410 players in the Los

Angeles Dodgers organization who played from 1992-1995 found no statistical significance when evaluating the performances associated with the dominant eye and laterality of pitchers and batters (Laby, Kirschen, Rosenbaum, & Mellman, 1998).

MLB players who bat with a left-sided lateral preference and throw left-handed were found to have considerably higher batting averages than those who bat with a right lateral preference and throw right-handed (McLean & Ciurczak, 1982). It was theorized by McLean and Ciurzak that this difference could reveal neurological differences between the two groups, but such a theory should have been refuted when the researchers found no difference in the career batting averages of batters with a right lateral preference who throw right-handed and batters with a right lateral preference who throw left-handed (Wood & Aggleton, 1989). McLean and Ciurczak also faced criticism for their methodology (Hemenway, 1983).

Rather than hemispheric lateralization as the cause of the advantage in the batting average of left-handed batters, Wood and Aggleton (1989) proposed that a batter's stance should be considered. Citing the correlation between hand preference and foot preference found by Porac and Coren (1981), Wood and Aggleton surmised that foot preference may play a role in batting outcomes since the back foot supports the batter's weight and contributes to balance. Contrary to how hitting was taught in the 1980s, the role of the back foot is often viewed with less importance in hitting today. A rotational approach to hitting has permeated baseball and softball rather than the linear approach that emphasizes a transfer of weight from one foot to the other, as described by Wood and Aggleton. In support of a rotational approach to hitting, trunk rotation has been found to be significantly correlated with bat velocity during the swing (Chu, Keenan, Allison, Lephart, & Sell, 2014).

Albert (1994) considered eight situation variables for 154 MLB players who had at least 390 at-bats in the 1992 season. Other than a pitcher getting ahead by two strikes in the count, Albert found no factor had more of an impact on batting average than the laterality of pitcher and hitter matchups. A median batting average difference of 20 points was found when the batters were of opposite laterality rather than the same laterality. Albert's analysis, which used Bayesian hierarchical models, is shown according to boxplots in Figure 2.3.

Figure 2.3

Situational Variables

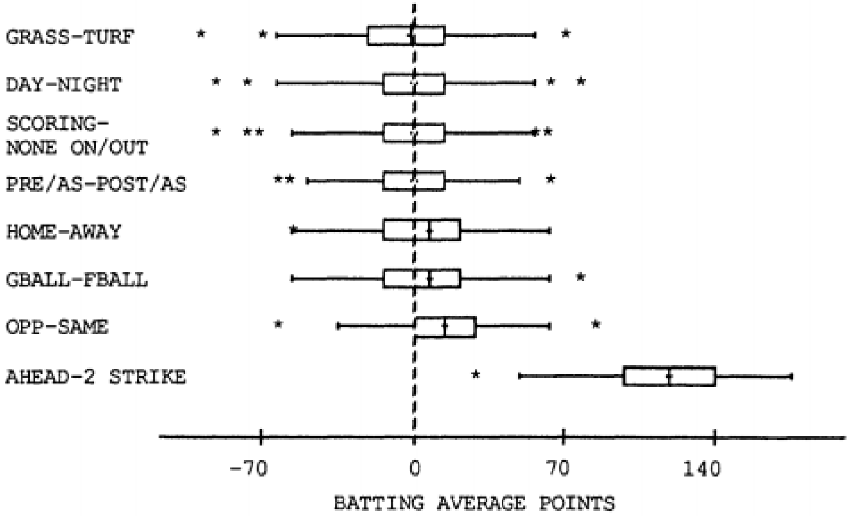


Figure 2.3: Boxplots for the differences in the posterior means of eight situational variables according to batting average (Albert, 1994).

A study by Yates (2008) reproduced Albert's methodology but used on-base percentage plus slugging percentage (OPS) rather than batting average. OPS combines the ability to get on base with the ability to hit for power (Thorn & Palmer, 1984). Like Albert, Yates also found that other than when a pitcher is ahead in the count by two strikes, the opposite throwing arm versus the same throwing arm had the largest median differential. The median effect for either the opposite or the same throwing arm in MLB, according to Yates, was 81 points in OPS in 2006 and 101 points in OPS in 2007. As a metric, OPS is an improvement on batting average because it takes into account ways to get on-base other than just via hits and it distinguishes different types of hits, but it is questionable because it combines a proportion metric, on-base percentage, with the average metric, slugging percentage (Albert et al., 2017).

By applying the laterality data of Thorn and Palmer (1985) to evolutionary stable strategy (ESS), Goldstein and Young (1996) found that a mixed stable strategy accurately predicted the evolution of a left-sided lateral preference in MLB. Goldstein and Young posited that over time the laterality population in MLB will develop and adjust to advantageous and disadvantageous traits until frequency-dependent strategies achieve equilibrium. Figure 2.4 shows the increase in left-preference batters, a decrease in right-preference batters, and a slight increase in switch hitters in MLB over the 110 years surveyed.

Figure 2.4

Proportion of Batter Lateral Preference in MLB

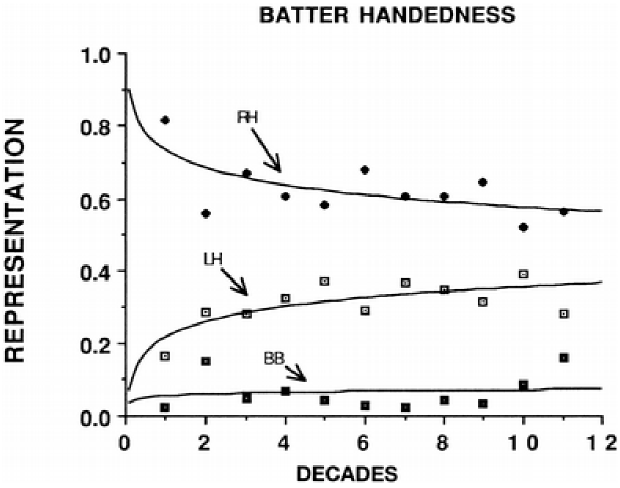


Figure 2.4: The proportion of batters with a right lateral preference (RH), left lateral preference (LH), and switch-hitting (BB) batters in MLB for 11 decades represented as trendlines, with data points along the trendlines representing the estimates of the logarithmic equation by decade (Goldstein & Young, 1996).

The proportion of left-handed pitching in MLB has also increased and then stabilized from 1876 to 1985, as shown in Figure 2.5.

Figure 2.5

Proportion of Pitcher Handedness in MLB

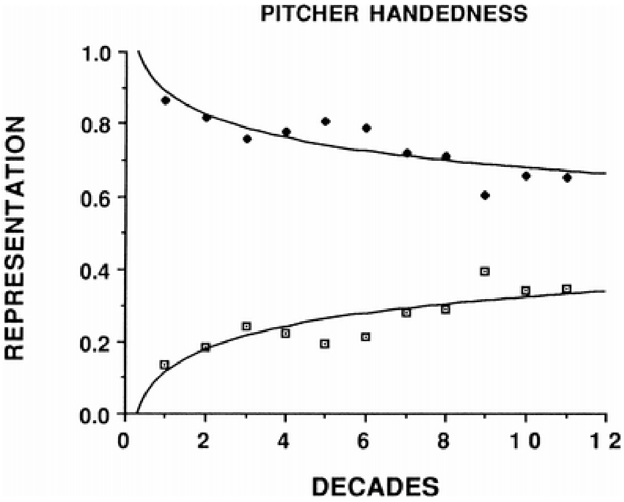


Figure 2.5: The proportion of left-handed

(lower trendline) and right-handed pitchers
(upper trendline) in MLB over 11 decades
(Goldstein & Young, 1996).

Batter left-sidedness increased faster than pitcher left-handedness in two decades: 1886-1895 and 1916-1925 (Goldstein & Young, 1996). Otherwise, the converging pattern for the lateral preference of batters and the handedness of pitchers suggests an ESS in MLB according to Goldstein and Young.

Goldstein and Young utilized the mean values for batting average, slugging percentage, and on-base percentage in their calculations. The authors predicted that equilibrium would be achieved when 31% of pitchers in MLB are left-handed, 27% of batters are left-handed, and 11% are switch hitters. However, a study by Clotfelter (2008) found different frequency-dependent associations.

To test negative frequency selection, Clotfelter (2008) looked at the effect that the population of left-handed or right-handed pitchers in MLB had on performance from 1957-2005. Pitchers were evaluated with ERA. Using multiple linear regression, Clotfelter found that right-handed pitchers were more successful when they were relatively rare in MLB, although right-handed pitchers still substantially outnumbered their left-handed counterparts. Clotfelter theorized that when a ratio of 67% right-handed pitchers and 33% left-handed pitchers existed, for example, then cognitive representations resulted in improved performance of pitchers. Left-handed pitchers were more successful when their population increased, which is contrary to negative frequency selection (Clotfelter, 2008). The ratios of handedness for pitchers were found to change randomly (Clotfelter, 2008). Clotfelter proposed that the balance of pitchers by handedness disrupts the ability of batters to form a cognitive representation, resulting in lower batting averages. This post-hoc interpretation of his findings caused Loffing and

Hagemann (2012) to caution against accepting Clotfelter's findings without further investigation.

Clotfelter stated that in addition to batting average, he also evaluated batters according to on-base percentage and slugging percentage but did not report his findings. This is unfortunate because on-base percentage and slugging percentage correlate better with runs scored than does batting average (Law, 2017).

Just as Goldstein and Young (1996) applied game theory to laterality in professional baseball, so too did Flanagan (1998) by using a mixed-strategy models approach. Flanagan constructed models to predict laterality proportions of pitchers and lateral preferences of batters in MLB for the 1995 season. Neither a 2 X 2 model by Flanagan that excluded switch hitters nor a 3 X 2 model that included switch hitters proved to be accurate. Nevertheless, Flanagan concluded that empirical data supported:

- The shortage of left-handed pitchers is due to human biology. Meta-analysis suggests a rate of left-handedness in men of 12% (Papadatou-Pastou, Martin, Munafò, & Jones, 2008).
- Batters who naturally throw right-handed take up batting left or switch hitting because they can gain an advantage due to the shortage in left-handed pitching.
- The increase in left-handed pitchers was a response to the success of left-handed pitchers early in the history of MLB.
- A rise in switch-hitting could be due to an increase in the number of left-handed pitchers. Flanagan suggested that switch hitters, 93.8% of whom threw right-handed in 1995, have less natural hitting ability than other

> batters. In 1995, 53.6% of left-preference batters in MLB threw right-handed (James, 1995).

Flanagan attributed the platoon effect to the movement of curveballs.

Grondin, Guiard, Ivry, and Koren (1999) found performance differences between MLB batters depending upon their throwing hand, as shown in Figure 2.6. In their study of MLB players from 1871-1992, Grondin et al. concluded that left-preference batters who throw left-handed were superior batters to left-preference batters who throw right-handed according to the power categories of home runs and slugging percentage. Left-preference batters who throw right-handed were less likely to strikeout than were left-preference batters who throw left-handed (Grondin et al., 1999). No significant differences were found in the study between these two groups in batting average, walks, or stolen bases.

Left-preference batters who throw right-handed outperformed right-preference batters who throw right-handed in every offensive category except stolen bases, which showed no significant difference (Grondin et al., 1999). Left-preference batters who throw left-handed were also found by the study's authors to outperform right-preference batters who throw right-handed in every category but strikeouts, where there was no statistical difference.

Figure 2.6

Mean Performance Scores

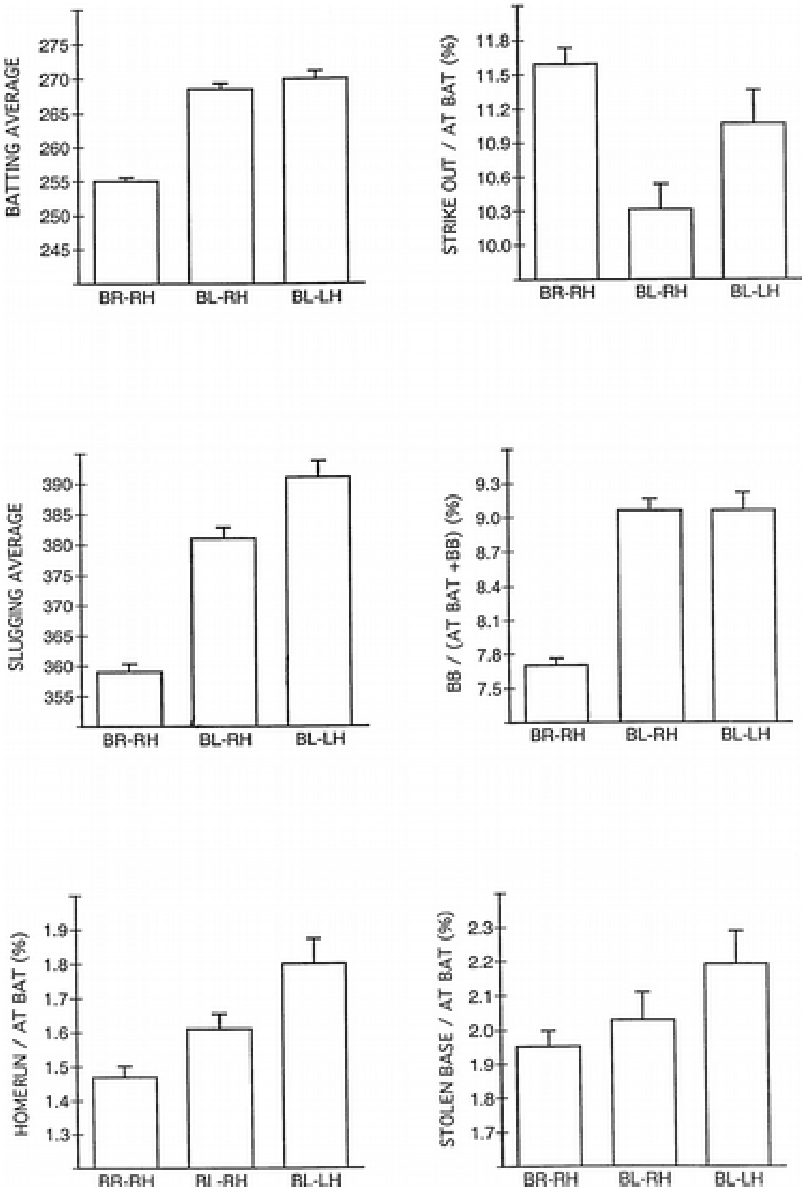


Figure 2.6: Performance scores for the study's six dependent variables according to right-preference batting and right-handed throwing players (BR-RH), left-preference batting and right-handed throwing players (BL-RH), and left-preference batting and left-handed throwing players (BL-LH) (Grondin et al., 1999).

Switch hitters were not considered for the study due to a lack of data (Grondin et al., 1999). While 3,355 players met the criteria for the study of having had 502 plate appearances, only 18 players were identified who threw left-handed but were right-preference batters (Grondin et al., 1999). Due to their rarity, left-handed throwers who batted right were not considered for analysis (Grondin et al., 1999).

By analyzing height data, and weight data, and stolen base totals, Grondin et al. found no evidence that the players who batted left and threw right-handed were an unusual population regarding their potential for power hitting.

To explain the performance differences, Grondin et al. referenced Guiard's (1987) kinematic chain model, which posits that one hand has a preferred role and the other hand a non-preferred role. Grondin et al. theorized that the hitting differences between left-preference batters and right-preference batters were due to either hand dominance or hand specialization.

In an analysis of the relative age effect in baseball, Grondin and Koren (2000) found that the trimester of birth was statistically significant for right-handed pitchers and batters in MLB. The birth trimester for right-handed pitchers in MLB peaked for those born in the first six months of the year, however left-handed pitchers peaked for those born in the third trimester (Grondin & Koren, 2000).

Hirotsu and Wright (2005) used a Markov chain model to determine optimized substitution strategies for pitchers. It was concluded that baseball managers should consider not just the lateral preference of the batter first being faced by a relief pitcher but also the lateral preference of subsequent batters (Hirotsu & Wright, 2005). By considering both the batter's lateral preference and the lateral preference of subsequent batters, managers can achieve an optimal substitution strategy for relief pitchers (Hirotsu & Wright, 2005).

The introduction of a relief pitcher late in a close game dramatically affects win probability (Hirotsu & Wright, 2005). This study used the baseball data of Lindsey (1959), who made a similar conclusion when he found that, according to win probability, the most important run in baseball is the run scored late in a game that either ties the score or puts a team ahead by a run (Lindsey, 1963).

Hirotsu and Wright's model is based on the rules of runner advancement proposed by D'Esopo and Lefkowitz (1977). A weakness of these rules is that baserunners advance from base to base according to set rules for an event rather than accounting for baserunners who sometimes take extra bases. For example, in the D'Esopo and Lefkowitz model when a runner is at first base and the batter hits a double, the runner advances to third base. In the game of baseball as it is played, sometimes a runner on first will score as a result of a double depending upon variables such as the ability and positioning of the defense, the speed and skill of the baserunner, and the number of outs. These variables are not accounted for in the D'Esopo and Lefkowitz model.

Hirotsu and Wright also devised the baseball statistic defensive earned run average (DERA) for use in their simulations. While similar to ERA, DERA is the average number of runs per nine innings based upon the expected value of an event rather than the number of earned runs allowed. Hirotsu and Wright assigned values based on the probability of a batting event. Linear weights is a preferred method for assigning value to the offensive events in a baseball game because events are weighted in proportion to their run value.

Bradbury and Drinen (2008) took an economic approach to pitcher and batter matchups in MLB, using an instrumental variable probit method to evaluate the effect that the on-deck batter has on the at-bat of the batter at the plate. Two variables pertaining to lateral preference, the on-deck batter's platoon advantage and the batter's platoon advantage, were among 30 variables analyzed by Bradbury and Drinen. The study reported only a small, negative impact for the batter who is hitting in relation to the quality of the batter on-deck.

Differential person functioning was applied to 60 MLB batters by Johanson and Brooks (2008) to research the platoon effect. Differential person functioning is based upon differential item functioning, where the relationship between two independent groups is controlled for by a third variable that measures overall skill (Dorans & Holland, 1993). In the study, batting success and handedness of the pitcher were conditioned by ERA (Johanson & Brooks, 2008). No statistically significant differential function was found for 52 of 60 batters studied, and Johanson and Brooks reported that patterns either did not exist or were uninformative. Successful at-bats in this study were those that produced a hit, walk, or sacrifice, while all other outcomes were coded as a failure. This coding method is inadequate since not all hits are created equal (e.g., home runs are more valuable than singles), the value of a sacrifice is dependent upon the score and inning of a game, outs that advance runners can sometimes improve the likelihood of a run scoring, and ERA is not the best method for measuring pitcher skill.

A study on the applicability of the generalized matching equation to switch hitting in MLB found that three of the game's all-time best switch hitters almost exclusively batted with the opposite lateral preference of the opposing pitcher's handedness (Poling, Weeden, Redner, & Foster, 2011). The study found that of the 33,355 at-bats taken during the MLB careers of Mickey Mantle, Eddie Murray, and Pete Rose, only five

(.01%) at-bats were with the same lateral preference as the pitcher's handedness. This small percentage of at-bats meant that no conclusion could be drawn as to whether these three hitters benefitted from switch hitting, though Poling et al. theorized that Mantle, Murray, and Rose may have benefitted had they taken all of their at-bats with a left-sided lateral preference. Poling et al. concluded that the at-bats of these three hitters were controlled by the rule of the platoon effect and not by the consequences of their at-bats.

Cricket

It is not surprising that cricket, the precursor to baseball, is another sport influenced by handedness. As in baseball, the effect of handedness on cricket has long been recognized. In an 1861 essay on cricket, Lundie wrote:

> Among a generally right-handed race, it is not difficult to see the reason of this. Any one who has watched a cricket-match in which a left-handed batsmen was taking part, knows what trouble he causes to his opponents; how the fielders have to change either their position or their function every time he faces the bowler; and how odd he appears at the wrong, that is, the unusual, side of the wicket (p. 9).

Regarding an excess of left-sided male batsmen in cricket, Wood and Aggleton (1989) found that many left-sided batsmen were right-handed. The performance advantage of left-sided batsmen in cricket is due to a strategic advantage inherent to the game rather than left-handers having a higher capacity for visuo-spatial thinking (Wood & Aggleton, 1989).

Edwards and Beaton (1996) evaluated the frequency distribution of left-handed bowlers in cricket and found an over-representation of spin bowlers. Spin bowlers put more rotation on the ball causing it to spin away from right-sided batsmen.

Brooks, Bussiére, Jennions, and Hunt (2004) evaluated the batting records from the men's 2003 cricket World Cup and found left-sided batsmen were more successful than their right-sided counterparts. Brooks et al. concluded that because opponents in cricket are less accustomed to competing against left-handers, they are less likely to adapt to bowling to them. Therefore, according to the study's authors, left-sided batters benefit from negative frequency dependent effect.

Brooks et al. (2004) also looked at team success and found a positive correlation with the percentage of left-sided batsmen on a cricket team. The run rate peaked when the proportion of innings played by left-sided batsmen reached 50.5%. In addition, left-sided batsmen overall were more successful than right-sided batsmen, and this difference increased when playing lower ranked teams which typically include fewer left-sided batsmen (Brooks et al., 2004).

Mann, Runswick, Oliver, and Allen (2016) looked at the handedness, eye dominance, and batting stance of 43 male professional cricket players and 93 male inexperienced players. Professional batsmen were found to be 7.1 times more likely to adopt a reversed stance in relation to their handedness, independent of their dominant eye.

Fastpitch Softball

Loffing et al. (2014) studied the relationship between sport-specific lateral preferences and handedness variables with a goal of establishing reference values.

Though the study referenced baseball batting preferences for males and females, the findings are presented here for fastpitch softball rather than baseball because baseball is predominantly a male sport while fastpitch softball is predominantly a female sport. Using Cohen's conventions, baseball batting for men and women was determined to be the only activity of 16 activities studied that showed an excess of left-handed performers (Loffing et al., 2014). While 84% of 38 female, left-handed, German university students threw left-handed, the authors found that 73% of the 38 left-handers studied preferred to bat from the left side. Of 448 female right-handed students surveyed by Loffing et al., 99% reported throwing right-handed and 91% batted from the right side. Overall, seven percent of females preferred to throw with their left-hand and 14% preferred to bat with a left preference (Loffing et al., 2014). Loffing et al. found that, as determined by the Edinburg Handedness questionnaire, lateral preference for bimanual activities such as swinging a bat or golfing have a much lower point-biserial correlation to handedness than unilateral activities such as throwing or fencing.

A limitation of the study, according to Loffing et al. (2014), was that participants were potentially unfamiliar with certain activities. This could have been the case with batting preference since the study took place with predominantly college students in Germany, where baseball and softball are likely less popular than in the United States. Other limitations identified by Loffing et al. were that performance measures were not considered and the overall handedness was based on the Edinburg Handedness Inventory, although it is a popular hand-preference questionnaire.

Though not specifically referencing softball, studies have reported on the throwing hand of women. One study found that 7.6% of women in the United States throw with their left-hand, with fewer women throwing left-handed than writing left-handed (Gilbert & Wysocki, 1992). In a survey of women 18–40 years of age, throwing left-handed ranged from 6.93% to 7.99% (Papadatou-Pastou, Martin, Munafò, & Jones, 2008). A study of English women 18-30 years of age found that 7.5% throw left-handed (Raymond, Pontier, Dufour, & Møller, 1996).

Ice Hockey

Grondin, Trottier, and Houle (1994) sought to correlate handedness and the bimanual shooting side of a small group of amateur men's hockey players according to whether their shooting style was one of power or accuracy, but their findings were inconclusive. Ala, Swiderek, and Benson (2013), meanwhile, surveyed 40 American boys and girls who had never played hockey. The researchers recommended that, because the hand at the top of the hockey stick exerts a greater degree of control and accuracy than the lower hand, right-handed hockey players should use a left-sided stick and left-handed players should use a right-sided stick. Ala, Swiderek, and Benson concluded that most Americans use the wrong handed hockey stick.

In a three-study article on the lateral preference of male professional hockey players, Puterman, Schorer, and Baker (2010) found that:

- The distribution of players' shooting-side and catching-side exhibited changes over time, with left-shooters increasing proportionally over the 90-year history of the National Hockey League (NHL).
- Right-shooters often score more goals while left-shooters assist more goals.

- Goaltenders who use their right hand to catch are associated with more saves and had a greater advantage against left-shooting opponents.
- The proportion of left-catching goalkeepers significantly increased according to competition level: 66% in the Ontario Hockey League, 86% in the American Hockey League, and 90% in the NHL. This left-sided preference makes ice hockey an exception in sports (Loffing & Hagemann, 2016).

Puterman et al. (2010) concluded their findings supported the skill-based laterality effects of frequency-dependent theory.

Stick-side preference was measured by Loffing et al. (2014) as part of an evaluation of sport-specific tasks. For women, 124 of 447 (27.7%) participants surveyed preferred to hold a hockey stick left-sided rather than right-sided. This percentage is considerably higher than the 7.88% left-handedness of study participants as determined by the Edinburgh Handedness Inventory (Loffing et al., 2014). For comparison, the study found that 14% of female participants held a baseball bat left-handed.

Table Tennis

As in other interactive sports, left-handers are over-represented in table tennis (Raymond, Pontier, Dufour, & Møller, 1996). In an evaluation of the top female players in the world, Raymond et al. found 16.4% were left-handed. In a survey of elite Danish players, the researchers found nine (18.75%) of 48 female youth, junior, and senior table tennis players were left-handed. Raymond et al. proposed that the over-representation of left-handers in table tennis and other interactive sports, in combination with a lack of left-handed over-representation in non-interactive sports, is consistent with the fighting hypothesis.

In a study of skilled athletes in Greece, of 25 females surveyed regarding table tennis, four (16%) were found to play left-handed (Grouios et al., 2000). Overall, 14 (15.7%) of the 89 female participants in the study who played indirect interactive sports were left-handed, although the pattern of more left-handed individuals in interactive sports than in non-interactive sports was less pronounced in females than in males (Grouios et al, 2000). Grouios et al. attributed the over-representation of left-handed individuals in interactive sports to the fighting hypothesis.

Tennis

Neither left-handed female (7.69%) nor left-handed male (6.98%) tennis players were found to be over-represented at the professional level (Holtzen, 2000). Though it is no longer the case, Holtzen determined that the highest ranked left-handed males in the world at one time had an advantage over right-handed players. These findings support the theory of a neurologic advantage for left-handed athletes, according to Holtzen. However, Loffing and Hagemann (2012) found no convincing empirical evidence in support of Holtzen's proposal.

A study of 108 male tennis players found that 58.43% of shots were directed to the backhands of right-handed players while 55.3% of shots were to the backhands of left-handed players (Loffing, Hagemann, & Strauss, 2010). This lack of adjustment in play depending upon handedness suggests support for the strategic advantage hypothesis, according to the study's authors.

Unlike their right-handed counterparts, left-handed male tennis players may benefit by negative frequency-dependent selection to help counter the effects of aging (Loffing, Schorer, & Cobley, 2010). In the study, left-handed male players were found to be over-represented in the top 500 male professional tennis players, appearing to avoid the effects of relative aging (Loffing et al., 2010).

In Grand Slam tournament matches involving higher-ranked, right-handed male professional tennis players opposing lower-ranked, left-handed players, right-handed players have a 5.9% lower probability of winning (del Corral & Prieto-Rodriguez, 2010). Researchers del Corral and Prieto-Rodriguez suggested that the scarcity of left-handed players gives them a strategic advantage. No explanation was given as to why a similar effect was not found with female professionals, this despite matches involving a higher-ranked, right-handed female facing a lower ranked, left-handed opponent occurring even less often than in the men's game.

In a study of Grand Slam and ATP World Tour tournaments, Radicchi (2011) found that eight of the top 30 male tennis players in the history of the sport were left-handed.

Left-handedness was found to have a moderate effect on high achievement in men's professional tennis, but almost no impact in women's tennis (Loffing, Hagemann, & Strauss, 2012). The authors cited previous research to potentially explain the lack of effect in women's tennis. Explanations include stronger competition in men's tennis as opposed to female tennis which causes left-handedness to occur more often in male than female tennis players (Raymond, Pontier, Dufour, & Møller, 1996) and a greater shot rate resulting in heavier spatiotemporal constraints in men's tennis as compared to women's tennis (O'Donoghue & Ingram, 2001).

Loffing, Sölter, Hagemann, and Strauss (2016) found that if an opponent is left-handed, there may be a bias toward expecting a shot down the line. This study evaluated 20 male tennis players and 20 male non-players.

Volleyball

In a study of hand injuries in 226 volleyball players over a five-year period, left-handedness was associated with an increased risk of hand injury in recreational players (Bhairo, Nijsten, van Dalen, & ten Duis, 1992).

Loffing, Schorer, Hagemann, and Baker (2012) found that volleyball opponents have difficulty predicting the outcome of left-handed shots. Although the study does not mention whether the participants were male or female, it can be assumed that all were male because the study mentions that of the 18 skilled and 18 novice participants, six men were recruited for video analysis. In a subsequent study using video analysis, a similar effect was found for predicting the outcome of left-handed shots, with experienced volleyball players outperforming novices in anticipating left-handed shots (Loffing, Hagemann, Schorer, & Baker, 2015).

A Brief History of Fastpitch Softball

George Hancock is credited with inventing the game of softball in the United States in 1887, with the Young Men's Christian Association formalizing the game's rules in the 1920s (Westly, 2016). Westly noted that the game of fastpitch softball, which resembled baseball but with a bigger ball and underhand pitching, was popular because of the pace of play, a smaller field that took up less space than a baseball field, and both men and women were welcomed to play. At the fastpitch softball national tournament in 1935, 14 women's teams and 42 men's teams participated, though this disparity decreased by the late 1930s (Westly, 2016). By the mid-1940s, according to Westly, 250,000 men's and women's teams were competing nationally in the Amateur Softball Association. While the popularity of men's fastpitch softball would wane, girls' and women's softball continued to see growth in the sport (Westly, 2016). The first International Softball Federation World Championships were held in 1965 (Potter & Johnson, 2007). In 1969, the Division for Girls' and Women in Sports began sanctioning a women's college softball championship, which then migrated control of the tournament to the Association of Intercollegiate Athletics for Women (Plummer & Floyd, 2013). By the 1970s, fastpitch softball was played almost exclusively by women (Westley, 2016). Fastpitch softball joined the Pan American Games in 1979 (Potter & Johnson, 2007). The NCAA held its first women's college softball tournament in 1982 and fastpitch softball joined the Olympics in 1996 (Westley, 2016). The Women's Pro Softball League began in 1997, suspended play in 2001, then reformed as National Pro Fastpitch in 2004 (Sim, 2014). Though there are currently just six professional women's fastpitch softball teams (Sievers, 2017), fastpitch softball at the youth and college ranks is popular in the United States. Over 1.2 million girls participate in USA Softball ("About Us", n.d.). There are 295 NCAA Division I schools, 295 NCAA Division II schools, and 415 NCAA Division III schools playing fastpitch softball ("NCAA Statistics," n.d.). There are 195 National Association of Intercollegiate Athletics member schools with women's fastpitch softball teams ("2017-18 NAIA Softball," n.d.). There are 366 National Junior College Athletic Association fastpitch softball teams ("Member College Directory," n.d.).

For the 2016-2017 season in the three divisions of NCAA women's college softball, 19,999 females participated in the sport ("NCAA Sport Sponsorship, Participation and Demographics Search," n.d.).

CHAPTER III. METHODOLOGY

The purpose of this study was to examine manual and bimanual laterality in women's college softball. This study does not involve human subjects, and all data were derived from publicly-accessible data sources.

This study was evaluated by the University of New Mexico's (UNM's) Institutional Review Board (IRB). Because the research involves compiling data that is publicly available and involves no interaction with the participants, a formal review by IRB was not required.

Research Design

The laterality preferences of women's college softball players from 2015 to 2017 were obtained from online sources for all teams competing in Power Five and Group of Five conferences. Performance data for batters and pitchers were also collected for this period. By combining and analyzing these data, the study addressed whether women's college softball players had a different incidence of left-handedness than the general population, the interaction of hand preference for throwing and lateral preference for batting, to what degree the platoon effect existed, and the extent of a positional bias based on the preference of throwing hand in women's college softball.

A one-way Analysis of Variance (ANOVA) test was used to determine if statistically significant differences exist involving laterality data and performance metrics. ANOVA was used to evaluate mean differences between two or more treatments (Gravetter, Wallnau, & Forzano, 2017). Mean differences were evaluated with ANOVA by partitioning the dependent variable's sources of variance (Miller & Yang, 2007).

Descriptive statistics were also utilized for data analysis. Descriptive statistics provide an overview in a research study and lay the groundwork for analyses (Woodrow, 2014).

Data Sources

Publicly available sources for women's softball statistics include the NCAA's women's softball website, the websites of colleges participating in the sport, online media guides, and online game-day programs. These published records were primary sources of data in this study. To help validate these sources, game summaries and platoon splits can be cross-referenced with roster information, descriptive statistics, and play-by-play data to help ensure accuracy and consistency.

It is understood that softball statistical data may include some degree of error. Analysis of professional baseball data has found more than 1,000 discrepancies in baseball's historical record, though most are minor errors involving data entry in a sport with a dataset that dates back over a century (Fatsis, 2002).

Population

Data were collected for schools in the ten preeminent conferences in NCAA D-I college softball, commonly referred to as the Power Five conferences (Athletic Coast Conference [ACC], Big Ten, Big 12, Pac-12, and the Southeastern Conference [SEC]) and the Group of Five conferences (American Athletic Conference [AAC], Conference USA [C-USA], Mid-American Conference [MAC], Mountain West Conference [MWC], and the Sun Belt Conference). The Big Five conferences describe the 54 schools playing softball in the Atlantic Coast Conference (ACC), Big Ten Conference, Big 12 Conference, Pac-12 Conference, and the Southeastern Conference (SEC). The Group of

Five conferences describe the 50 schools playing softball in the American Athletic Conference (AAC), Conference USA (C-USA), Mid-American Conference (MAC), Mountain West Conference (MWC), and Sun Belt Conference. The schools, the conference affiliation for each school, and the home page for each softball program's website, which typically provide information such as team rosters, are listed in Appendix A

Because the throwing hand or batting preference for every player participating in softball in the Power Five and Group of Five conferences from 2015-2017 could not be obtained, the totals for throwing hand and batting preference differ. The throwing hands of 3,507 softball players were identified, while the batting preferences of 3,496 players were identified. When evaluating the combination of throwing hand and batting preference, the lateral preferences of 3,492 players were identified.

Data Assembly

Performance data measure how well batters and pitchers perform and are collected for college softball by the NCAA. Some examples of performance data include batting average, home runs, walks, strikeouts, and stolen bases.

Situational statistics measure specific types of matchups that occur within fastpitch softball and are provided for college softball by the NCAA. Some examples of situational statistics provided by the NCAA include how a pitcher performs against the first hitter of every inning, how a batter performs when the bases are empty, or how a batter performs with the bases loaded. The situational statistic of interest in this study was how batters performed against left-handed and right-handed pitchers, and how pitchers performed against right-sided and left-sided batters.

When handedness and lateral preference information is combined with performance data, different patterns of motor performance may be found that can reflect a difference in motor skills. Handedness and lateral preference information, in conjunction with situational statistics, can be used to determine if the platoon effect exists in fastpitch softball and provide further information concerning the laterality of women playing college softball.

Data were assembled for this study between November 2017 and March 2018.

Research Questions

Research Question 1 – Frequency of a Left-Sided Lateral Preference

The first research question (R_1) for this study was as follows: To what extent is a left-sided lateral preference found in women's college softball for the Power Five and Group of Five Conferences?

Due to the popularity of slap hitting, it is possible that left-handed throwers and left-sided batters are more common in women's softball. Conversely, it was expected that switch hitters and left-handed throwers with a right-sided batting preference were rare and would, beyond being described by descriptive statistics, be excluded from further analysis from the study.

The rosters for teams in the Power Five and Group of Five conferences from 2015-2017 were collected to determine the throwing hand of defensive players and the lateral preference of batters. This analysis involved descriptive statistics, with throwing handedness totals that were compared to previous studies in the field of laterality to determine if left-sided players are more common in women's college softball.

This information was collected from the softball websites for each school playing in the ten conferences studied. An example of a URL for one school, the University of Alabama, providing roster information is: http://www.rolltide.com/roster.aspx?roster=161&path=softball&print=true. Not all schools provide the throwing hand and batting laterality preference of their players in the roster on their website. Media guides were another source for information on player laterality. An example of a media guide containing laterality information is the Southeastern Conference softball media guide from 2016, which can be found at: http://a.espncdn.com/photo/2016/0219/2016%20SEC%20Softball%20Media%20Guide.pdf. If additional laterality information was needed, game-day programs published by the colleges were another source for identifying the laterality of players. An example of a game-day program can be found at: https://s3.amazonaws.com/rolltide.com/documents/2016/6/28/25568__w_softbl_2014_15_release__release_20150219aaa.pdf.

Research Question 2 - Batter Lateral Preference and Throwing Hand

The second research question (R_2) for this study was as follows: To what extent do the recorded statistics vary for players who throw right and bat left, who throw left and bat left, and who throw right and bat right in women's college softball for the Power Five and Group of Five Conferences?

Variables were used with an Analysis of Variance (ANOVA) test to determine if performance differences existed between right-handed throwers who bat with a left-sided preference, left-handed throwers who bat with a left-sided preference, and right-handed throwers who bat with a right-sided preference. A small population of switch hitters and left-handed throwers who were right-sided batters prevented their inclusion in ANOVA testing.

Performance data were collected for teams in the Power Five and Group of Five conferences from 2015-2017 and combined with the laterality preferences obtained from rosters, media guides, and game-day programs. The NCAA assembles performance data and makes it available to the public at the website: http://www.ncaa.com/stats/softball/d1. Performance data that was found to be skewed would be modified for symmetry. When the variable of stolen base percentage was found to be skewed, an alternate variable that measures stolen bases, net stolen bases, was utilized. Whereas stolen base percentage is a rate statistic, net stolen bases measures the impact of a player's stolen bases (Tsao, Bolado, & Distelheim, 2007). A 100 at-bat qualifier was selected to eliminate part-time players from impacting the results.

The linear weights for wOBA analysis were calculated through use of a spreadsheet based upon the Markov chain model of Tom Tango, the creator of wOBA (Staude, 2013). The linear weights used in the formulas to calculate wOBA for the 10 conferences in this study are shown in Appendix C.

Research Question 3 – The Platoon Effect

The third research question (R_3) for this study was as follows: To what extent does a platoon effect exist in women's college softball for the Power Five and Group of Five Conferences?

Using platoon splits for pitchers and batters, the extent to which a platoon effect exists was determined for women's college softball for teams in the Power Five and Group of Five conferences between 2015-2017. Platoon splits were calculated by subtracting the effectiveness of batters or pitchers against opponents with the same lateral preference from opponents with the opposite lateral preference (Marchi & Albert, 2014). A finding with a negative value would mean the existence of a reverse platoon split (Marchi, 2010, April 23). A 20 at-bat qualifier was selected to eliminate part-time players from impacting the results.

This analysis was descriptive and involved public sources for data such as the NCAA softball statistics website, rosters, media guides, and game-day programs.

Research Question 4 – Positional Bias

The fourth research question (R_4) for this study was as follows: To what extent does positional bias exist in women's college softball for the Power Five and Group of Five Conferences?

If a platoon effect exists in softball, the over-representation of right-handed players at the positions of third base, shortstop, second base, and catcher was investigated as a potential cause. The hypothesis was based on the work of Walsh (2007a), who attributed much of the platoon effect in MLB to positional bias due to the game's asymmetrical design that favors right-handed throwers. Women's softball has the same asymmetrical design that favors right-handed throwers at certain defensive positions. Descriptive statistics related to positional bias included the tabulation of the lateral preference used in at-bats and batting average, both of which were grouped by positions that are typically associated with players who throw left-handed or right-handed.

A one-way ANOVA was used to determine how throwing and batting lateral preferences and position impacted performance according to batting average, OBP, slugging percentage, and wOBA. ANOVA can determine whether there are statistically significant differences between groups, and, in this study, whether biases existed in performance metrics based on batting preferences, throwing preferences, and the positions played. A 50 at-bat qualifier was selected to eliminate part-time players from impacting the results.

This information was collected from public sources for data such as the NCAA softball statistics website, rosters, media guides, and game-day programs. Data collection involved teams in the Power Five and Group of Five conferences from 2015-2017.

Data Analysis

Descriptive statistics and results of a one-way Analysis of Variance (ANOVA) test were produced using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 25.0.0.1. Data were assembled, and descriptive statistics were tabulated, using Microsoft Excel version 16.0.9029.2106. MySQL Workbench version 6.3.10 was used to evaluate data integrity.

Descriptive statistics were utilized for each of the four research questions to examine the laterality characteristics of the women's college softball players. A one-way ANOVA was run for this research question, with the alpha level set to 0.05. Results from the statistical analyses can be found according to each research question.

Data were analyzed with a one-way ANOVA with a significance level of $\alpha =$ 0.05, using independent variables of throwing hand, batting preference, and field position, and dependent variables of batting average, OBP, slugging percentage, and wOBA.

Defensive, offensive, and pitching statistical categories commonly used to analyze softball are listed in Appendix B.

CHAPTER IV. RESULTS

Introduction

This research study examined the laterality of players participating in women's college softball for teams from the Power Five and Group of Five conferences in the 2015-2017 seasons and the relationship with identified dependent variables. This research was exploratory in nature with the goal of providing a better understanding of laterality and its impact on college softball.

Chapter IV includes the analysis of all four research questions and provides an overview of the characteristics of the sample. Under each of these four research question sections, all results related to questions and the statistical analyses are described.

Research Question 1 – Frequency of a Left-Sided Lateral Preference

The first research question (R_1) for this study was as follows: To what extent is a left-sided lateral preference found in women's college softball for the Power Five and Group of Five Conferences?

Table 4.1

Throwing Preferences

Throws	Frequency	Percent
Left	328	9.35
Right	3,179	90.65
Total	3,507	100.0

Table 4.1 shows descriptive statistics for the throwing preferences of players evaluated in the study. Of 3,507 players, 3,179 (90.65%) were found to throw right handed while 328 (9.35%) were found to throw left-handed. The percentage of left-handed, female throwers identified in this study is higher than that for females in the

studies of Gilbert and Wysocki (1992), Loffing et al. (2014), Papadatou-Pastou et al. (2008), and Raymond et al. (1996).

Table 4.2

Batting Preferences

Bats	Frequency	Percent
Left	1,087	31.09
Right	2,393	68.45
Switch	16	0.46
Total	3,496	100.0

Table 4.2 shows the batting preferences of players evaluated in the study. Of 3,496 players, 2,393 (68.45%) were found to bat with a right-sided lateral preference, 1,087 (31.09%) bat with a left-sided lateral preference, and 16 (0.46%) were switch hitters. The percentage of left-sided, female batters identified in this study is higher than that for females when baseball batting and gripping of a hockey stick found by Loffing et al. (2014).

Research Question 2 – Batter Lateral Preference and Throwing Hand

The second research question (R_2) for this study was as follows: To what extent do the recorded statistics vary for players who throw right and bat left, who throw left and bat left, and who throw right and bat right in women's college softball for the Power Five and Group of Five Conferences?

As shown in Table 4.3, most players (67.10%) bat right and throw right, followed by players who bat left and throw right (23.14), and players who bat left and throw left (7.93%). For some conditions, a limited number of batters were available for study. There were only 48 (1.37%) players who bat right and throw left, 15 (0.43%) switch hitters who throw right-handed, and one (0.03%) player who was a switch hitter and throws left-handed were available in the sample. Therefore, due to a small sample size, players who bat right and throw left, and switch hitters were not included for further study.

Table 4.3

Batting and Throwing Preferences

Bats	Throws	Frequency	Percent
Left	Left	277	7.93
Left	Right	808	23.14
Right	Left	48	1.37
Right	Right	2,343	67.10
Switch	Left	1	0.03
Switch	Right	15	0.43
Total		3,492	100.0

Descriptive statistics for the dependent variables used for this research question are shown in Table 4.4. The criteria for each dependent variable were a batter who bats left and throws left, bats left and throws right, bats right and throws right, and collects 100 at-bats in a season.

Table 4.4

Descriptive Statistics of Seven Dependent Variables: Minimum 100 At-Bats

		BA	SLG	HR%	K%	BB%	SB%	wOBA
N	Valid	2366	2366	2366	2366	2366	2366	2366
	Missing	0	0	0	0	0	0	0
Mean		.302	.463	3.29	14.92	11.95	3.64	.247
Std. Deviation		.058	.134	3.022	6.397	6.377	4.498	.052
Variance		.003	.018	9.131	40.924	40.672	20.229	.003
Skewness		.202	.798	1.158	.596	1.179	2.119	.514
Std. Error of Skewness		.050	.050	.050	.050	.050	.050	.050
Kurtosis		-.118	.853	1.596	.202	2.335	5.858	.319
Std. Error of Kurtosis		.101	.101	.101	.101	.101	.101	.101

The three conditions of batting preference and throwing hand with the qualifier of 100 at-bats are described in Table 4.5.

Table 4.5

Batting and Throwing Preferences: Minimum 100 At-Bats

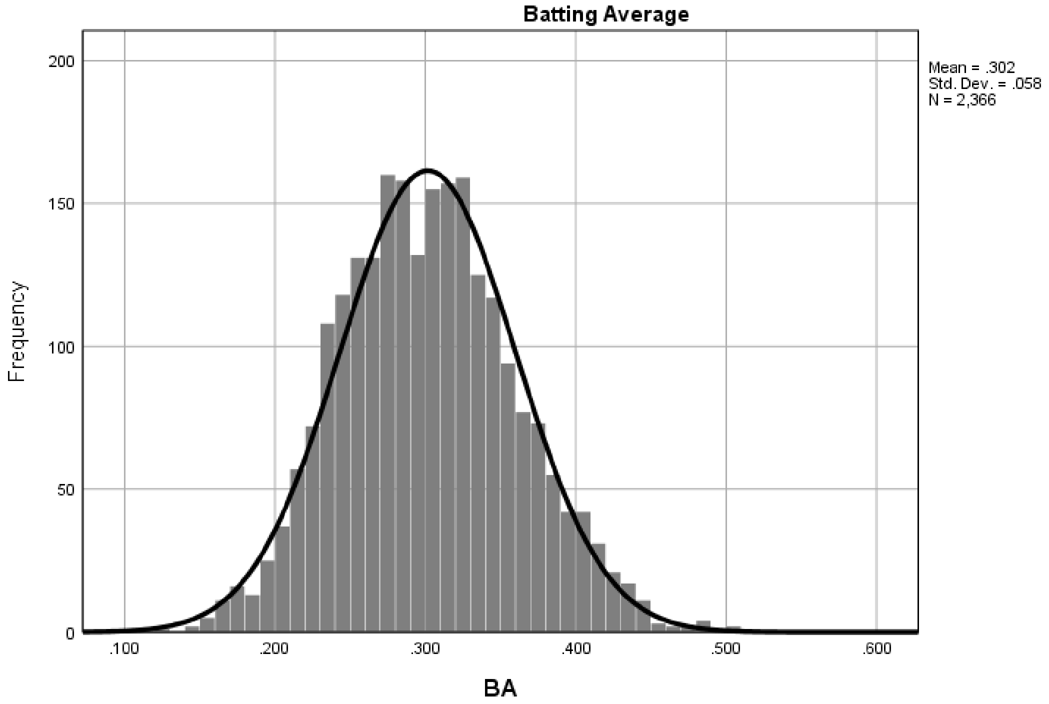
Bats	Throws	Frequency	Percent
Left	Left	200	8.45
Left	Right	765	32.33
Right	Right	1,401	59.21
Total		2,366	100.0

The study's results for this research question were divided into groups according to the seven dependent variables. The data for each dependent variable were illustrated using histograms and bar charts. For two variables, home run percentage and stolen base percentage, the data were skewed so subsequent analysis was performed. Each dependent variable was analyzed using a one-way ANOVA, and six of the seven dependent variables receive post hoc testing. A one-way between-subjects ANOVA was used to compare the effect of batting preference and throwing hand on batting average (BA), slugging percentage (SLG), home run percentage (HR%), strikeout percentage (K%), walk percentage (BB%), net stolen bases (NS), and weighted on-base average (wOBA) for players batting left and throwing left, batting left and throwing right, and batting right and throwing right. For a post hoc test, Hochberg's GT2 test was used due to the differences in sample sizes for the three conditions of lateral preference.

Batting Average

Figure 4.1

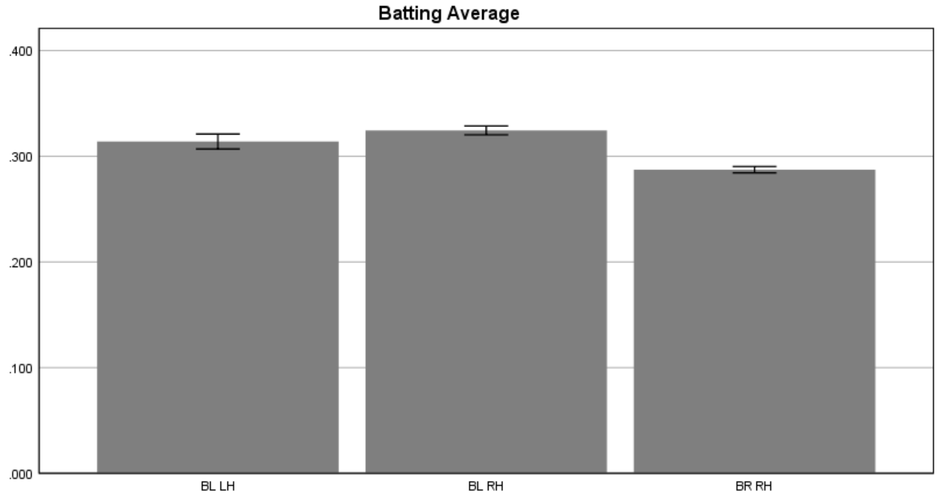
Histogram of Batting Average: Minimum 100 At-Bats



The histogram in Figure 4.1 shows that the data for batting average was mostly symmetrical.

Figure 4.2

Bar Chart of Batting Average: Minimum 100 At-Bats



The bar chart in Figure 4.2 shows the means ± two standard error in batting average for the conditions of bats left and throws left (BL LH), bats left and throws right

(BL RH), and bats right and throws right (BR RH). The mean batting average (ranked high to low) for BL RH was .324, BL LH was .314, and BR RH was .287.

Table 4.6

One-Way ANOVA of Batting Average: Minimum 100 At-Bats

		Sum of Squares	df	Mean Square	F	Sig.
BA	Between Groups	.717	2	.358	115.064	.000
	Within Groups	7.359	2,363	.003		
	Total	8.075	2,365			

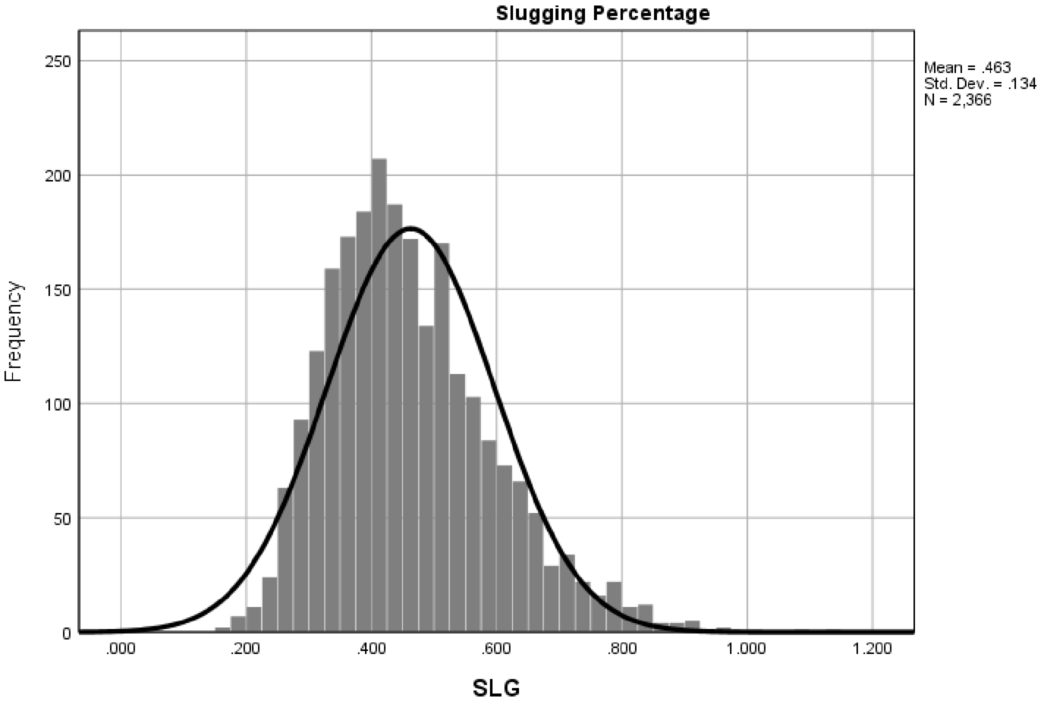
As shown in Table 4.6, the ANOVA found significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on batting average [$F(2, 2{,}363) = 15.064$, p = 0.000],

For batting average, the Hochberg GT2 test indicated that both the mean score for the bats left and throws left condition (*M* = .314, SD = .05) and the mean score for the bats left and throws right condition (*M* = .324, SD = .06) significantly differed from the bats right and throws right condition (*M* = .287., SD = .06). The mean score for the bats left and throws left condition (*M* = .314, SD = .05) was marginally significantly different from the bats left and throws right condition (*M* = .324, SD = .06).

Slugging Percentage

Figure 4.3

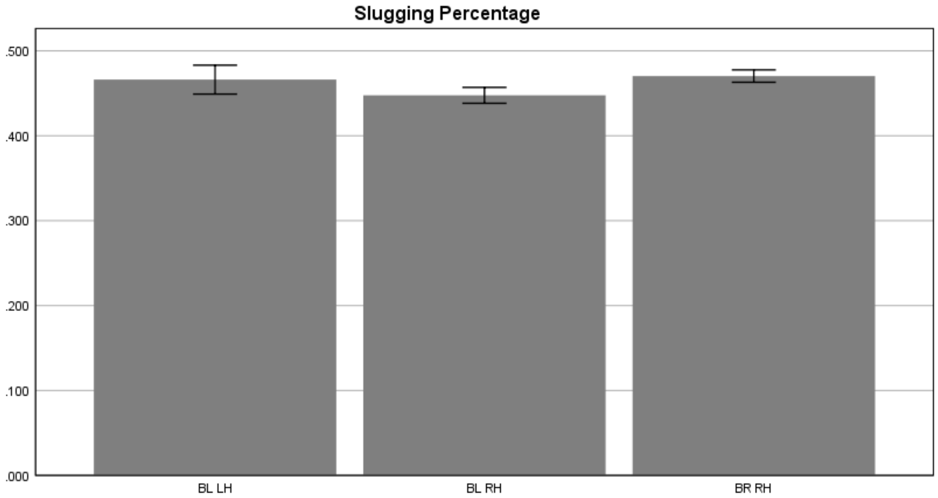
Histogram of Slugging Percentage: Minimum 100 At-Bats



The histogram in Figure 4.3 shows that the data for slugging percentage was mostly symmetrical.

Figure 4.4

Bar Chart of Slugging Percentage: Minimum 100 At-Bats



The mean slugging percentages are shown in Figure 4.4 for the conditions of BR RH (.470), BL LH (.466), and BL RH (.448).

Table 4.7

One-Way ANOVA of Slugging Percentage: Minimum 100 At-Bats

		Sum of Squares	df	Mean Square	F	Sig.
SLG	Between Groups	.257	2	.129	7.227	.001
	Within Groups	42.019	2,363	.018		
	Total	42.276	2,365			

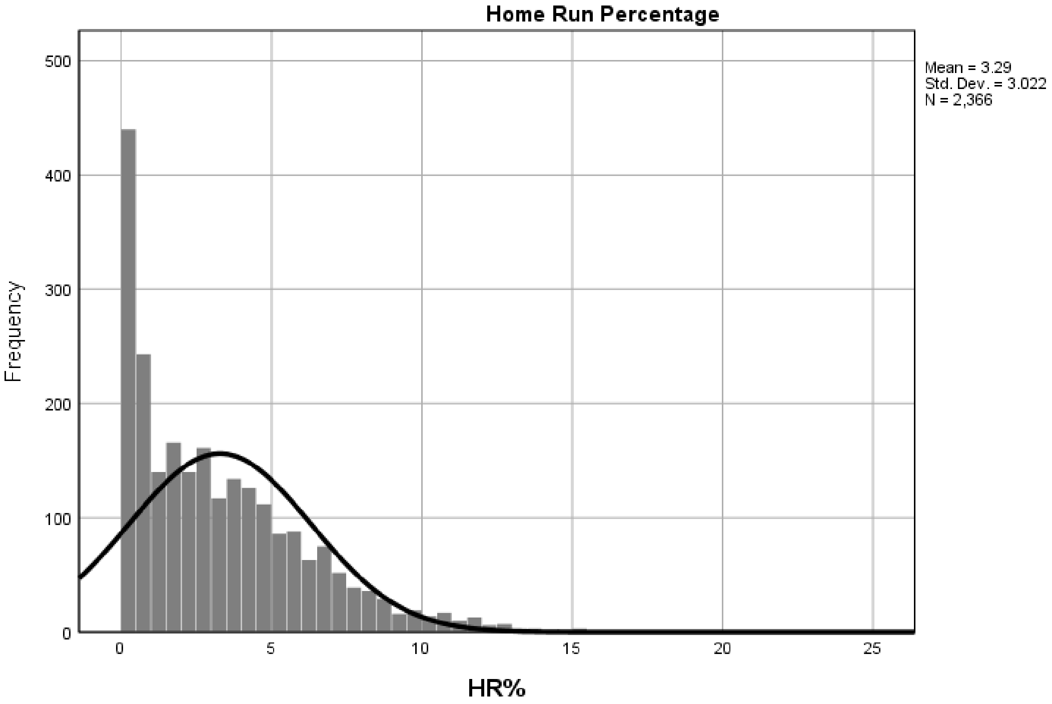
As shown in Table 4.7, the ANOVA found significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on slugging percentage [$F(2, 2{,}363) = 7.227$, p = 0.001],

Regarding the post hoc test for slugging percentage, the test indicated that the mean score for the bats right and throws right condition (*M* = .470., SD = .14) significantly differed from the bats left and throws right condition (*M* = .448, SD = .13). Neither the mean score for the bats left and throws right condition (*M* = .448, SD = .13) nor the bats right and throws right condition (*M* = .470, SD = .14) were significantly different from the bats left and throws left condition (*M* = .466, SD = .12).

Home Run Percentage

Figure 4.5

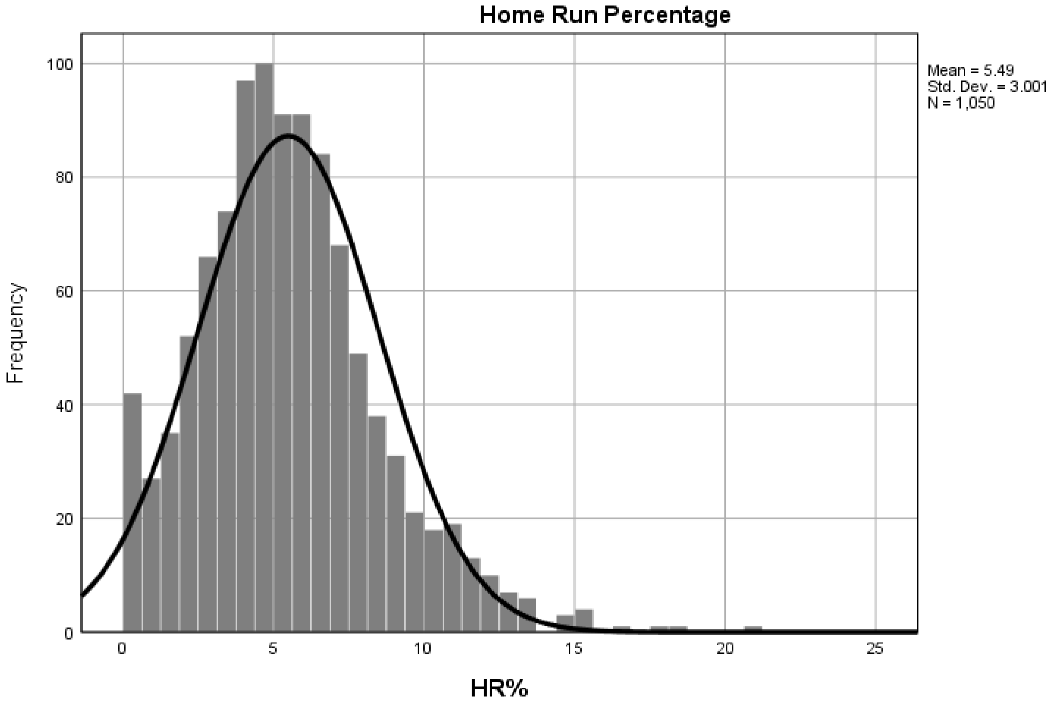
Histogram of Home Run Percentage: Minimum 100 At-Bats



Despite finding the skewness and kurtosis values for home run percentage to be within an acceptable range in Table 4.4, the histogram in Figure 4.5 shows many batters at the lower range of home run percentage. Home run percentage may be skewed, in part, by slap hitters, who rarely hit home runs. Because slap hitters are not identified on rosters, an attempt was made to select cases that did not involve slap hitters and other non-power hitters by using a qualifier for slugging percentage.

Figure 4.6

Histogram of Home Run Percentage: Minimum 100 At-Bats and .463 Slugging Percentage



By using a minimum of 100 at-bats and the mean slugging percentage of .463, the data displayed in the histogram for home run percentage was transformed into a more symmetrical distribution (see Figure 4.6).

Descriptive statistics for home run percentage using a minimum of 100 at-bats and the mean slugging percentage of .463 are shown in Table 4.8.

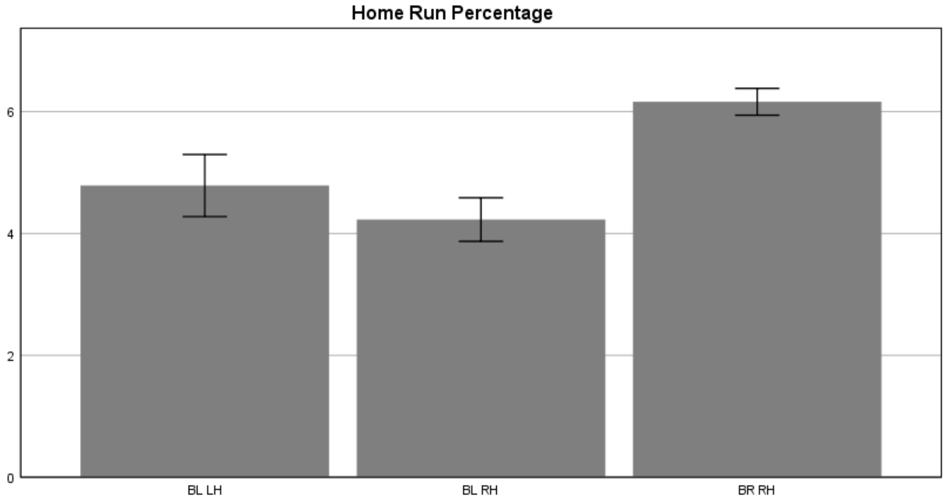
Table 4.8

Batting and Throwing Preferences: Minimum 100 At-Bats and .463 Slugging Percentage

Bats	Throws	Frequency	Percent
Left	Left	96	9.14
Left	Right	297	28.29
Right	Left	657	62.57
Total		1,050	100.0

Figure 4.7

Bar Chart of Home Run Percentage: Minimum 100 At-Bats and .463 Slugging Percentage



The mean home run percentages are shown in Figure 4.7 for the conditions of BR RH (6.16%), BL LH (4.79%), and BL RH (4.23%).

Table 4.9

One-Way ANOVA of Home Run Percentage: Minimum 100 At-Bats and .463 Slugging Percentage

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	816.430	2	408.215	49.503	.000
Within Groups	8,633.912	1,047	8.246		
Total	9,450.342	1,049			

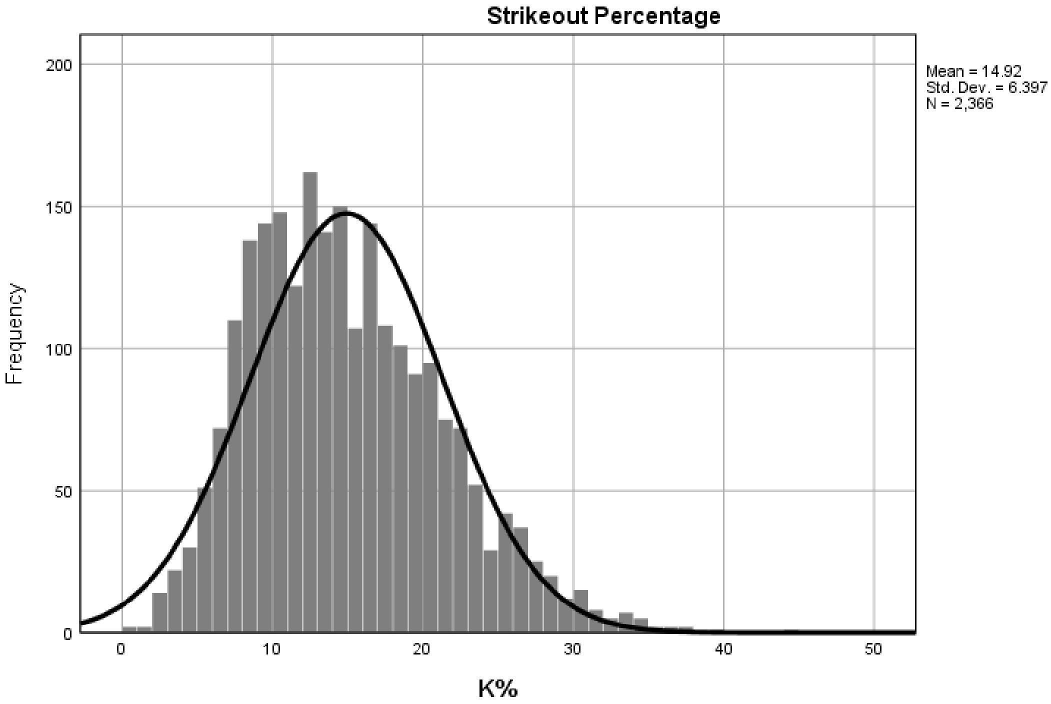
As shown in Table 4.9, the ANOVA found significant effects at the p<0.05 level for the three conditions of batting preference and throwing hand on home run percentage [F(2, 1,047) = 49.503, p = 0.000].

Using the post hoc test on the mean scores for Home Run Percentage with the slugging percentage qualifier, the bats right and throws right condition (*M* = 6.16%, SD = 2.824) significantly differed from bats left and throws left condition (*M* = 4.79%, SD 2.496) and the bats left and throws right condition (*M* = 4.23%, SD = 3.082). The bats left and throws left condition (*M* = 4.79%, SD = 2.496) was found to be not significantly different from the bats left and throws right condition (*M* = 4.23%, SD = 3.082).

Strikeout Percentage

Figure 4.8

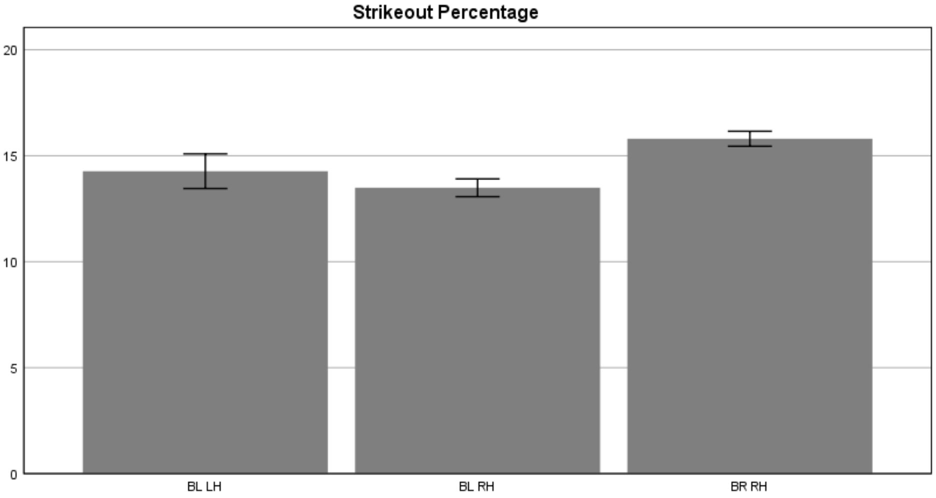
Histogram of Strikeout Percentage: Minimum 100 At-Bats



The histogram in Figure 4.8 shows that the data for strikeout percentage was mostly symmetrical.

Figure 4.9

Bar Chart of Strikeout Percentage: Minimum 100 At-Bats



The mean strikeout percentages are shown in Figure 4.9 for the conditions of BR RH (15.80%), BL LH (14.27%), and BL RH (13.49%).

Table 4.10

One-Way ANOVA of Strikeout Percentage: Minimum 100 At-Bats

		Sum of Squares	df	Mean Square	F	Sig.
K%	Between Groups	2,744.305	2	1,372.152	34.479	.000
	Within Groups	94,040.218	2,363	39.797		
	Total	96,784.523	2,365			

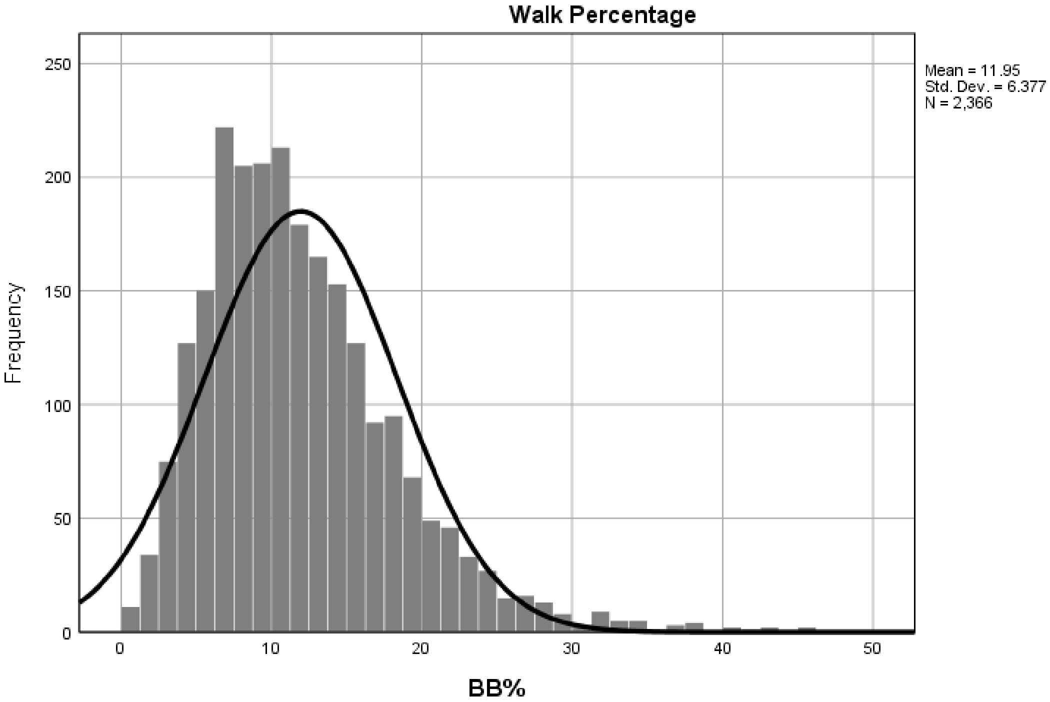
As shown in Table 4.10, the ANOVA found significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on strikeout percentage [$F(2, 2{,}363) = 34.479$, p = 0.000]

For strikeout percentage, the post hoc test indicated that both the mean score for the bats left and throws left condition ($M = 14.27\%$, SD = 5.79) and the bats left and throws right condition ($M = 13.49\%$, SD = 5.81) differ significantly from the bats right and throws right condition ($M = 15.80\%$, SD = 6.63). The mean score for the bats left and throws left condition ($M = 14.27\%$, SD = 5.79) was not significantly different from the bats left and throws right condition ($M = 13.49\%$, SD = 5.81)

Walk Percentage

Figure 4.10

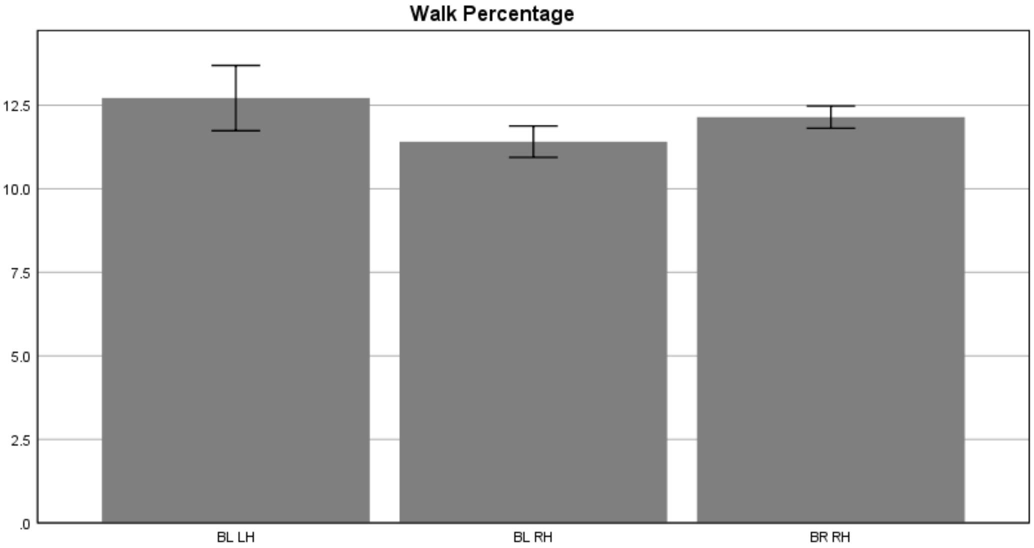
Histogram of Walk Percentage: Minimum 100 At-Bats



The histogram in Figure 4.10 shows that the data for walk percentage was somewhat symmetrical.

Figure 4.11

Bar Chart of Walk Percentage: Minimum 100 At-Bats



The walk percentages are shown in Figure 4.11 for the conditions of BL LH (12.71%), BR RH (12.14%), and BL RH (11.41%).

Table 4.11

One-Way ANOVA of Walk Percentage: Minimum 100 At-Bats

		Sum of Squares	df	Mean Square	F	Sig.
BB%	Between Groups	392.907	2	196.454	4.846	.008
	Within Groups	95,796.584	2,363	40.540		
	Total	96,189.491	2,365			

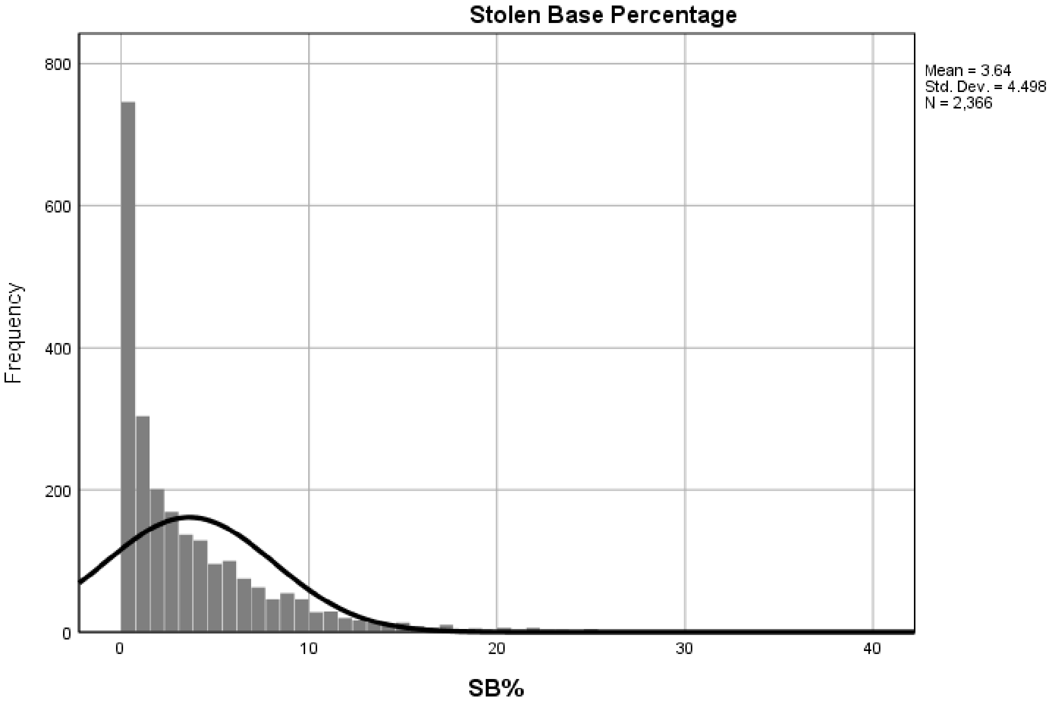
As shown in Table 4.11, the ANOVA found significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on walk percentage [$F(2, 2{,}363) = 4.846$, p = 0.008],

The mean scores for walk percentage significantly differed for the bats left and throws left condition (*M* = 12.71%, SD = 6.91) and the bats right and throws right condition (*M* = 12.14%., SD = 6.22) from the bats left and throws right condition (*M* = 11.41%, SD = 6.48). The mean score for the bats left and throws left condition (*M* = 12.71%, SD = 6.91) was not significantly different from the bats right and throws right condition (*M* = 12.14%, SD = 6.22).

Stolen Base Percentage/Net Stolen Bases

Figure 4.12

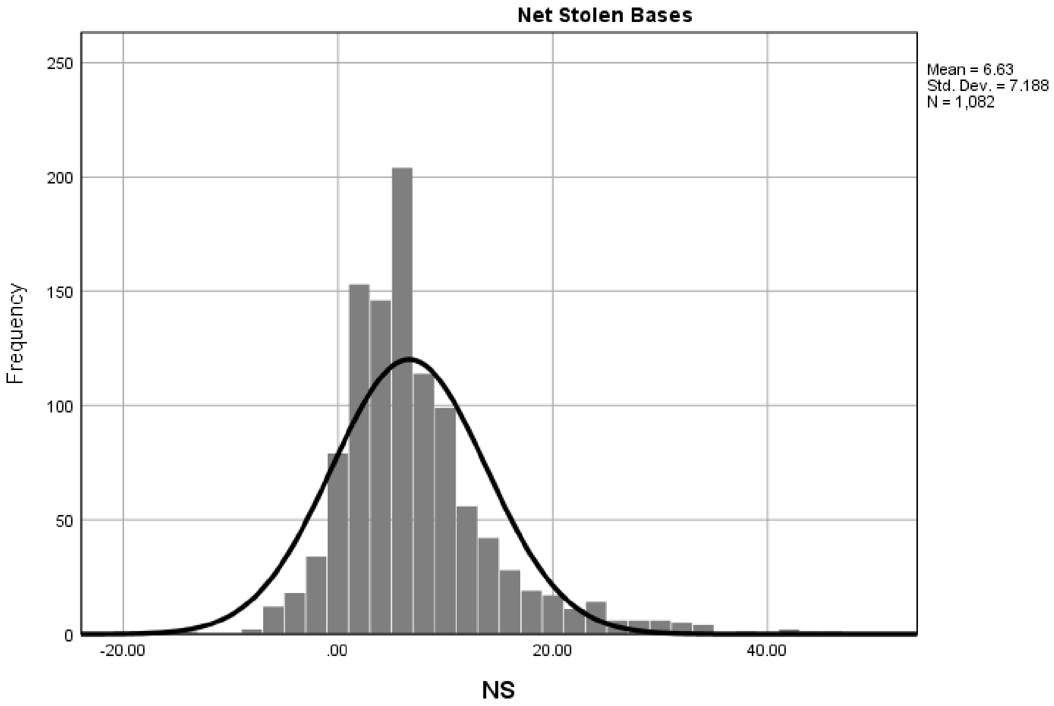
Histogram of Stolen Base Percentage: Minimum 100 At-Bats



The histogram in Figure 4.12 shows that the data for stolen base percentage was skewed right. Table 4.4 also indicates elevated skewness and kurtosis values for stolen base percentage. This may not be surprising since stolen base percentage, with at-bats as the denominator, is not a commonly used metric. Because at-bats do not include walks, sacrifice flies, sacrifice hits, and hit by pitches, plate appearances or games played may have been better choices since these statistics are more commonly used as denominators. In addition, stolen bases per at-bat does not account for the number of times the base runner was caught stealing. Another option was to use net stolen bases, as shown in Figure 4.13.

Figure 4.13

Histogram of Net Stolen Bases: Minimum 100 At-Bats and Five Stolen Base Attempts



By using net stolen bases with a minimum of 100 at-bats and five stolen base attempts as the qualifiers rather than stolen base percentage, the data displayed in the histogram transforms into a more symmetrical distribution (see Figure 4.13).

Table 4.12

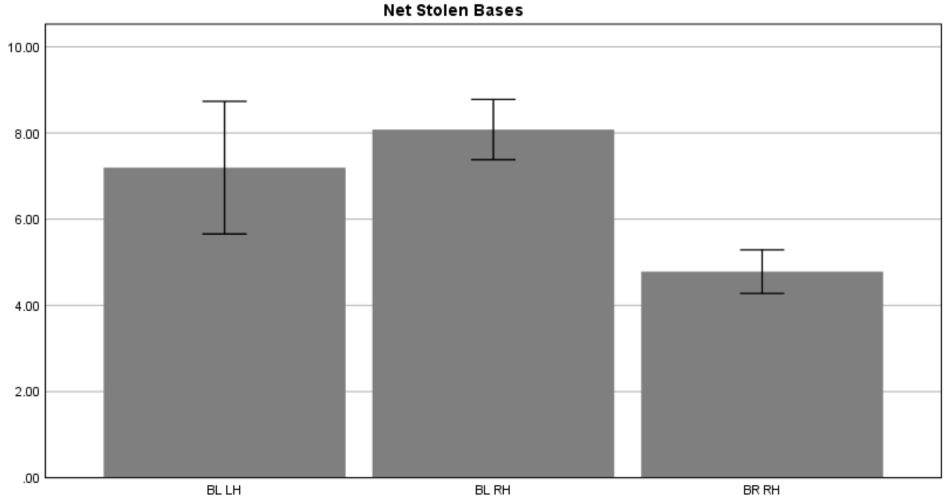
Batting and Throwing Preferences: Minimum 100 At-Bats and Five Stolen Base Attempts

Bats	Throws	Frequency	Percent
Left	Left	97	8.96
Left	Right	534	49.35
Right	Left	451	41.68
Total		1,082	100.0

Descriptive statistics for net stolen bases using a minimum of 100 at-bats and five stolen base attempts are shown in Table 4.12.

Figure 4.14

Bar Chart of Net Stolen Bases: Minimum 100 At-Bats and Five Stolen Base Attempts



The means for net stolen bases are shown in Figure 4.14 for the conditions of BL RH (8.08), BL LH (7.20), and BR RH (4.78).

Table 4.13

One-Way ANOVA of Net Stolen Bases: Minimum 100 At-Bats and Five Stolen Base Attempts

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2,693.633	2	1,346.816	27.341	.000
Within Groups	53,151.521	1,079	49.260		
Total	55,845.153	1,081			

As shown in Table 4.13, the ANOVA found significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on net stolen bases [$F(2, 1{,}079) = 27.341$, p = 0.000].

A post hoc test for net stolen bases finds both the bats left and throws left condition ($M = 7.20$, SD 7.58) and the bats left and throws right condition ($M = 8.08$, SD = 8.06) significantly differed from the bats right and throws right condition ($M = 4.78$, SD = 5.37). The mean score for the bats left and throws left condition ($M = 7.20$, SD =

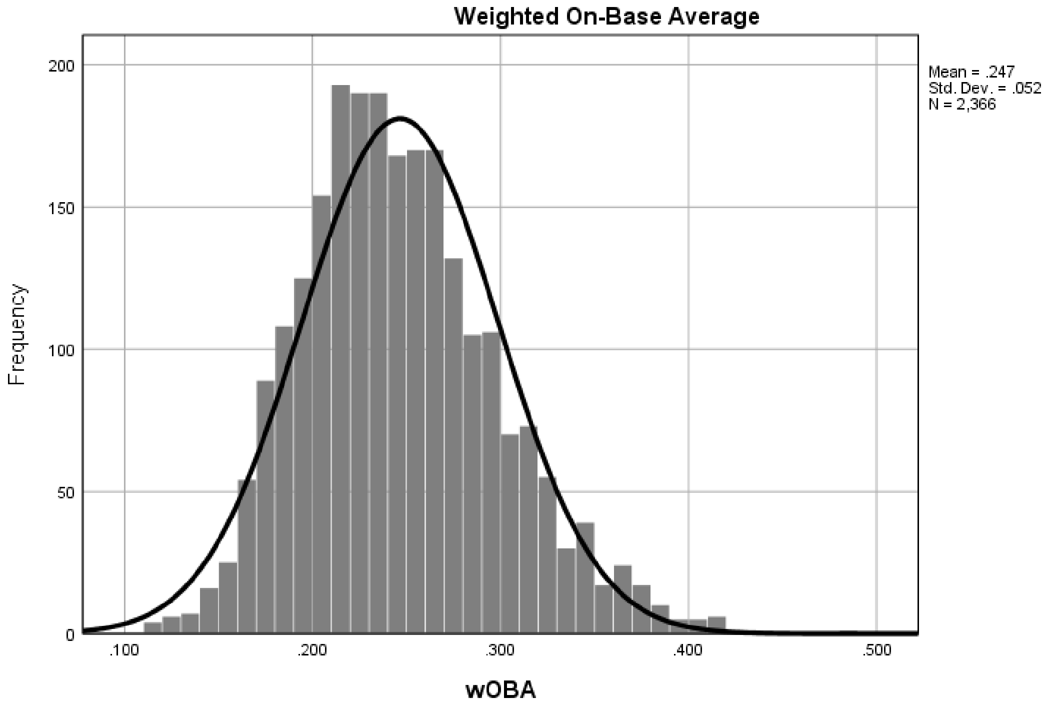
7.58) was not significantly different from the bats left and throws right condition (*M* = 8.08, SD = 8.06).

Weighted On-Base Average

The values for batting events that populate the formula for weighted on-base average (wOBA) were calculated using an aggregate of the team statistics from the Power Five and Group of Five conferences for the 2015-2017 seasons. The linear weights used in the formulas to calculate wOBA for the 10 conferences in this study are shown in Appendix C.

Figure 4.15

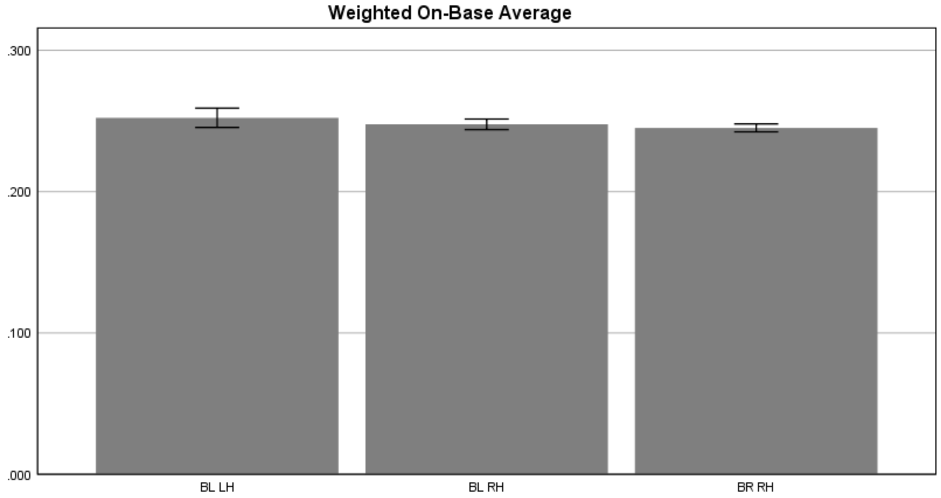
Histogram of Weighted On-Base Average: Minimum 100 At-Bats



The histogram in Figure 4.15 shows that the data for weighted on-base average was mostly symmetrical.

Figure 4.16

Bar Chart of Weighted On-Base Average: Minimum 100 At-Bats



The mean weighted on-base averages are shown in Figure 4.16 for the conditions of BL LH (.252), BL RH (.248), and BR RH (.245).

Table 4.14

One-Way ANOVA of Seven Dependent Variables: Minimum 100 At-Bats

		Sum of Squares	df	Mean Square	F	Sig.
wOBA	Between Groups	.010	2	.005	1.884	.152
	Within Groups	6.412	2,363	.003		
	Total	6.423	2,365			

As shown in Table 4.14, the ANOVA found no significant effects at the $p<0.05$ level for the three conditions of batting preference and throwing hand on weighted on-base average [$F(2, 2{,}363) = 1.884$, p = 0.152]. Therefore, no post hoc test was run for wOBA.

Research Question 3 – The Platoon Effect

The third research question (R_3) for this study was as follows: To what extent does a platoon effect exist in women's college softball for the Power Five and Group of Five Conferences?

Batting Platoon Splits

The platoon effect for batters, according to batting average, for teams in the Power Five and Group of Five conferences from 2015-2017 is shown in Table 4.15. Left-sided batters have a positive overall platoon effect, hitting .041 points better against right-handed pitchers than against left-handed pitchers. Right-sided batters have a reverse platoon effect, hitting .007 points worse against left-handed pitchers than against right-handed pitchers.

Table 4.15

Overall Platoon Effect for Batters in Batting Average

Bats	H LHP	AB LHP	BA	H RHP	AB RHP	BA	Platoon Effect
Left	6,821	24,430	.279	48,069	150,273	.320	.041
Right	9,578	35,738	.268	64,030	232,827	.275	-.007

Platoon splits are shown in Table 4.16 for batters with at least 20 at-bats in a season against left-handed pitchers and 20 at-bats against right-handed pitchers. Batters were described as bats left (BL) and bats right (BR), which were combined with the performance statistics of batting average (BA), on-base percentage (OBP), slugging percentage (SLG), and weighted on-base average (wOBA).

Table 4.16

Batting Platoon Splits for 2015-2017: Minimum 20 At-Bats Against Left-Handed Pitchers and 20 At-Bats Against Right-Handed Pitchers

		BL BA Platoon	BR BA Platoon	BL OBP Platoon	BR OBP Platoon	BL SLG Platoon	BR SLG Platoon	BL wOBA Platoon	BR wOBA Platoon
N	Valid	544	658	544	658	544	658	544	658
	Missing	672	558	672	558	672	558	672	558
Mean		.046	-.014	.058	-.021	.085	-.030	.040	-.014
Median		.053	-.020	.060	-.024	.084	-.037	.043	-.014
Mode		.000	.000	.000	-.089[a]	-.688[a]	.000	-.222[a]	-.245[a]
Std. Deviation		.103	.101	.102	.103	.174	.209	.070	.078
Range		.559	.631	.563	.609	1.362	1.396	.501	.472

Minimum	-.254	-.277	-.223	-.287	-.688	-.726	-.222	-.245
Maximum	.306	.354	.341	.322	.674	.671	.279	.227

a. Multiple modes exist. The smallest value is shown

According to the means shown in Table 4.16, left-sided batters have a positive platoon split in all four offensive categories while right-sided batters have a reverse platoon split in all four offensive categories.

Pitching Platoon Splits

The platoon effect for pitchers according to batting average for the entire population studied is shown in Table 4.17. Left-handed pitchers have a reverse platoon effect, pitching .012 points worse against left-sided batters than against right-sided batters. Right-handed pitchers have a positive platoon effect, pitching .039 points better against right-sided batters than against left-sided batters.

Table 4.17

Overall Platoon Effect for Pitchers in Batting Average

Throws	H LHB	AB LHB	BA	H RHB	AB RHB	BA	Platoon Effect
Left	5,572	21,829	.255	8,523	35,037	.243	-.012
Right	40,532	138,226	.293	60,406	238,054	.254	.039

Table 4.18 shows descriptive statistics for platoon splits for pitchers from 2015-2017 in women's college softball for the Power Five and Group of Five conferences with a minimum of 20 at-bats against left-handed batters and 20 at-bats against right-handed batters in a season. Platoon splits are shown according to BA, OBP, SLG, and wOBA for pitchers who threw left-handed and right-handed. The calculations of OBP and wOBA were performed without the inclusion of sacrifice flies since this category was not tabulated by the NCAA by pitcher handedness. The linear weights used to calculate wOBA for pitchers are shown in Appendix C. The linear weights for pitchers were calculated using an aggregate of the team statistics from each of the Power Five and

Group of Five conferences for the 2015-2017 seasons. The calculation of linear weights was performed without the inclusion of statistics for double plays and stolen bases since these categories were not tabulated by the NCAA for pitchers.

Table 4.18

Pitching Platoon Splits for 2015-2017: Minimum 20 At-Bats Against Left-Handed Batters and 20 At-Bats Against Right-Handed Batters

		LHP BA	RHP BA	LHP OBP	RHP OBP	LHP SLG	RHP SLG	LHP wOBA	RHP wOBA
N	Valid	134	961	134	961	134	961	134	961
	Missing	961	134	961	134	961	134	961	134
Mean		-.013	.041	.005	.031	.066	-.048	.073	-.068
Median		-.009	.041	.006	.031	.067	-.034	.038	-.005
Mode		-.25[a]	-.27[a]	-.241[a]	.000	-.37[a]	-.15	.00	.00
Std. Deviation		.054	.069	.058	.071	.191	.201	.147	.140
Range		.37	.59	.409	.552	1.12	1.43	.67	.75
Minimum		-.25	-.27	-.241	-.248	-.37	-.92	-.33	-.40
Maximum		.12	.33	.168	.304	.75	.51	.34	.35

a. Multiple modes exist. The smallest value is shown

According to the means shown in Table 4.18, left-handed pitchers have a reverse platoon split for BA (-.013) but positive platoon splits for OBP (.005), SLG (.066), and wOBA (.073). Right-handed pitchers have a positive platoon split for BA (.041) and OBP (.031) but negative platoon splits in SLG (-.048), and wOBA (-.068).

Research Question 4 – Positional Bias

The final research question (R_4) for this study was as follows: To what extent does positional bias exist in women's college softball for the Power Five and Group of Five Conferences?

Table 4.19

At-Bats and Batting Average by Positions

Positions	AB L	AB R	BA L	BA R	L Minus R
1B-OF	87,401	44,071	.314	.277	.037
C-3B-SS-2B	11,217	48,461	.311	.343	-.032

Note: Grouped according to first basemen and outfielders (1B-OF), and catchers, third basemen, shortstops, and second basemen (C-3B-SS-2B), displaying total number of at-bats by left-preference batters (AB L), right-preference batters (AB R), batting average for left-preference batters (BA L), right-preference batters (BA R), and the differential in batting average between left-preference batters and right-preference batters (L Minus R).

As shown in Table 4.19, for the first base and outfield positions (1B-OF) for teams in the Power Five and Group of Five conferences from 2015-2017, left-preference batters recorded more at-bats than right-preference batters (87,401 at-bats to 44,071 at-bats). At the catcher, third base, shortstop, and second base positions (C-3B-SS-2B), right-preference batters recorded more at-bats than left-preference batters (48,461 at-bats to 11,217 at-bats). Overall for the players evaluated in Table 4.19, left-preference batters hit for a .314 batting average while right-preference batters hit for a .312 batting average.

Table 4.20

Right-Sided Batters by Positions: Minimum 50 At-Bats

Positions	N	BA	OBP	SLG	wOBA
1B-OF	325	.274	.260	.442	.234
C-3B-SS-2B	460	.266	.252	.428	.228

Table 4.20 shows the performance means for right-sided batters with at least 50 at-bats according to positional groups for batting average (BA), on-base percentage (OBP), slugging percentage (SLG), and weighted on-base average (wOBA). While right-

sided batters at the C-3B-SS-2B positions outnumber right-sided batters at the 1B-OF positions, right-sided batters at the 1B-OF positions perform better in every category.

Table 4.21

Left-Sided Batters by Positions: Minimum 50 At-Bats

Positions	N	BA	OBP	SLG	wOBA
1B-OF	598	.310	.291	.408	.231
C-3B-SS-2B	74	.310	.289	.469	.255

Most left-sided batters in the sample play the 1B-OF positions, as shown in Table 4.21. The performance categories of batting average and on-base percentage were similar for the two positional groups. Left-sided batters, however, have higher means at the C-3B-SS-2B positions for slugging percentage and wOBA.

CHAPTER V. CONCLUSION

This chapter presents an overall summary of the study and essential conclusions from the data analysis in Chapter IV. Included in this chapter are a *Summary of the Study*, research questions headings with subheadings for limitations and future directions, and *Implications of Results*.

Summary of the Study

As stated in Chapter I, the purpose of this study was to explore laterality in women's college softball. Specifically, this study focused on the extent of a left-sided lateral preference in women's college softball within the population studied, performance differences between throwing hand and batting lateral preference, to what extent the platoon effect exists in the sport, and positional bias in women's college softball.

The methodology for this study included descriptive statistics to examine the research questions and a one-way ANOVA to examine the influence of batting lateral preference and throwing hand on performance.

Research Question 1 – Frequency of a Left-Sided Lateral Preference

For this research question, 9.35% of the softball players studied throw left-handed while 90.65% throw right-handed. This rate of left-handed throwing was slightly higher than the findings for women in other studies. Gilbert and Wysocki (1992) found that 7.6% of women throw left-handed, Raymond et al. (1996) found 7.5% of women 18-30 years of age throw left-handed, Papadatou-Pastou et al. (2008) found 6.93% to 7.99% of women between 18-40 years of age throw left-handed, and Loffing et al. (2014) found 7.2% percent of female college students preferred to throw left-handed. McManus (2002) identified the overall percentage of left-handedness in women as 8.6%. Therefore, left-handed throwers appear to be more common in women's college softball for teams in the Power Five and Group of Five conferences from 2015-2017 than found in other studies.

This research question also looked at batting preferences for women's softball players. The study found that 31.09% of participants batted with a left-sided lateral preference, 68.45% batted with a right-sided preference, and 0.45% were switch hitters. The only other study to look at laterality and the bi-manual act of batting by women found 14.0% of female college students preferred to bat with a left-sided lateral preference (Loffing et al., 2014). Regarding the bi-manual act of holding a hockey stick, Loffing et al. found that 27.7% of female participants preferred a left-sided grip. It appears, therefore, that women's college softball players have a greater frequency of left-sided batting preference than women in other studies that evaluated bi-manual acts in sport.

Limitations

A limitation of this study was that other than research in 2014 by Loffing et al., no studies were available for comparing the batting preferences of softball players. The study by Loffing et al. involved German college students, who potentially were unfamiliar with baseball and softball. Females, in general, and females in sport, specifically, have been studied less than men, which means fewer studies were available for comparison

The study evaluates a three-year period in women's softball. Therefore, the study was limited longitudinally. The data also encompasses 104 out of the 295 teams playing NCAA Division I softball, so it may not be representative of all of Division I college softball.

Future Direction

Future research should explore trends in handedness in softball. This can involve investigating the handedness aspects of additional teams, conferences, and divisions. The National Pro Fastpitch league is another potential subject of study. Longitudinal studies should be conducted to determine laterality rates over time in softball and the relationship of laterality to different run-scoring environments.

Research Question 2 – Batter Lateral Preference and Throwing Hand

This research question addressed combinations of batting and throwing preferences in women's college softball. Right-sided batters who throw right were found to be the majority (67.10%) of players who make up rosters in college softball for the study group, followed by left-sided batters who throw right (23.14%), left-sided batters who throw left (7.93%), right-sided batters who throw left (1.37%), switch hitters who throw right (0.43%), and switch hitters who throw left (0.03%).

Of 325 left-handed throwers evaluated in the study (see Table 4.3), 85.23% bat with a left-sided lateral preference. Of 3,151 right-handed throwers, 74.36% bat with a right-sided lateral preference. By comparison, Loffing et al. (2014) used the Edinburgh Handedness Inventory to identify handedness in a group of college students, finding that 73% of female left-handers bat with a left-sided lateral preference and 91% of right-handers bat with a right-sided lateral preference. Considering the popularity of slap hitting in women's college softball, it is not surprising that this study found more left-handed throwers who bat left and more right-handed throwers who bat left than that found by Loffing et al.

The histograms shown for each of the metrics used in this research question show mostly symmetrical distributions for batting average, slugging percentage, strikeout percentage, walk percentage, and weighted on-base average. By refining the criteria for home run percentage and net stolen bases, more symmetrical data were illustrated in the corresponding histograms. For sample sizes greater than 300, such as the sample in this study, it is recommended that researchers rely on histograms, a skewness value of greater than two, and a kurtosis value of greater than seven to determine non-normality (Hae-Young, 2013).

Left-preference batters who throw left-handed were superior, according to significant differences in means, to right-preference batters who throw right in batting average, strikeout percentage, and net stolen bases, and were superior to left-preference batters who throw right in walk percentage. Left-preference batters who throw right were superior to right-preference batters who throw right in strikeout percentage and net stolen bases, and were marginally superior to left-preference batters who throw left in batting average. Right-preference batters who throw right were superior to left-preference batters who throw left in home run percentage and to left-preference batters who throw right in slugging percentage, home run percentage, and walk percentage.

No significant differences were found in slugging percentage, home run percentage, strikeout percentage, and net stolen bases for left-preference batters who throw left and left-preference batters who throw right. No significant differences were found in slugging percentage and walk percentage for left-preference batters who throw left and right-preference batters who throw right.

To explain the performance differences in MLB, Grondin et al. (1999) referenced Guiard's (1987) kinematic chain model, which posits that one hand has a preferred role and the other hand a non-preferred role. Grondin et al. theorized that the hitting differences between left-preference batters and right-preference batters in MLB were due to either hand dominance or hand specialization. In women's softball, the results suggest that slap hitters possibly skew the results and no such conclusions regarding the role of each hand should be inferred.

Limitations

To better understand the impact of laterality on performance in women's college softball, a method for identifying slap hitters is needed. Ideally, scorekeepers would note whether the outcome of the at-bat resulted from the batter swinging the bat or batting as a slap hitter. This change in record keeping seems unlikely since it would be an additional responsibility for scorekeepers tracking a sport that is typically not given the attention or resources of other sports, such as football or basketball. Bunting, an important part of a slap hitter's repertoire, would raise additional issues for the scorekeeper, who would have to determine whether the bunt was performed as a slap hitter or as a hitter who swings away. A second option would be to observe games to determine the batter's method of hitting in at-bats. Games could be evaluated using either video recordings or by a researcher in attendance. This may be necessary because slap hitters can alternate within an at-bat between slap hitting and swinging the bat. A third possibility would be to use existing statistics to determine if slap hitters can be identified through certain offensive characteristics. It was impossible to know if the effort to introduce slugging percentage as a minimum standard to home run percentage removed slap hitters from the sample. If using the mean slugging percentage with home run percentage did remove slap hitters from the sample, right sided batters who throw right were superior home run hitters to left-sided batters who throw left and to left-sided batters who throw right.

Walk percentage had a skewness value (see Table 4.4) similar to home run percentage and a higher kurtosis value, however the data were not modified because the histogram appeared somewhat symmetrical.

Future Direction

The Edinburgh Handedness Inventory should be utilized to evaluate the correlation between player handedness, throwing hand, and batting preference. Variables could then be introduced to evaluate the impact of handedness, throwing hand, and batting preference on performance.

The NCAA and the National Fastpitch Coaches Association (NFCA) should be petitioned to request that scorekeepers begin identifying slap hitters. This change would allow researchers to draw conclusions on the performance of slap hitters by differentiating slap hitters from left-sided batters who swing the bat.

Statistical methods could also be utilized to evaluate the performance characteristics of slap hitters. If successful, this would allow the separation of slap hitters from those left-sided batters who swing the bat so that further analysis could be performed on laterality in women’s softball. One alternative to using slugging percentage for identifying slap hitters would be to analyze the ground out to fly out rates for slap hitters. Ground outs and fly outs are statistics provided by the NCAA for each batter. Slap hitters should have higher rates of ground outs since their goal typically is to hit the ball on the ground.

Although seven performance variables were evaluated using a one-way ANOVA for this research question, these statistics were not an exhaustive list of those available for study. Additional variables should be used to analyze play in women's college softball. Economic differences amongst the schools and the relationship to performance should also be investigated.

Research Question 3 – The Platoon Effect

Taken together, these results suggest that the platoon effect exists in women's softball, although it varies for batters, pitchers, laterality preference, and performance metric.

In the mid-nineteenth century, Henry Chadwick introduced the statistic batting average for baseball (Henry Chadwick, n.d.). Batting average was long the preferred metric for evaluating hitters, and thus traditionally was used for evaluating the platoon effect, which for softball is shown for the entire dataset in Table 4.15. More recent statistics are shown in Table 4.16, in addition to batting average, to evaluate the platoon effect for batters in women's college softball.

Batters who bat left in softball fare better on average against right-handed pitchers in all four performance categories, as shown in Table 4.16. Left-sided batters hit .046 points higher in batting average (BA) against right-handed pitchers than left-handed pitchers, .058 points higher in on-base percentage (OBP), .085 points higher in slugging percentage (SLG), and .040 points higher in weighted on-base average (wOBA). Interestingly, right-sided batters also hit better (.014 BA, .021 OBP, .030 SLG, and .014 wOBA) against right-handed pitchers, therefore displaying a reverse platoon effect. A potential explanation for better performance against right-handed pitchers is the strategic advantage hypothesis, which states that left-handed athletes gain an advantage due to unfamiliar strategies and patterns of attack in interactive sports (Faurie & Raymond, 2005). An explanation for the strategic advantage hypothesis is that the motor responses to left-handed attacks may be practiced less (Hagemann, 2009). This seems plausible for women's college softball since left-handed pitchers comprise only 12.24% of the pitchers referenced in Table 4.18.

The platoon splits for pitchers, as shown in Table 4.18, were potentially influenced by slap hitters. Slap hitters, who often hit for a higher batting average but less power than other hitters, possibly skew the performance categories of batting average and on-base percentage in favor of left-sided batters and slugging percentage and wOBA in favor of right-sided batters.

From both a batter's perspective and from a pitcher's perspective, left-handed pitchers were more effective overall than right-handed pitchers against right-sided batters as measured by batting average. For batters (see Table 4.15), right-sided batters have a .268 batting average against left-handed pitchers and a .275 batting average against right-handed pitchers. For pitchers (see Table 4.17), left-handed pitchers have a .243 batting average when facing right-sided batters and right-handed pitchers have a .254 batting average when facing right-sided batters.

Limitations

Slap hitters possibly skew the data in this research question. Without a method for identifying slap hitters, it is impossible to know the impact slap hitters have on the platoon effect for batters and pitchers.

With the collection of additional softball data beyond the 2015-2017 seasons, more at-bats than the 20 at-bat minimum that was used for this research question could be used to analyze the platoon effect. A larger minimum requirement for at-bats would likely provide a better estimate of the platoon effect in women's college softball.

Future Direction

Video analysis should be performed using women's softball players to determine the predictability of pitches from left-handed and right-handed pitchers, and what role this may have on the platoon effect. If left-handed pitchers were found to gain an advantage because they were less common and batters have difficulty predicting pitch direction, this could support the strategic advantage hypothesis. Such research, if proven to improve pitch recognition from a left-handed minority, could also lead to new training methods for facing left-handed pitchers.

Question 4 – Positional Bias

Right-sided batters in Table 4.20 who play the catcher, third base, shortstop, and second base positions (C-3B-SS-2B) hit .066 points higher in batting average than right-sided batters who play the first base and outfield positions (1B-OF). Right sided batters at 1B-OF have higher statistics in all four offensive categories (batting average, on-base percentage, slugging percentage, and weighted on-base percentage) than right-sided batters playing C-3B-SS-2B.

Almost twice (87,401) the number of at-bats (as shown in Table 4.19) were taken by left-sided batters than right-sided batters (44,071) who play the 1B-OF positions. Walsh (2007a) found a more equal distribution in MLB between left-sided batters

(243,784) and right-sided batters (223,599). As Walsh found in baseball, few left-sided batters in softball play the C-3B-SS-2B positions.

Walsh concluded that the platoon effect was largely due to a lack of weak hitting left-sided batters playing the C-3B-SS-2B positions. In softball, as in baseball, considerably fewer left-sided batters play the C-3B-SS-2B positions. In contrast to baseball, left-sided softball players who play C-3B-SS-2B were found to be exceptional hitters.

Limitations

Only players whose positions were exclusively labeled within the 1B-OF and C-3B-SS-2B groups were included in these results, meaning many players who played at multiple position outside of these groups were excluded from consideration. The reason so many players were excluded from analysis was because scorekeepers do not specify a player's defensive position at the time of an offensive at-bat. It also appears that a large percentage of softball players play multiple positions.

It was possible that the frequencies of at-bats quantified in Table 4.19 do not accurately reflect positional ratios. Ideally, the positional information for this research question would be associated with all nine positions on the softball field rather than just the two groups.

Future Direction

Analyzing throwing hand and batter lateral preference, in combination with positional groupings, may provide additional insight into the relationship between positional bias and the platoon effect in women's college softball.

Additional Research

This section provides additional research on topics involving women's college softball beyond what was defined by the research questions.

Lateral Preference in Softball and Major League Baseball

The findings from Table 4.3 for batting and throwing preference in softball are compared with the findings of Grondin et al. (1999) for Major League Baseball (MLB) in Table 5.1.

Table 5.1

Batting and Throwing Preferences: Softball and MLB

Bats	Throws	Softball %	MLB %
Left	Left	7.93	12.24
Left	Right	23.14	18.04
Right	Left	1.37	0.71
Right	Right	67.10	61.98
Switch	Left	0.03	0.54
Switch	Right	0.43	6.49
Total		100.0	100.0

Note: MLB figures are from Grondin et al. (1996).

Slap hitting, a type of batting performed exclusively with a left-sided lateral preference, occurs in women's college softball but not in professional baseball. Slap hitting was possibly the reason more right-handed throwers in women's softball (23.14%) bat with a left-sided lateral preference than in MLB (18.04%). Though handedness, throwing hand, and batting lateral preference are not perfectly correlated (Loffing, Sölter, & Hagemann 2014), throwing hand is typically one qualifier in determining hand preference (Grondin, Guiard, Ivry, & Koren, 1999). It was not surprising that Table 5.1 shows an overall higher percentage of males who throw left-handed than females since left-handedness is higher for men (11.6%) than for women (8.6%) (McManus, 2002).

According to the two studies, switch hitters were much more common overall in MLB (7.03%) than in women's college softball (0.46%).

Four of the performance variables used to evaluate batting preference and throwing hand in softball were compared with the MLB findings of Grondin et al. (1996) in Table 5.2. Not included were the performance categories of home run percentage and stolen base percentage, which were modified for softball to make the histograms more symmetrical. Weighted on-base average, which was a statistic not created at the time of the study by Grondin et al, also was not included. Due to small sample size, the figures for bats right and throws left were not calculated for women's softball.

Table 5.2

Batting Performance for Left- and Right-Handed Throwers in Softball and MLB

		Batting Preference			
Statistic	Throws	Softball Bats Left	Softball Bats Right	MLB Bats Left	MLB Bats Right
BA	Left	.314	NA	.281	.276
	Right	.324	.287	.276	.263
SLG	Left	.466	NA	.411	.368
	Right	.448	.470	.396	.360
BB%	Left	12.71	NA	10.39	11.06
	Right	11.41	12.14	10.56	10.12
K%	Left	14.27	NA	10.44	10.55
	Right	13.49	15.80	9.53	11.41

Note: MLB figures are from Grondin et al. (1996).

As shown in Table 5.2, the women playing college softball described in this study have superior offensive statistics to men playing professional baseball according to batting average (BA), slugging percentage (SLG), and walk percentage (BB%).

Professional baseball players strikeout (K%) at a lower percentage than the women's college softball players evaluated in this study.

These statistics support other research that found softball has a considerably higher run-scoring environment than that found in MLB when the length of games is considered (Nachtigal, 2014b). Softball games are typically seven innings in length while MLB games are nine innings. Softball games can also be limited in length by a run-rule that doesn't exist in MLB.

Limitations

The Major League Baseball statistics in Table 5.2 were calculated for players with a minimum of 502 at-bats in a season while the softball figures were based on players with a minimum of 100 at-bats in a season. The difference in the number of minimum at-bats was due to the disparate amount of data available for MLB in comparison to women's softball, and a considerably longer season in MLB.

Future Direction

If a method can be devised to identify slap hitters in women's college softball, further analysis could be performed comparing women's softball to MLB and the findings of Grondin et al. (1996). The collection of additional data involving softball players who throw left and bat right would also allow for their study inclusion.

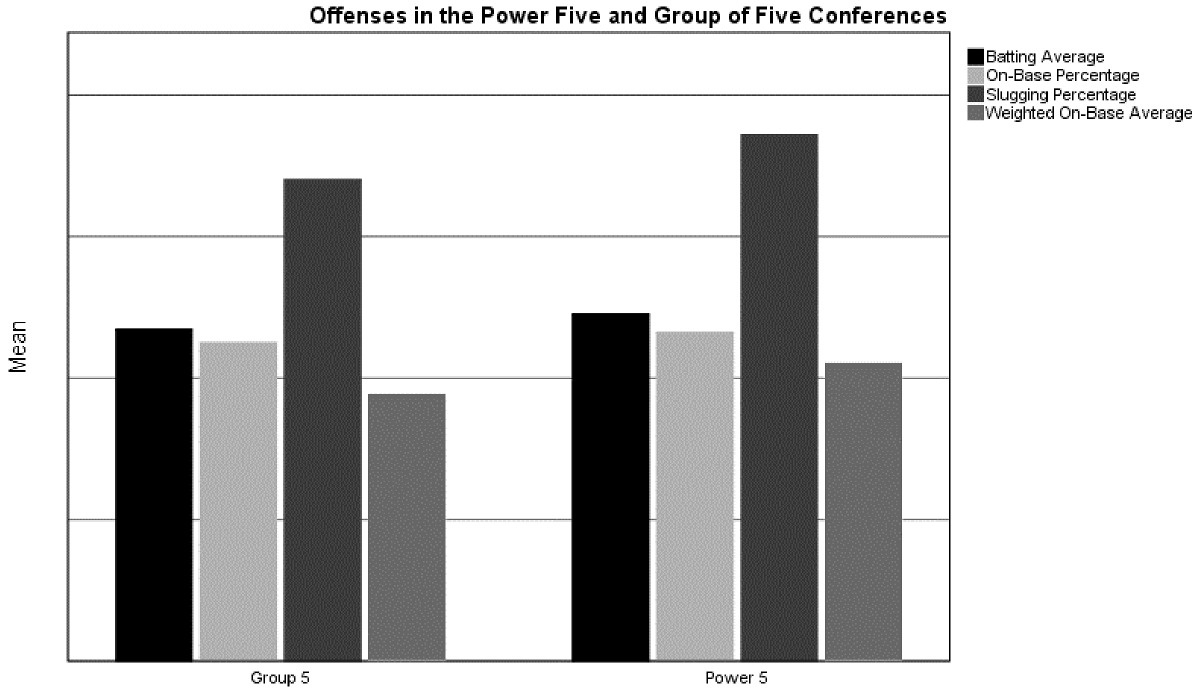
Comparing the Power Five and Group of Five Conferences

It has been 20 years since any teams other than those playing in the Power Five conferences have appeared in the championship game of Division I softball (Nachtigal, 2018). A comparison of offensive and pitching statistics for the Power Five and Group of Five conferences from 2015-2017 is shown below.

Offensive performance appears to favor the Power Five conferences. As shown in Figure 5.1, the teams in the Power Five conferences from 2015-2017 have higher overall offensive means in batting average, on-base percentage, slugging percentage, and weighted on-base average.

Figure 5.1

Bar Chart for Offenses in the Power Five and Group of Five Conferences



Fielding Independent Pitching (FIP) attempts to quantify only the statistics that a pitcher can control: home runs, walks, and strikeouts (Nachtigal, 2014a). Using FIP as a measure of pitching ability, little difference was found between the means for the pitchers from the Power Five (4.57 FIP) and Group of Five (4.58 FIP) conferences.

According to these two measurements, it appears that the difference between the Power Five conferences and the Group of Five conferences exists on the offensive side of the game.

Limitations

Only four metrics were used to evaluate the Power Five and Group of Five offenses, and only one was used to evaluate pitchers. Additional statistics may provide additional insights. Also, by grouping the 54 schools into the category for the Power Five conferences and the 50 schools into the category for the Group of Five conferences, individual differences between schools and conferences were not identified.

Future Direction

Further exploration should be performed using alternative statistical categories to evaluate the Power Five and Group of Five conferences. Comparisons should be performed on the performances of individuals, teams, and conferences with one another. Strategies for roster development and the characteristics of rosters should also be evaluated.

Implications of Results

The results indicate that a left-sided lateral preference was more common in women's softball, with slap hitters a possible cause. Until a method is devised for identifying which batters are slap hitters and which are not, it is difficult to draw as rich of conclusions about laterality for women's softball as those drawn for men's professional baseball. Nevertheless, the study provides a quantitative assessment of laterality preferences for batting and throwing in women's college softball that fills a research gap. The study also provides an assessment of performance variables that could impact the way the game is played and how coaches make recruiting decisions.

APPENDICES

Appendix A

Population

Table A1

Schools, Conferences, and Websites

School	Conf.	Softball Website URL
Akron	MAC	http://gozips.com/index.aspx?path=softball
Alabama	SEC	rolltide.com/index.aspx?path=softball
Appalachian St.	Sun Belt	https://appstatesports.com/index.aspx?path=softball
Arizona	Pac-12	arizonawildcats.com/index.aspx?path=softball
Arizona State	Pac-12	http://thesundevils.com/index.aspx?path=softball
Arkansas	SEC	arkansasrazorbacks.com/sport/w-softbl/
Auburn	SEC	http://www.auburntigers.com/sports/w-softbl/aub-w-softbl-body.html
Ball State	MAC	http://ballstatesports.com/index.aspx?path=softball
Baylor	Big 12	baylorbears.com/sports/w-softbl/bay-w-softbl-body.html
Boise State	MWC	http://www.broncosports.com/sports/w-softbl/bosu-w-softbl-body.html
Boston College	ACC	bceagles.com/roster.aspx?path=softball
Bowling Green	MAC	http://bgsufalcons.com/index.aspx?path=softball
Buffalo	MAC	http://www.ubbulls.com/sports/sball/index
California	Pac-12	calbears.com/roster.aspx?path=softball
Central Michigan	MAC	http://www.cmuchippewas.com/sports/w-softbl/cmu-w-softbl-body.html
Charlotte	C-USA	https://www.charlotte49ers.com/index.aspx?path=softball
Coastal Carolina	Sun Belt	http://www.goccusports.com/sports/w-softbl/coas-w-softbl-body.html
Colorado State	MWC	http://csurams.com/index.aspx?path=softball
East Carolina	AAC	https://ecupirates.com/index.aspx?path=softball
Eastern Michigan	MAC	http://www.emueagles.com/index.aspx?path=softball
FIU	C-USA	https://www.fiusports.com/index.aspx?path=softball
Florida	SEC	http://floridagators.com/index.aspx?path=softball
Florida Atlantic	C-USA	http://www.fausports.com/sports/w-softbl/fau-w-softbl-body.html
Florida State	ACC	seminoles.com/sports/softball/
Fresno State	MWC	http://www.gobulldogs.com/index.aspx?path=softball
Georgia	SEC	georgiadogs.com/index.aspx?path=softball
Georgia Southern	Sun Belt	https://gseagles.com/index.aspx?path=softball
Georgia State	Sun Belt	http://www.georgiastatesports.com/SportSelect.dbml?DB_OEM_ID=12700&SPID=5659&SPSID=53552&DB_OEM_ID=

Georgia Tech	ACC	ramblinwreck.com/sports/w-softbl/geot-w-softbl-body.html
Houston	AAC	http://www.uhcougars.com/sports/w-softbl/hou-w-softbl-body.html
Illinois	Big Ten	fightingillini.com/index.aspx?path=softball
Indiana	Big Ten	iuhoosiers.com/index.aspx?path=softball
Iowa	Big Ten	hawkeyesports.com/index.aspx?path=softball
Iowa State	Big 12	cyclones.com/index.aspx?path=softball
Kansas	Big 12	kuathletics.com/index.aspx?path=softball
Kent State	MAC	https://kentstatesports.com/index.aspx?path=softball
Kentucky	SEC	ukathletics.com/index.aspx?path=softball
Louisiana	Sun Belt	https://www.ragincajuns.com/index.aspx?path=softball
Louisiana Tech	C-USA	http://www.latechsports.com/sports/w-softbl/latc-w-softbl-body.html
Louisiana-Monroe	Sun Belt	https://ulmwarhawks.com/index.aspx?path=softball
Louisville	ACC	gocards.com/index.aspx?path=softball
LSU	SEC	lsusports.net/SportSelect.dbml?SPID=2174
Marshall	C-USA	http://www.herdzone.com/sports/w-softbl/mars-w-softbl-body.html
Maryland	Big Ten	http://www.umterps.com/SportSelect.dbml?&DB_OEM_ID=29700&SPID=120719&SPSID=716357
Memphis	AAC	http://gotigersgo.com/index.aspx?path=softball
Miami (OH)	MAC	http://www.miamiredhawks.com/sports/w-softbl/mioh-w-softbl-body.html
Michigan	Big Ten	mgoblue.com/index.aspx?path=softball
Michigan State	Big Ten	msuspartans.com/sports/w-softbl/msu-w-softbl-body.html
Mid. Tennessee St.	C-USA	http://goblueraiders.com/index.aspx?path=softball
Minnesota	Big Ten	gophersports.com/sports/w-softbl/minn-w-softbl-body.html
Mississippi St.	SEC	hailstate.com/index.aspx?path=softball
Missouri	SEC	mutigers.com/index.aspx?path=softball
NC State	ACC	gopack.com/index.aspx?path=softball
Nebraska	Big Ten	huskers.com/SportSelect.dbml?DB_LANG=C&DB_OEM_ID=100&SPID=34&SPSID=110
Nevada	MWC	http://nevadawolfpack.com/index.aspx?path=softball
New Mexico	MWC	http://golobos.com/index.aspx?path=softball
North Carolina	ACC	goheels.com/index.aspx?path=softball
North Texas	Sun Belt	http://www.meangreensports.com/sports/w-softbl/ntex-w-softbl-body.html
Northern Illinois	AAC	https://www.niuhuskies.com/index.aspx?path=softball
Northwestern	Big Ten	nusports.com/?path=softball
Notre Dame	ACC	und.com/sports/w-softbl/nd-w-softbl-body.html
Ohio	MAC	http://www.ohiobobcats.com/sports/sball/index
Ohio State	Big Ten	ohiostatebuckeyes.com/sports/w-softbl/osu-w-softbl-

		body.html
Oklahoma	Big 12	http://www.soonersports.com/SportSelect.dbml?DB_OEM_ID=31000&SPID=127251&SPSID=750353&KEY=
Oklahoma State	Big 12	okstate.com/index.aspx?path=softball
Ole Miss	SEC	olemisssports.com/sports/w-softbl/ole-w-softbl-body.html
Oregon	Pac-12	goducks.com/index.aspx?path=softball
Oregon State	Pac-12	osubeavers.com/index.aspx?path=softball
Penn State	Big Ten	gopsusports.com/sports/w-softbl/psu-w-softbl-body.html
Pittsburgh	ACC	pittsburghpanthers.com/index.aspx?path=softball
Purdue	Big Ten	purduesports.com/sports/w-softbl/pur-w-softbl-body.html
Rutgers	Big Ten	scarletknights.com/index.aspx?path=softball
S. Florida	AAC	http://gousfbulls.com/index.aspx?path=softball
San Diego State	MWC	http://www.goaztecs.com/sports/w-softbl/sdsu-w-softbl-body.html
San Jose State	MWC	http://www.sjsuspartans.com/sports/w-softbl/sjsu-w-softbl-body.html
South Alabama	Sun Belt	http://www.usajaguars.com/index.aspx?tab=softball&path=softball
South Carolina	SEC	gamecocksonline.com/sports/w-softbl/scar-w-softbl-body.html
Southern Miss	C-USA	http://www.southernmiss.com/sports/w-softbl/smis-w-softbl-body.html
Stanford	Pac-12	gostanford.com/index.aspx?path=softball
Syracuse	ACC	cuse.com/index.aspx?path=softball
Tennessee	SEC	utsports.com/index.aspx?path=softball
Texas	Big 12	texassports.com/index.aspx?path=softball
Texas A&M	Big 12	12thman.com/index.aspx?path=softball
Texas State	Sun Belt	http://txstatebobcats.com/index.aspx?path=softball
Texas Tech	Big 12	texastech.com/index.aspx?path=softball
Toledo	MAC	http://utrockets.com/index.aspx?path=softball
Troy	Sun Belt	https://www.troytrojans.com/index.aspx?path=softball
Tulsa	AAC	http://tulsahurricane.com/index.aspx?path=softball
UAB	C-USA	https://www.uabsports.com/index.aspx?path=softball
UCF	AAC	http://ucfknights.com/index.aspx?path=softball
UCLA	Pac-12	uclabruins.com/index.aspx?path=softball
UConn	AAC	http://www.uconnhuskies.com/sports/w-softbl/conn-w-softbl-body.html
UNLV	MWC	http://www.unlvrebels.com/sports/w-softbl/unlv-w-softbl-body.html
UT Arlington	Sun Belt	http://www.utamavs.com/sports/w-softbl/txar-w-softbl-body.html
Utah	Pac-12	utahutes.com/index.aspx?path=softball
Utah State	MWC	http://www.utahstateaggies.com/sports/w-softbl/ust-w-softbl-body.html

UTEP	C-USA	http://utepathletics.com/index.aspx?path=softball
UTSA	C-USA	http://goutsa.com/index.aspx?path=softball
Virginia	ACC	virginiasports.com/sports/w-softbl/
Virginia Tech	ACC	www.hokiesports.com/softball/
Washington	Pac-12	gohuskies.com/index.aspx?path=softball
Western Kentucky	C-USA	http://wkusports.com/index.aspx?path=softball
Western Michigan	MAC	http://wmubroncos.com/index.aspx?path=softball
Wisconsin	Big Ten	uwbadgers.com/index.aspx?path=softball

Appendix B

Softball Statistics

Table B1

Defensive Softball Statistics

Statistic	Abbreviation
Assists	A
Errors	E
Fielding Percentage	FldPct
Games Played	GP
Games Started	GS
Passed Ball	PB
Put Outs	PO

Table B2

Offensive Softball Statistics

Statistic	Abbreviation
At-bat	AB
Batting Average	AVG
Caught Stealing	CS
Double	2B
Extra-base Hit	XBH
Fly Out	FO
Grounded into Double Play	GIDP
Ground Out	GO
Groundout-to-Flyout Ratio	GO/FO
Hit-by-pitch	HBP
Hit	H
Home Run	HR
Intentional Walk	IBB
On-base Percentage	OBP
On-base Plus Slugging	OPS
Plate Appearance	PA
Run Batted In	R
Run Batted In	RBI
Sacrifice Bunt	SH
Sacrifice Fly	SF
Single	1B
Slugging Percentage	SLG

Stolen Base	SB
Stolen-base Percentage	SB%
Total Bases	TB
Triple	3B
Walk	BB
Weighted On-base Average	wOBA

Table B3

Pitching Softball Statistics

Statistic	**Abbreviation**
Appearance	APP
Batters Faced	BF
Complete Game	CG
Earned Run	ER
Earned Run Average	ERA
Flyout	FO
Groundout	GO
Hits Allowed	HA
Shut Out	SHO
Wild Pitch	WP

Appendix C

Softball Linear Weights

Table C1

Batting Linear Weights

Conference	BB/HBP	1B	2B	3B	HR
AAC	.421	.555	.856	1.109	1.467
ACC	.437	.564	.846	1.099	1.464
Big 12	.461	.591	.877	1.124	1.474
Big Ten	.451	.580	.865	1.120	1.481
C-USA	.429	.563	.861	1.109	1.463
MAC	.402	.534	.828	1.080	1.445
MWC	.455	.583	.872	1.128	1.481
Pac-12	.478	.600	.879	1.132	1.484
SEC	.479	.607	.889	1.139	1.493
Sun Belt	.446	.575	.861	1.116	1.480

Table C2

Pitching Linear Weights

Conference	BB/HBP	1B	2B	3B	HR
AAC	.406	.539	.845	1.107	1.485
ACC	.412	.548	.855	1.119	1.501
Big 12	.407	.558	.896	1.169	1.551
Big Ten	.436	.573	.878	1.145	1.524
C-USA	.416	.553	.865	1.129	1.500
MAC	.413	.543	.836	1.098	1.476
MWC	.450	.581	.877	1.138	1.495
Pac-12	.407	.556	.897	1.164	1.541
SEC	.373	.534	.901	1.177	1.571
Sun Belt	.417	.551	.857	1.122	1.501

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