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Examining changes in bat swing kinematics in various regions of the strike zone in collegiate baseball and softball players

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EXAMINING CHANGES IN BAT SWING KINEMATICS IN DIFFERENT AREAS OF THE STRIKE ZONE IN COLLEGIATE BASEBALL AND SOFTBALL PLAYERS

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ABSTRACT

According to the National Collegiate Athletic Association (NCAA) there are over 50,000 men and women who compete in collegiate baseball and softball. These individuals spend hours improving their ability to swing a bat with the hope of improving his or her batting performance during a game situation typically off a tee in a position of their own choosing. However, during a game situation an athlete may swing a bat through his or her strike zone depending upon the pitch thrown by an opposing pitcher. The strike zone is defined as the space over home plate in a region that is above an athlete's knee and below the armpit when they set up in their chosen batting stance. To date there is a limited amount of information regarding changes in swing kinematics throughout a person's strike zone.

The purpose of this study investigated changes in swing kinematics throughout an individual's strike zone in collegiate baseball and softball players. The aims of this study were (1) to investigate the changes in bat kinematics within various regions of an individual's strike zone, (2) investigate changes in full body kinematics within an individual's strike zone, (3) investigate changes in EMG activity throughout an individual's swing and how that changes in different areas of his/ her strike zone.

A total of 26 intercollegiate baseball (n=13) and softball (n=13) players between the ages of 18-25 were recruited for the following study. The experimental session analyzed changes in both bat and full body kinematics throughout an individual's strike zone using a motion capture system. Lower extremity EMG was used to analyze mean muscle activity and percent activation of the stride leg over the nine regions of the strike zone. A series of repeated measures analysis of variance were used to determine differences in bat swing kinematics and lower body EMG.

Significant differences were seen in bat swing kinematics for both baseball and softball players across the nine regions of the strike zone ($p<.05$). Significant differences in stride leg EMG was seen over the three phases of the swing for both groups($p<.05$). There were significant changes in full body kinematics when examining elbow flexion angle at bat-ball contact among baseball and softball players ($p<.001$).

Both athlete and sport coach can use this data to work on hitting technique along with bat speed/angle depending on where he or she is deficient in the strike zone. This information can also be used to establish what would be considered an ideal bat angle for both baseball and softball so both sport coaches and athletes can practice achieving the ideal bat angle in a given region of the strike zone not only for collegiate populations, but others as well.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
BABC	Bat angle at ball contact
BAMRV	Bat angle at maximal resultant velocity
EMG	Electromyography
MG	Medial Gastrocnemius
MH	Medial Hamstrings
MMT	Maximum Muscle Test
MQ	Medial Quadriceps
MRV	Maximal Resultant Velocity
MVIC	Maximal Voluntary Isometric Contraction
NCAA	National Collegiate Athletic Association
PAR-Q	Physical Activity Readiness Questionnaire
RVBC	Resultant Velocity at Ball Contact
SB	Standard Bat
TA	Tibialis Anterior
WU	Warm-up

CHAPTER I

INTRODUCTION

Within the realm of collegiate athletics, baseball and softball have over 50,000 participants who compete against each other according to the National Collegiate Athletic Association (NCAA) (Association, 2017). Intercollegiate athletics creates a very competitive environment for athletes to play at the highest level with the hope of a winning conference/ national title for their sport. Of these two sports, the average median revenue generated by baseball and softball is $414,000 and $99,000 respectively (Fulks, 2009). In an effort to provide intercollegiate sports teams with the greatest advantage both competitively and monetarily, extensive research has been done examining how to improve hitting performance.

Evidence based literature has examined the effectiveness of various batting techniques on hitting performance specifically focusing on increasing bat speed. If a 70 miles per hour (mph) fast ball is thrown towards home plate, a baseball player has just over .5 of a second to decide and swing a bat at that pitch. The reaction time further decreases to .43 seconds if a 97mph fast ball is thrown towards home plate (Scott, 1963). A similar reaction time can be seen in collegiate softball players, as the average reaction time from a 60mph fast ball is .47 seconds (Miller & Shay, 1964). Based on these short reaction times, one can see that bat speed is an important factor in determining bat swing performance. The faster one can swing a bat, more time can be devoted towards deciding whether or not to swing at a given pitch. One defining characteristic that has been shown to be a contributing factor for an increase in bat speed is the stride an individual takes during their swing (Breen, 1967; Escamilla et al., 2009a; Hay, 1978; Messier & Owen, 1986; Race, 1961).

One of the original rules put into place allows a batter the option to complete a warm-up (WU) prior to an at bat situation against an opposing pitcher (Technology, 2015). Research has examined the effectiveness of varying WU's based on a variety of protocols and implements in an effort to find the ideal protocol towards enhancing bat swing velocity prior to an at bat situation (Coop DeRenne, Ho, Hetzler, & Chai, 1992; Fleisig, Zheng, Stodden, & Andrews, 2002; Montoya, Brown, Coburn, & Zinder, 2009; Otsuji, Abe, & Kinoshita, 2002; Reyes & Dolny, 2009; Sergo & Boatwright, 1993; Southard & Groomer, 2003; Szymanski et al., 2012; Szymanski et al., 2011; Wilson et al., 2012). WU devices can vary in terms in of overall mass along with where the mass is located on a particular device, as an athlete completes their on-deck WU. Previous work has shown that maintaining ±12% of the standard bat (SB) weight during their on-deck WU will yield the greatest increase in bat swing velocity (Coop DeRenne, 1982; Coop DeRenne et al., 1992; Montoya et al., 2009), along with various bat properties (Fleisig et al., 2002; Southard & Groomer, 2003). Research has also shown that regardless of the weight or implement an individual uses during an on-deck WU does not influence bat speed prior to an at bat-situation (Reyes & Dolny, 2009; Szymanski et al., 2012; Szymanski et al., 2011). This could be attributed to the time set aside for athletes to work on hitting mechanics in addition to having a structured strength and conditioning program designed to improve sports performance.

Increasing age and skill could lead to more time being devoted towards improving batting performance through sport specific practice along with structured strength and conditioning programs. The NCAA has time set aside for an athlete to devote his or herself to improving sport specific skill on the field, in addition to participating in collegiate strength and conditioning programs (Ayers, Pazmino-Cevallos, & Dobose, 2012). Research has shown the more an athlete practices a sport specific skill such as swinging a bat, and performs exercises specific to that sport leads to an increase in a given skill set (Coop DeRenne, Buxton, Hetzler, & Ho, 1995; Hughes, Lyons, & Mayo, 2004; Sergo & Boatwright, 1993; Szymanski et al., 2007; Szymanski et al., 2006; Szymanski et al., 2010).

Despite the extensive amount of research that has been completed to date, the aforementioned studies have asked participants to swing a bat at either pitched balls from a machine or were instructed to hit a ball placed in a position of their choosing which isn't realistic in a game situation. Opposing teams can pitch a ball to a batter in an area that is called the strike zone. The strike zone covers the area beneath the knee cap of the batter and extends upwards towards the point right below the number on their jersey, and covers the width of home plate (See figure 6). Placing a ball in different areas of the strike zone can put a batter in an uncomfortable position as he or she may have to overextend themselves in an attempt to make contact with the ball. Another characteristic of one's batting performance that seems to be of importance is the angle of the bat as an individual approaches contact with a ball. Having the ideal bat angle when approaching contact with a ball, allows for a greater surface area of the bat exposed for ball contact. Surprisingly, there is a lack of research examining the angle of a bat as an individual approaches contact with a ball.

To our knowledge, there are no studies to date that have examined whole body kinematics along with bat swing kinematics in different areas of the strike zone in intercollegiate baseball and softball players. Therefore, the purpose of this study is to examine changes in bat swing kinematics specifically maximal resultant velocity (MRV), resultant velocity at ball contact (RVBC), bat angles at MRV, and RVBC, and time difference between MRV and RVBC. A secondary aim of this study is to examine full body kinematics in terms of displacements, velocities, and angles of the knee, pelvis, torso, trunk, and elbow in different areas of the strike zone. A tertiary aim of this study is to examine EMG activity throughout the four phases of an individual's swing based on previous work by Shaffer (Shaffer, Jobe, Pink, & Perry, 1993). The overall aim of this investigation is to provide both sport and strength coaches what is to be expected when intercollegiate baseball and softball make contact with a ball in various regions of their respective strike zone. This study is intended to help both player and coach improve areas of his/ her strike zone by quantitatively knowing how they perform in terms of bat swing kinematics.

Hypotheses

Kinematic Hypotheses

Specific Aim 1:

In order to investigate the effects of various regions of an individual's strike zone in terms of how consistent an athlete is at contacting a ball placed on a tee. This information will be tracked and analyzed with a Vicon Nexus motion capture system.

H_{01}: There will be no differences in bat swing kinematics in terms of maximal resultant velocity (MRV), resultant velocity at ball contact (RVBC), bat angle at MRV, bat angle at RVBC, and time difference between MRV and RVBC between the nine regions of the strike zone.

H_{A1}: There will be significant differences in bat swing kinematics in terms of MRV, RVBC, bat angle at MRV, bat angle at RVBC, and time difference between MRV and RVBC between the nine regions of the strike zone.

Changes in full body kinematics

Specific Aim 2:

H_{02}: There will be no differences in full body kinematics in different areas of the strike zone.

H_{A2}: There will be significant differences in full body kinematics in different areas of the strike zone.

Electromyography (EMG) Hypothesis

Changes in lower body EMG among phases of the swing and strike zone

Specific Aim 3:

H_{03}: There will be no difference in lower body EMG activity of the vastus medialis, semimembranosus, tibilias anterior, medial gastrocnemius, and gluteus maximus in different phases of the swing in different areas of the strike zone.

H_{A3}: There will be significant differences in lower body EMG activity of the vastus medialis, semimembranosus, tibilias anterior, medial gastrocnemius, and gluteus maximus in different phases of the swing in different areas of the strike zone.

Operational Definitions

Kinematics:

Movement, independent of the forces that cause a specific movement. Kinematics can be both linear and angular in nature that can utilize displacement, velocity, and acceleration in describing how an object moves (Winter, 2009).

Velocity:

Phases of a baseball swing:

One of the earliest studies to examine the distinct phases of a baseball swing was completed by Shaffer, Jobe, Pink, and Perry in 1993. This study examined the electrical activity of certain muscle groups while an individual swings a bat. Their study examined the electrical activity of certain muscle groups while an individual swings a bat. They define four phases of the swing:

<u>Phase 1:</u> Known as the windup, this phase begins when an athlete's lead heel leaves the ground and ends when the forefoot of the lead foot is back on the ground.

<u>Phase 2:</u> This phase is known as the Pre-swing phase and begins when the forefoot of the lead foot touches the ground and ends when the barrel of the bat begins to move forward.

<u>Phase 3</u>: Known as the Swing phase, this is broken into three sub phases consisting of early, mid, and late phases. The early potion of the swing begins when the barrel of the bat begins to move forward and ends when the bat is perpendicular with the ground. The middle phase of is from when the bat is perpendicular with the ground and ends with the bat is parallel with the ground. The late phase continues from the bat being parallel with the ground through contact with the ball.

Phase 4: This phase is known as the follow-through phase and begins once contact with the ball is made and ends when the lead shoulder is at maximal external rotation and abduction. (Shaffer et al., 1993)

Standard bat based on weight, gender, and skill level:

A standard bat ranges in terms of length and weight based on the athletes weight, gender, and level of skill. Descriptive characteristics of a standard bat for adolescent baseball players, collegiate baseball, and collegiate softball players are reported in Figure 1.

Adolescent standard baseball bat: The length of a standard baseball bat with a younger age population can vary based on both height and weight of the individual. Below is a figure listing the appropriate type of bat from Louisville slugger.

College baseball standard bat: Rules concerning a bat within the collegiate baseball setting is that the weight of the bat must not weigh more than three units less than the length of the bat. Typical collegiate baseball bats are 33in/30oz (Paronto, 2014).

Collegiate softball standard bat: A collegiate softball bat cannot be longer than 34 inches long and cannot weigh more than 38 ounces. Typical standard collegiate softball bats are either 34in/ 24oz. or 33in/23oz (Dee Abrahamson, 2013).

Moment of Inertia:

Moment of Inertia can be defined as the resistance to change in motion in which an object can slow down or speed up during a rotational movement (Rodgers & Cavanagh, 1984).

Maximal Resultant Velocity (MRV):

Maximal resultant velocity (MRV) will be defined as squaring the sum of squares based on marker position data based on the top of the bat.

Resultant Velocity at ball contact (RVBC):

Resultant velocity at ball contact (RVBC) is defined as the frame when deformation of the tee at the point of when an athlete swing's a standard bat. Frame rate will be recorded in hertz (Hz) in which the sampling frequency for the current study will be set at 200Hz as defined in previous literature (Fleisig et al., 2002; Milanovich & Nesbit, 2014; Nicholls, Elliott, Miller, & Koh, 2003; Southard & Groomer, 2003).

Electromyography (EMG):

Electromyography (EMG) is an electrical signal describing which muscle(s) are responsible for creating a movement. These signals can be used to provide information based on muscular fatigue and recruitment of various muscle fiber types (Winter, 2009).

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study is to investigate differences in bat swing kinematics throughout an individual's strike zone over the course of a fall season among collegiate baseball and softball players. This specific chapter will discuss four important aspects regarding bat swing kinematics. First, a review of past studies regarding kinematics when an individual swings a SB based on age, gender, and skill level. The next portion of this chapter will discuss the role of how various weighted implements can alter bat swing kinematics specifically bat velocity. Third, a review of the role of strength and conditioning in altering bat swing kinematics on the field of play. Finally, a short review of electromyography (EMG) will be discussed and how these signals change over the course of a bat swing trial.

Swing Kinematics: What has been done?

In looking at the wide array of movements carried out by a human being, an argument can be made that swinging a bat and making contact with a ball can be one of the many complex movements a person can attempt (Coop DeRenne et al., 1992). This complex and rapid movement pattern involves both the lower and upper extremity moving in a sequential manner with the goal of maximizing one's ability to hit a ball (Garhammer, 1983). The earliest study to our knowledge that has examined the analysis of a baseball swing via cinematography was completed by Race in 1961. He used a 16mm camera which tracked various segments of the body and bat in 17 professional baseball players. The findings of this study reveal the importance of rapid hip and wrist action needed when one is attempting to contact a baseball. This study also was able to track the bat velocity of these professional athletes in which the mean hitting velocity was 88.2 miles per hour (Race, 1961).

The foundational study completed by Race in 1961 set the stage for future studies to investigate kinematics of various body segments and bat swing kinematics. Kinematics is simply defined as a way to describe how something is moving without taking into account the forces that allow for that movement to take place (Rodgers & Cavanagh, 1984; Winter, 2009). Shaffer, Jobe, Pink, and Perry (1993) were able to define the four distinct phases of a swing based on the swing pattern in 18 professional baseball players. The first phase of the swing consists of the "wind-up" which begins when an individual picks up his/her lead foot off the ground and ends when the toe of that lead toe reestablishes ground contact. This initial phase of the swing based on this study took an average time of .285 seconds. The 2^{nd} phase of the swing is referred to as "pre-swing". This phase starts when the lead toe reestablishes contact with the ground and ends when the individual begins the swing lasting .115 seconds. The "swing" or third phase of the batting motion is divided into three sub-phases consisting of early, mid, and late swing phase. The early swing phase begins when the bat begins to move forward and ends when the bat is perpendicular with the ground. Mid-swing phase begins at the point when the bat is perpendicular with the ground and ends when the bat is parallel with the ground. The third phase of the swing is called the late swing phase and begins when the bat is parallel with the ground through ball contact. The duration in which the swing phase takes place is .18 seconds. The final/ fourth phase of a swing is the "follow-through" that begins when ball contact is made and ends when the individual reaches maximal abduction and external rotation of the lead shoulder lasting a little over .4 seconds (Shaffer et al., 1993). A visual representation of the four distinct phases of a baseball swing is displayed in Figure 2.

Characteristics of an individual's swing that make him or her successful towards increasing bat speed have been highly debated (Breen, 1967; Escamilla et al., 2009a; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1986; Milanovich & Nesbit, 2014; Nicholls et al., 2003; Race, 1961; Smith, 2001; Welch, Banks, Cook, & Draovitch, 1995).

Motions achieved in athletic performance intended to produce maximal velocity are transferred up a kinetic chain, specifically movements geared towards rotation such as swinging an implement (Milburn, 1981; Putnam, 1993). Movement up this kinetic chain is based on segments transferring momentum from a larger slower moving segment into a smaller faster moving segment reaching a given velocity. This occurs when a large body segment slows down or negatively accelerates causing an increase in the remaining kinetic chain segments as it assumes the loss in the momentum from the initial body segment (Welch et al., 1995).

The kinematics of an individual's batting motion has been examined in an attempt to understand what characteristics make a positive transfer towards increasing one ability to increase bat velocity (Escamilla et al., 2009a; Escamilla et al., 2009; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1985a, 1986; Milanovich & Nesbit, 2014; Nathan, 2000; Nicholls et al., 2003; Race, 1961). The effectiveness of an athlete's stride of the lead foot approaching contact with a ball has been examined in previous literature (Breen, 1967; Escamilla et al., 2009a; Hay, 1978; Messier & Owen, 1986; Race, 1961). An investigation by Escamilla et al. (2009) examined the difference in baseball hitting kinematics among youth and professional baseball players. A total of 24 participants completed this study in which youth baseball players had a mean age of 14.7 ± 2.4 years and had a batting average above .300 which classified them as being skilled for their age (Coop DeRenne, 2007; Coop DeRenne, Morgan, Hetzler, & Taura, 2008; Race, 1961). The adult hitters in this study also had to have a batting average of .300 which would classify these participants as skilled (Coop DeRenne, 2007; Coop DeRenne et al., 2008; Race, 1961). Video cameras with a 120Hz sampling rate were used to track each participant's swing as they contacted a ball from a pitching machine. Participants in this study completed 10-15 maximal effort swings in which the data were collected and analyzed. Results of this study revealed that the adult hitters spent more time during the stride phase of the swing at .4± .07 seconds in comparison to youth hitters at .29±.06 seconds ($p<.01$).

Welch et al. (1995) found similar results during the stride phase of the swing when observing swing kinematics in professional baseball players (Welch et al., 1995). Having a longer stride time allowed these athletes to have a greater time loading the back foot before swinging the bat. The extended time during the stride phase of the swing allowed the adult hitters to generate a greater bat velocity at ball contact at 30±2 m/s in comparison to 25±3m/s for youth hitters ($p<.01$) (Escamilla et al., 2009a).

Work by Messier and Owen (1986) examined the effectiveness of three different stances and strides on ground reaction forces and bat velocity in seven collegiate softball athletes. The three-different strides completed by participants were parallel, open, and closed based on the position of the lead foot at ball contact. Figure 3 represents the direction and foot placement participants were asked to complete as they contacted softballs from a pitching machine. The investigators speculated that a close stance and stride would theoretically allow participants to use the musculature needed to rotate the body over a longer distance than the other two striding techniques. High speed photography was used to determine velocity of the bat and a force plate was used to record the ground reaction forces of each participant's stride as they approached contact with the ball. Results of this study showed the closed stance and stride technique produced more force per units of body weight in the y-direction at 0.25 in comparison to the open stride technique at -0.22 ($p<.01$). Despite having an increase in ground reaction force utilizing the close striding technique, this technique did not yield a higher bat velocity among the other striding techniques (parallel: 19.55m/s ± 2.30, open: 20.09m/s ± 2.33, closed: 18.74m/s ± 1.28) ($p>.01$). The authors speculated their non-significance in bat velocity among the three striding techniques could be attributed to participants not being as proficient in these stepping strategies due to a lack of practice (Messier & Owen, 1986). If athletes spend time practicing their approach towards ball contact by focusing on loading their back leg, in addition to having a longer stride length towards ball contact could lead to an increase in bat speed. This would allow an individual to transfer momentum up the kinetic chain from their lower to upper extremities over a greater period causing an increase in bat swing velocity (Escamilla et al., 2009a; Messier & Owen, 1985b, 1986; Milburn, 1981).

The effects of varying grips on a bat regarding full body kinematics and bat speed have also been examined in previous literature (Coop DeRenne, Morgan, Escamilla, & Fleisig, 2010; Escamilla et al., 2009). A common batting technique utilized by an individual who has multiple strikes against them in their pitch count is to choke up on the bat by bringing their hands closer to the center of percussion or "sweet spot". The thought process behind having a choked grip is to allow a batter more control over the bat making contact with a ball easier (C DeRenne & Blitzbau, 1990). Investigation by Escamilla et al. (2009) and DeRenne, Morgan, Escamilla, and Flesig (2010) examined changes in baseball hitting kinematics in college and professional baseball players utilizing various grips on a baseball bat. These participants were randomized to complete either 10 swings with their normal grip or 10 swings with a choked-up grip with maximal effort. Two synchronized cameras with a sampling rate of 120Hz were used to record swings as participants contacted pitched balls from a pitching machine. Results of this study revealed a quicker stride phase with the choked-up grip at .336±.072 seconds in comparison to .375± .075 seconds (p<.01). Decreases in bat velocity at ball contact also went down with a choked-up grip at 28±5 m/s in comparison to the normal grip at 31±4 m/s (p<.01) (Escamilla et al., 2009). Having a reduced stride and swing phase lead to a 10% decrease in swing velocity.

Despite these decreases in bat velocity, utilizing a choked-up grip lead to ball contact quicker at .535±.083 seconds in comparison to .586± .078 seconds from the time the lead foot left the ground to ball contact (p=.01) (Coop DeRenne et al., 2010).

During a game, there can be certain situations in which you have a runner in a scoring position that calls for a hit-and-run play. A hit-and-run play is when a runner is on base and in a scoring position. A sport coach would give a signal to the base runner confirming that he or she will run. The batter will swing regardless of the pitch they receive in their respective strike zone. During this situation, a batter will attempt to hit a ball to the opposite side of the field to create time for a runner on base to score. Having the ability to hit a ball to the opposite side of the field has been shown to be important skill in swing sports such as baseball and softball (T. Williams & Underwood, 1986). The side of the plate in which a batter receives a pitched ball is considered the same field and the remaining half of home plate is considered the opposite side of the field. Work by Mcintyre and Pfautsch (1982) wanted to see if there were any kinematic differences when an athlete swing's a bat between hitting a ball to the opposite or same side of the field. A sample of 20 current and former collegiate baseball players were used for this study with a mean age of 21.1± 3.3 years. These participants were broken into two groups in which one group was considered as being effective opposite field hitters while the other group was considered non-effective hitters. Each of the participants were asked to swing at pitched balls in which they were instructed to hit the balls to two distinct areas of the field (same/opposite). Cameras were used overhead to record movements of the bat and various body segments. Results of this study revealed there were no significant differences in the general movement kinematics when engaging in a fielding hit to either the same or opposite sides of the field (p<.05). There were however significant differences from when the bat began to move forward until ball contact for the opposite field condition at .125 seconds in comparison to .142 seconds in the same field hitting condition. Despite the decreases in time to ball contact, linear velocity measured at the tip of the bat was different at 39.4 m/s hitting towards the same field in comparison to opposite field hitting at 36.08 m/s (Mcintyre & Pfautsch, 1982). This decrease in bat velocity can be explained by a lack of batting practice hitting the ball to the opposite side of the field in addition to using less trunk rotation and more upper extremity movement leading to a quicker swing to ball contact. Previous research in addition to the investigation by Mcintyre and Pfautsch reported similar findings within their discussion (Bryant, Burkett, Chen, Krahenbuhl, & Lu, 1977; Coop DeRenne et al., 2010; Escamilla et al., 2009; Mcintyre & Pfautsch, 1982).

One of the remaining aspects of bat hitting kinematics that has been examined is observing the relationship between various compositions of bats and balls and its impact on bat-ball exit velocity (Milanovich & Nesbit, 2014; Nathan, 2000; Nicholls, Elliott, & Miller, 2004; Nicholls et al., 2003). Injuries have been associated with swing sports like baseball and softball due to a host of factors such the composition of both the bat and ball in relation to exit velocity of the ball once contact has been made (Nathan, 2000; Nicholls et al., 2004; Nicholls et al., 2003). The magnitude of exit velocity from a bat-ball collision is based on the coefficient of restitution. The coefficient of restitution is based on the speed of an object after and before contact with a ridged object (Nathan, 2000, 2003). The most susceptible infielder prone to injury due to exit velocity impacts is the pitcher (Dick, 1999). In an effort to reduce the likelihood of injury, research has examined the potential changes in swing kinematics based on material properties of both the bat and ball (Bryant et al., 1977; Milanovich & Nesbit, 2014; Nathan, 2000, 2003; Nicholls et al., 2003).

In 1974, the NCAA first legalized the use of aluminum bats to offset the number broken wooden bats during a season (Russell, 2014). The pioneer study that examined the performance characteristics of both wooden and aluminum bats was completed by Bryant et al. in 1977. Investigators brought in six collegiate baseball players to swing both types of bats. Participants were randomized into either an aluminum or wooden bat group in which they swung a bat and contacted a ball delivered from a pitching machine. A total of 30-line drive hits were recorded and then the same protocol was followed for the other condition following a rest period. Results of this study indicate there was a higher mean bat velocity in the aluminum bat at 92.49 mph compared to the wooden bat at 88.64 mph ($p<.003$) (Bryant et al., 1977).

There have been several changes made by governing bodies such as the NCAA on regulating the performance standards of bats within intercollegiate athletics. During the 1999 season, the NCAA adopted the ball-exit-speed-ratio which was set to regulate the performance of composite and aluminum bats (Russell, 2014). The adoption of this rule, led to the investigations by Nicholls, Elliott, Miller, and Koh (2003) and Milanovich and Nesbit (Nesbit) to quantify these differences in bat composition. Nicholls et al. (2003) measured ball exit velocity with wood and metal bats of similar mass utilizing 17 experienced baseball players (Nicholls et al., 2003). Milanovich and Nesbit (2014) on the other hand, utilized collegiate softball players examining bat hitting kinematics among two bats of different inertial properties (Milanovich & Nesbit, 2014). Both studies recruited collegiate athletes in which they were asked WU as if leading up to a practice or game situation. Participants were randomized into a chosen bat condition, where three trials were recorded with a 3-D motion capture system at a sampling rate of 200Hz. Results of the Nicholls et al. (2003) investigation revealed a significantly faster ball exit velocity 44.3± 2.5 m/s and linear bat velocity 37.2± 1.8 m/s in the metal bat, in comparison to the wooden bat with a ball exit velocity at 41.7± 1.9 m/s and linear bat velocity at 35.2± 1.8 m/s ($p<.01$) (Nicholls et al., 2003). The investigation by Milanovich and Nesbit (2014) revealed similar swing characteristics among the aluminum and composite bat conditions in terms of their grip and swing velocity ($p>.05$) (Milanovich & Nesbit, 2014).

A recent investigation by Katsumata et al. (2017) examined the coordination of collegiate baseball players swinging a bat in different areas of the strike zone. The investigators used a total of 10 baseball players who were currently playing at the division I level in which they asked participants to complete two distinct tasks. The first of these tasks, each participant was asked to visualize a fast ball passing through each of the nine regions of their respective strike zone and to place the bat in the position where bat-ball contact would occur to establish each participant's intended swing trajectory to that given pitch. In the 2nd task, participants made contact with a plastic ball placed on a tee in each of the nine regions of the strike zone based on where they placed the bat asked of them in the first task. All movement was recorded with an 8 camera Vicon motion capture system at 250Hz. Each participant made completed a total of 45 swing trials all in a randomized order collecting a total of five trials per region of each participant's respective strike zone. Changes in movement was calculated using numerical differentiation of various body segments. Results indicated a significant main effect for height and course (inside, middle, outside) for ball location. There were significant differences in lead wrist angle, elbow angle, arm horizontal abduction/adduction angle, arm elevation angle, shoulder rotation, shoulder tilt, and shoulder translation among the varying heights of an individual's respective strike zone (Katsumata, Himi, Ino, Ogawa, & Matsumoto, 2017)

The studies in this section of the literature review have examined characteristics that have a positive influence on his or her bat swing kinematics based on age, various grips on the bat, technique of hitting the ball, position in their strike zone, or the composition of the bat itself (Coop DeRenne et al., 2010; Escamilla et al., 2009a; Escamilla et al., 2009; Hay, 1978; Katsumata, 2007; Katsumata et al., 2017; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1986; Milanovich & Nesbit, 2014; Nicholls et al., 2003; Race, 1961; Smith, 2001; Welch et al., 1995). The next portion of the literature will be examining what has been done in terms of bat swing kinematics when participants have the opportunity to utilize varying warm-ups leading to an at bat situation.

Effects of Weighted Implements on Bat Swing Kinematics

Baseball can be considered "America's favorite pastime" with its inaugural game taking place in 1845 under the direction of Alexander Cartwright (Technology, 2015). One of the original rules put into place allows an athlete the opportunity to WU on-deck before facing an opposing pitcher during an at bat situation. Athletes among various ages and skill sets have access to a variety of implements to utilize with the hope of increasing bat velocity, in addition towards increasing the perception of improving their swing velocity prior to an at bat situation. There are several research studies that have investigated the acute effects of various WU implements on bat swing velocity (Coop DeRenne et al., 1992; Fleisig et al., 2002; Montoya et al., 2009; Otsuji et al., 2002; Reyes & Dolny, 2009; Sergo & Boatwright, 1993; Southard & Groomer, 2003; Szymanski et al., 2012; Szymanski et al., 2011; Wilson et al., 2012).

One of the earliest investigations examining the effectiveness of various weighted implements on bat swing kinematics was completed by DeRenne, Ho, Hetzler and Chai in 1992. They wanted to observe changes in bat swing velocity with various weighted bats in sixty high school baseball players ranging 16-18 years of age. There was a total of 13 differently weighted implements in which five were heavier than a high school standard bat (SB), and four that were lighter than a SB. There were also four different weighted implements that were affixed to a SB that was also utilized in the current study. Participants came in and completed a WU with a given implement and completed maximal swing trials in which bat velocity was recorded through a photocell gate timing device. This was performed over 13 consecutive days until all experimental implements were utilized. Results of this study showed that individuals who swung a weighted device within ±12% of the SB bat weighted yielded the greatest increase in a participant's bat swing velocity (Coop DeRenne et al., 1992). To our knowledge, this is the only investigation that has examined the impact of various weighted implements on bat swing velocity in high school athletes.

Similar findings were also observed in an investigation completed by Montoya, Brown, Coburn, and Zinder (2009) utilizing recreational baseball players. These participants came in and completed WU protocols with a control, light, and heavy weighted condition followed by maximal swing attempts with a SB. Results of this study showed the greatest increase in bat velocity after participants warmed up with the lighter implement (63.57 ± 3.58 mph) followed by the normal/control implement (51.25 ±3.01 mph) in comparison to the heavy implement (41.79 ±3.01 mph) (p<.05)(Montoya et al., 2009). The two aforementioned studies are the only ones to our knowledge that have examined the effectiveness of various weighted WU implements on bat swing kinematics in a recreational or high school population.

To date, there are several studies that have examined the possible influence of differently weighted implements within collegiate varsity participants. Work by Reyes and Dolny (2009) wanted to observe the acute effects of nine different WU protocols with three different implements (light, normal, and heavy) among Division III baseball players. After completion of each WU protocol, participants were instructed to swing a normal bat through two photocell sensors, which tracked velocity of each swing. Results of this study revealed increases in bat swing velocity, however these improvements were not statistically significant ($p>.05$) (Reyes & Dolny, 2009). A study by Wilson et al. (2012) also examined bat swing velocity of Division II baseball players following five different WU protocols with weighted implements. A total of sixteen collegiate varsity baseball players with a mean age of 20 came in for five testing sessions. Each participant completed a standard WU with a given weighted implement followed by swinging a SB three maximal times after a pre-determined rest period of 1,2,4, and 8 minutes. Results of this study showed no difference in swing velocity among the five different implements however; the greatest increase in bat swing velocity occurred when the participants rested between 4 to 8 minutes post WU ($p<.05$) (Wilson et al., 2012).

Szymanski et al. (2011, 2012) also wanted to examine the possible changes in bat swing velocity among Division I intercollegiate baseball and softball players. These studies had participants randomly assigned to a given implement followed by performing a standardized WU. After the WU, each participant swung the implement three maximal times. Once this was completed, each participant swung a SB specific to their sport through a Setpro SPRT5A chronograph which was used to measure bat velocity. Results of these studies revealed no significant changes in bat velocity when warming up with any implements ($p>.05$) (Szymanski et al., 2012; Szymanski et al., 2011). These studies suggest that if given a variety of implements to WU with, the athlete should select what is most comfortable for them personally before approaching an at bat situation.

A similar study completed by Williams et al. (2017) investigated the effects of various weighted implements on baseball swing kinematics in collegiate baseball players. The aim of this study was to not only investigate performance measures of bat speed, but also the angle of the bat as it approaches contact with a ball placed on a tee. The investigators in this study recruited 15 intercollegiate baseball players in which participants were counterbalanced to WU with one of four implements. Participants completed their normal on-deck WU simulating a situation prior to an at bat situation in a game. From there, participants completed a total 5 maximal swings making contact with a ball placed on a tee. After this was completed, a brief 10-minute washout period was carried out, followed by the completion of the remaining WU implement conditions. Results of this revealed no statistical significance in any of the bat swing kinematics variables of interest ($p>.05$) (C. C. Williams et al., 2017).

Similar studies conducted by Flesig, Zheng, Stodden, and Andrews (2002); and Southard and Groomer (2003) investigated the effects of varying bat mass properties and moments of inertia on bat swing velocity and swing patterns in collegiate athletes. Flesig et al. (2002) recruited 17 baseball and softball players that were randomized to swing a variety of bats based on weight and varying mass moments of inertia for an on-deck WU. After completion of the WU, participants swung a SB specific to their sport in which bat velocity was tracked through a motion capture system. Results of this study indicated the larger mass moment of inertia in the bats used for their on-deck WU, yielded the greatest decrease in bat swing velocity for both baseball and softball players ($p<.05$) (Fleisig et al., 2002). Southard and Groomer (2003) saw similar results with their study in which the implement with the largest moment of inertia saw the greatest decrease in bat velocity when compared to the standard and light bat condition ($p<.001$) (Southard & Groomer, 2003).

Evidence based literature appears to show that the weight of the implement does play a role in one's ability to maximize bat velocity (Coop DeRenne et al., 1992; Montoya et al., 2009) in addition to varying moments of inertia (Fleisig et al., 2002; Southard & Groomer, 2003). The weight of the WU implement seems to alter bat velocity in younger, less experienced athletes during an at bat situation. Other literature suggests the mass of the implement does not affect bat velocity in intercollegiate participants (Reyes & Dolny, 2009; Szymanski et al., 2012; Szymanski et al., 2011; Wilson et al., 2012).

Role of Strength and Conditioning on Baseball Hitting Kinematics

An increase in skill level especially within intercollegiate athletics, leads to an increase in time spent practicing a given sport in addition to having a structured strength and conditioning program. The NCAA sets aside 8 hours per week during off-season activities and 20 hours per week while the sport is in-season to participate in a strength and conditioning regiment and practice for their given sport (Ayers et al., 2012). Implementing a strength and conditioning program is designed to reduce the risk of injury in addition to increasing sport specific performance by exercises completed within a structured training environment (Haff & Triplett, 2015). Allotting time for an athlete to practice specific movements related to a given sport should theoretically develop an athlete to become better at that sport based on the Law of Specificity. The Law of Specificity was first termed by DeLorme in 1945, and is based on training a person in a manner to produce a specific adaptation or training outcome (DeLorme, 1945). Research has examined the various effects of implementing various training protocols on improving bat swing kinematics (Coop DeRenne et al., 1995; Hughes et al., 2004; Sergo & Boatwright, 1993; Szymanski et al., 2007; Szymanski et al., 2006; Szymanski et al., 2010).

Work by Sergo and Boatwright (1993); along with DeRenne, Buxton, Hetzler, and Ho (1995) examined the effects of training with various weighted bats on bat swing velocity. The protocol utilized by Sergo and Boatwright utilized 24 collegiate baseball players dividing participants into three groups. These groups completed a swing training protocol in which participants completed 20 sets of 5 dry-swing protocol either with a SB, heavy bat, or a heavy and light bat swing protocol for a period of six weeks (Sergo & Boatwright, 1993). DeRenne et al. (1995) implemented a similar protocol utilizing 60 male university players over a 12-week study. These participants were divided into three separate groups consisting of a batting practice, dry-swing, and control group. The control group completed a dry-swing protocol with a SB while the batting practice group swung at live pitched baseballs and the dry-swing group swung at both heavy and light bats over 12 weeks. Results from the Sergo and Boatright revealed a positive increase in all three training groups from baseline of at least 8% ($p<.05$), however there were no between group differences ($p>.05$) (Sergo & Boatwright, 1993). Results from DeRenne et al. (1995) showed a significant increase in bat swing velocity among all three groups when comparing pre-to post-test values ($p<.05$). Further results indicate the batting practice and dry-swing groups did significantly better at improving bat swing velocity at 10 and 6% from pre-test values compared to a 1% increase from baseline for the control group ($p<.05$) (Coop DeRenne et al., 1995).

Investigations by Szymanski et al. (2006, 2007, 2010) took high school baseball players through a 12-week training program. Participants in these studies were divided into one group consisting of a traditional strength training group and the other traditional strength training plus specific exercises designed towards improving linear bat velocity by the training wrist, forearm, and torso to better tailor the hitting motion while swinging a baseball bat (Szymanski et al., 2007; Szymanski et al., 2006). These participants came in for two sessions (baseline, post) where swing velocity was recorded using a motion capture system. Results from the 2006 Szymanski et al. paper revealed significant increases in bat swing velocity from baseline values at 3.5% for group 1 and 3.2% for group 2, however there were no between group differences with the addition of specific grip training (p>.05) (Szymanski et al., 2006). The second group who specialized in grip training also performed rotational exercises with the goal of improving rotational strength for when participants swing a bat in an effort to improve bat swing velocity. Results from this study showed that these additional rotational exercises in conjunction with traditional strength training yielded a significantly faster bat velocity at the conclusion of 12 weeks at 31.5± 2.5m/s in comparison to just traditional strength training 30.4± 2.2m/s ($p<.05$) (Szymanski et al., 2007). Szymanski et al. (2010) wanted to further investigate what specific components within these two training protocols allowed the 2nd group to statistically surpass group 1 in terms of bat swing velocity. Investigators concluded there were greater increases in the 2nd group when it came to medicine ball hitters throw, dominant torso strength, non-dominant torso strength, and angular shoulder velocity in comparison to group who completed traditional strength training ($p<.05$) (Szymanski et al., 2010).

Researchers have made an effort to understand what aspects of an individual's swing causes him or her to be successful when making contact with a ball (Coop DeRenne et al., 2010; Escamilla et al., 2009a; Escamilla et al., 2009; Hay, 1978; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1986; Milanovich & Nesbit, 2014; Nicholls et al., 2003; Race, 1961; Smith, 2001; Welch et al., 1995). WU protocols have been developed attempting to improve bat swing velocity prior to an at bat situation (Coop DeRenne et al., 1992; Fleisig et al., 2002; Montoya et al., 2009; Otsuji et al., 2002; Reyes & Dolny, 2009; Sergo & Boatwright, 1993; Southard & Groomer, 2003; Szymanski et al., 2012; Szymanski et al., 2011; Wilson et al., 2012).

With increasing skill level, along with specificity of training for sport, the development of strength and conditioning protocols have been developed to improve sports specific performance when it comes to swing sports such as baseball and softball (Coop DeRenne et al., 1995; Hughes et al., 2004; Sergo & Boatwright, 1993; Szymanski et al., 2007; Szymanski et al., 2006; Szymanski et al., 2010). To date, there are only a few studies examining the muscle activity via electromyography (EMG) during a baseball swing (Nakata, Miura, Yoshie, Kanosue, & Kudo, 2013; Nakata, Miura, Yoshie, & Kudo, 2012; Shaffer et al., 1993).

EMG During a Baseball Swing

The foundational study examining the muscle firing pattern of 12 different muscles throughout the body in 18 professional baseball players was completed by Shaffer, Jobe, Pink, and Perry in1993. Investigators in this study utilized fine wire electrodes to record muscle activity of the long head of the triceps, posterior deltoid, serratus anterior, and the supraspinatus muscle. Surface electrodes were utilized to examine trunk and lower extremity muscle activity of the erector spinae, vastus medialis, biceps femoris, and semimembranosus. Baseline EMG signals were based on a resting signal while peak EMG activity was based on a one-second maximum muscle test (MMT) for each muscle. Participants were asked to complete a WU until they were comfortable to swing a bat and hit a total of six pitched fast balls. Motion capture was used to record the movements of the swing and were broken down into four distinct phases: Wind-up, pre-swing, swing, and follow-through. A detailed description is discussed in depth earlier within this literature review. Results of this study revealed hamstring activity (bicep femoris, semimembranosus) reached the highest percentage of MMT during the pre-swing phase of the swing at 154% and 157% respectively. During the middle phase of the swing yielded the highest MMT% of the vastus medialis at 107%.

Work by Nakata, Miura, Yoshie, and Kudo (2012); along with Nakata et al. (2013) examined lower extremity muscle activity during a baseball swing and stopping a baseball swing. The investigators wanted to examine the lower extremity muscle firing pattern between 10 skilled baseball players in comparison to 10 novice baseball players. Surface electrodes were placed bilaterally on four lower body muscles consisting of the rectus femoris, biceps femoris, medial gastrocnemius, and tibilias anterior in which signals were digitized at 1,000Hz. Maximal voluntary isometric contractions were taken on all four muscles over a 4 second period in which participants were asked to maximally contract a given muscle. The baseball swing for the current studies broke down the phases of the swing into seven distinct phases shown in Figure 4.

Participants were asked to perform a total of 60 swing trials in which 45 of them consisted of swinging a bat with maximal effort. The other 15 trials, participants were asked to check their swing mimicking a motion regularly performed during an at bat situation in which a ball is outside his or her strike zone (Dee Abrahamson, 2013; Paronto, 2014). All trials were recorded with a motion capture system sampling at a rate of 200Hz. Results of this study indicate a higher peak amplitude defined as a percent of their maximal voluntary isometric contraction in the following muscles of interest (rectus femoris, biceps femoris, tibialis anterior, medial gastrocnemius) in skilled baseball players compared to the novice baseball participants when swinging a bat ($p<.05$) (Nakata et al., 2013). Results of this study further indicated a shorter peak latency when participants were asked to stop their swing in the biceps femoris, tibialis anterior, and medial gastrocnemius compared to when they were asked to swing maximally at a pitched ball ($p<.05$) (Nakata et al., 2012).

CHAPTER III:

MANUSCRIPTS

MANUSCRIPT I

EXAMINING CHANGES IN BAT SWING KINEMATICS IN VARIOUS REGIONS OF THE STRIKE ZONE IN COLLEGIATE BASEBALL AND SOFTBALL PLAYERS

1. Introduction

According to the National Collegiate Athletic Association (NCAA) there are over 50,000 individuals who compete within intercollegiate baseball and softball (Association, 2017). These athletes compete against themselves to become a conference or national champion within a given sport. Considering this, evidence based literature has examined a variety of areas intended to maximize batting performance in terms of bat speed as it has been shown to be an important predictor of a batter's performance as they attempt to make contact with a ball (Miller & Shay, 1964; Scott, 1963). Another important aspect of batting performance is the angle of the bat as he or she approaches contact with a ball. Having the ideal bat angle can increase the overall surface area of the bat exposed for ball contact which in turn can lead to a higher likelihood of making a hit. To date, there are several previous research designs that has examined bat swing kinematics (Escamilla et al., 2009a; Escamilla et al., 2009; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1985a, 1986; Milanovich & Nesbit, 2014; Nathan, 2000; Nicholls et al., 2003; Race, 1961; Welch et al., 1995; C. C. Williams et al., 2017).

Previous work by Messier and Owen (1986) along with Welch et al. (1995) wanted to investigate the effects of an individual's stance and stride had on batting performance specifically that of bat speed in high level softball and baseball athletes. The paper completed by Messier and Owen used a total of 7 collegiate softball players and asked them to complete three different stride techniques consisting of either a parallel, open, or closed stance as they approached contact with a pitched softball. Participants were asked to only swing at balls pitched within the top half of their respective strike zone. Results of this study revealed a greater ground reaction force was generated in the y-direction utilizing the closed stance and stride technique however; this increase in force production did not lead an increase in bat speed (p>.05)(Messier & Owen, 1986). Welch et al. utilized professional baseball players and they discovered the longer they spent during the stride phase of the swing lead to an increase in bat swing velocity.

Work by Escamilla et al. (2009a) wanted to examine age-related difference in baseball hitting kinematics among youth and professional baseball players. A total of 24 players participated in this study that all had a batting average of at least .300 classifying them as skilled athletes in previous research (Coop DeRenne, 2007; Coop DeRenne et al., 2008; Race, 1961). Participants were asked to swing at balls pitched at the inner half of the participant's strike zone establishing a standardized pitch. Results of this study indicated the older adult hitters spent more time during the stride phase of the swing .4± .07 seconds in comparison to youth hitters ay .29±.06 seconds (*p*<.01). The extended time during the stride phase of the swing allowed the adult hitters to generate a greater bat velocity at ball contact at 30±2 m/s in comparison to 25±3m/s for youth hitters (*p*<.01) (Escamilla et al., 2009a).

A recent investigation by Williams et al. (2017) took a different approach and examined the acute changes in bat swing kinematics after collegiate baseball players warmed up with a variety of differently weighted implements. Participants were counter-balanced into completing one of four warm-up (WU) protocols with either a heavy, normal, or light-weight condition. After completion of their on-deck WU, they were asked to swing a standard baseball bat five times at a ball placed on a tee in a position comfortable for each participant. Results of this study revealed no statistical differences among the WU implements in any of the swing kinematic variables of interest however, there were significant intra-class correlation coefficients (ICC's) among the WU implements used in this study in the bat swing kinematic variables of interest. This suggests that collegiate baseball players can produce similar bat swing kinematics in terms of bat speed and bat angle at contact regardless of the implement used during their on-deck WU (C. C. Williams et al., 2017).

Previous research examining changes bat swing kinematics has been measured by asking participants to swing at a pitched ball in a position convenient for them or swinging a bat at a ball placed on a tee in a position of their choosing (Escamilla et al., 2009a; Messier & Owen, 1986; C. C. Williams et al., 2017) to standardized each trial for processing. Unfortunately, this is not ideal in a game situation considering a pitcher can throw a ball in an area known as the strike zone. The National Collegiate Athletic Association defines the strike zone as an area covering the entire width of home plate and a region extending from a batter's knee cap and extends to below the area of their number as he or she sets up in their respective stance (Paronto, 2014). The strike zone can be broken into nine distinct regions and to our knowledge no one has examined three-dimensional (3D) kinematics of a baseball or softball swing changes in each of these nine regions. Common batting practices utilize a tee which an athlete can place at various heights to practice at making ball contact within varying regions of their strike zone. This study can allow both sport coaches and athletes information regarding their batting performance in terms of bat speed and angle of the bat at ball contact.

Therefore, the purpose of this study is to investigate changes in bat swing kinematics within the nine regions of an athlete's strike zone specifically maximal resultant velocity (MRV), resultant velocity at ball contact (RVBC), time difference between MRV and RVBC. A secondary aim of this study is to identify the angle of the bat as he or she approaches contact with a ball placed on a tee within the nine regions of their respective strike zone. We suspect the kinematic variables of interest will change based on where the tee is placed in their strike zone specifically bat angle and bat speed.

2. *Methodology*

2.1 Experimental Approach to the Problem

This experimental design is comparing how bat swing kinematics change throughout an individual's respective strike zone in collegiate baseball and softball players. A Vicon Nexus motion capture system will be used to calculate all bat swing kinematic variables of interest. The use of a motion capture systems has been shown to be a reliable measure of kinematics in addition to being used in previous swing analysis research (Bonnechere et al., 2014; Fleisig et al., 2002; Milanovich & Nesbit, 2014; Tsushima, Morris, & McGinley, 2003; C. C. Williams et al., 2017). This study used a total of 26 collegiate varsity baseball and softball players that completed one experimental session during their fall competitive season.

2.2 *Participants*

Thirteen (age:19.69± 1.18 years, height: 184 ± 6.16cm, mass: 93.32± 9.8kg) NCAA division I baseball players along with 13 NCAA division I softball players (age: 19.46± 1.33years, height: 171.31± 9.13cm, mass: 73.05± 8.1kg) participated in the current study. All participants in this study were classified as being recreationally trained as having at least one year of resistance training experience as well as being free of musculoskeletal injuries after filling out a physical activity readiness questionnaire (PAR-Q) prior to testing. Prior meetings with both sport coaches and athletes took place to become aware of the potential benefits and risks of completing the current study. All participants signed a University informed consent and this study was approved by the University Institutional Review Board (IRB) with the following experimental protocol.

2.3 *Procedures*

A Vicon Nexus 3D motion capture system (Oxford, UK) equipped with 8 near-infrared T-Series cameras were utilized to record all kinematic variables of interest. A modified, full body Helen Hayes marker system was used in addition to two custom made models for both the bat and tee to recording at a sampling rate of 200Hz of 47 retro-reflective markers (Figure 5). In order to quantify 3D motion, a global coordinate system was put in place to best record the trajectories of the individual markers affixed to the bat. The X-direction was defined as the vector in which all participants swung their bat as they approach contact with a ball towards home plate. The Z-direction was defined as the vertical projection upward. The cross-product of the X and Z directions were used to define the Y-direction. The aforementioned definitions of the global coordinate system has been used in previous bat swing literature (Fleisig et al., 2002; C. C. Williams et al., 2017).

Procedures for this study design utilized a traditional hitting tee and standard bat (SB) based on their respective sport. For baseball, their SB must not weigh more than three units than the length of the bat which normal bats are 33in/30oz (Paronto, 2014). A SB for softball on the other hand cannot weigh more than 38 ounces and cannot be longer than 34 inches (Dee Abrahamson, 2013). Baseball participants for the current study used either a 33in/30oz or 34in/31oz bat based on what they used in practice or game situations. Softball participants for the current study used either a 34in/24oz or 33in/23oz bat. All participants came in for one laboratory visit lasting no more than 2 hours in duration after being informed of all the benefits and risks prior to signing an informed consent approved by the University IRB. Prior to their arrival, participants were asked to maintain normal activities of daily living regarding nutrition and hydration status. All participants came in around their class schedule and completed the protocol prior to fall practice. Anthropometrics measurements of the shoulder, hand, knee, and ankle were taken on all participants prior to testing. After measurements were recorded, scan, participants had a total of 39 retro-reflective markers secured to specific anatomical landmarks.

A counterbalanced design was implemented to determine the tee position for each participant. Every participant will have a different strike zone based on his or her height. In order to make each strike zone relative to each participant, the bottom of the strike zone will be defined as the region above the kneecap once the participant sets up in their respective stance. The top of their strike zone will be defined as 6 inches above each participant's belt line which represents the bottom of the number on a jersey. The middle of their strike zone is the middle distance between the top and bottom of each participant's strike zone. Considering the strike zone covers the entire width of home plate, the tee will be placed in different regions of home plate mimicking bat placement for an inside, middle, or outside pitch in a game situation (Figure 6). The following regions of the strike zone are as follows: inside high (IH), inside center (IC), inside low (IL), middle high (MH), middle center (MC), middle low (ML), outside high (OH), outside center (OC), and outside low (OL).

Once this is determined, each participant will complete a 2 minute on-deck WU mimicking what they would do prior to an at bat situation in a game with their SB. At the conclusion of the WU protocol, a short rest period took place allowing each participant the opportunity to set-up for each maximal swing trial. Each participant was asked to set-up in their respective batting stance relative to home plate as they would in a game situation. By doing this, participants could not adjust to where the tee was located within home plate. Participants were asked to maximally swing their SB at a ball placed on a tee in a random positon of their strike zone. Each swing was separated by a period of 20 seconds to mimic the time between pitches and to also allow investigators time to re-position the tee in another area of their strike zone. At the conclusion of the 15^{th} swing, a ten-minute washout period was implemented followed by another 15 maximal swing trials. This was repeated until there was a total of five swing trials within the nine regions of each participant's strike zone totaling 45 trials.

3. Data Analysis

The swing was broken into three distinct phases and four specific events based on previous work by Shaffer et al. (1993) and Escamilla et al. (2009). The first event began when each participant's lead (stride) foot left the ground which started the stride phase of the swing. The stride phase ended when the lead toe reestablishes contact with the ground representing the 2^{nd} event of the swing. The point at which the lead foot reestablishes contact with the ground up to the point where the bat reaches a perpendicular position with the ground (3^{rd} event) represents the transition phase of the swing (Escamilla et al., 2009a; Shaffer et al., 1993). The swing phase of the swing begins when the bat is perpendicular with the ground and ends when bat-ball contact is made (Escamilla et al., 2009a; Shaffer et al., 1993) which will be defined as the frame in which deformation of the tee occurred when bat-ball contact was made (C. C. Williams et al., 2017).

Determining MRV was calculated by squaring the sum squares based on the position data recorded from the top bat marker in all three planes of movement (X, Y, and Z-directions). RVBC was determined as squaring the sum of squares based on positional data for X,Y, and Z directions of the frame where deformation of the tee occurred from the bat as it made contact with the ball. Calculating the time difference (TD) between MRV and RVBC we simply subtracted the difference in time where RVBC and MRV occurred from each other. A global coordinate system was put into place to determine overall movement of all hitting variables of interest. In order to track BABC and BAMRV the global coordinate system was translated to the top of the tee which represented a relative 0° to represent ground level. A custom bat model was used to track where the angle of the bat at these distinct frames where bat ball contact occurred along with MRV (C. C. Williams et al., 2017).

4. Statistical Analysis

Results will be analyzed using SPSS 22 statistical software with a predetermined alpha level of 0.05 using a 1x (condition) x 9 (regions of strike zone) within subject's factor repeated measures analysis of variance (ANOVA) on all swing kinematic variables of interest. For our ANOVA's conducted Mauchly's test of sphericity and then adjusted the degrees of freedom using a Greenhouse-Geisser correction if there were violations of sphericity. If a significant main effect was found, Least Squares Differences were used to determine pairwise comparisons among the variables of interest.

5. Results

Table 1 and Table 2 display all participant characteristics for the current study. A total of twenty-six collegiate baseball (n=13) and softball (n=13) players with a mean age of 19.58±1.24 years old.

5.1 *Batting Kinematics: Baseball and Softball*

A significant main effect, within subject differences was found in MRV among the nine regions of the strike zone ($p<.05$) for baseball. There was no significant main effect regarding MRV over the nine regions found in collegiate softball players ($p=.507$). Within subject differences among baseball and softball players regarding MRV can be found in Tables 3, 4, and 5. Significant results were also seen in BABC and BAMRV ($p<.05$) (See Tables 6, 7&8) however; no group differences in BABC were seen between baseball and softball ($p=.852$). There was a significant main effect regarding RVBC across various regions of the strike zone in collegiate baseball players ($p<.05$). Pairwise comparisons revealed trials completed IH of one's strike zone yielded a faster RVBC (37.16±.693 m/s) in comparison to OH swing trials (35.70±.85 m/s) ($p=.007$). IC swing trials had a faster RVBC (37.62± .67 m/s) in comparison MH: (35.51±.89m/s) ($p<.01$), OH (35.70±.85m/s) ($p=.023$), OC (35.97±79m/s) ($p=.029$), OL (35.85±.833m/s) ($p=.040$). IL swing trials also exhibited a faster RVBC (37.47± .67m/s) in comparison to MH: (35.51±.89m/s) ($p<.05$) and OH (35.70±.85 m/s) ($p<.05$). There wasn't a significant main effect seen in the softball group when examining RVBC across the nine regions of the strike zone ($p=.179$). There were no statistical differences seen in time difference between MRV and RVBC over the nine regions of the strike zone in baseball or softball players ($p>.05$).

6. Discussion

Examining changes in MRV, our current study reveals differences in MRV among different regions of the strike zone for both baseball and softball players. The three fastest bat swing velocities for the baseball players occurred when they completed OL swing trials at 39.65 m/s followed by IL swing trials at 39.54 m/s and MC at 39. 38 m/s. With regard to examining the MRV among the softball participants. The three fast velocities in their respective strike zone was MH swing trials at 34.73m/s followed by ML swings at 34.62m/s and IL swing trials at 34.57 m/s however no statistically different from each other ($p>.05$).

It is interesting to note that when looking at RVBC the story changes in terms of where the fastest bat speeds occur over the course of the strike zone in collegiate baseball players. Examining RVBC in this population the fastest average bat speeds occurred in swing trials completed towards the inside of their strike zone in the following order: IC: (37.62± .67 m/s), IL (37.47± .67m/s) and IH (37.16±.693 m/s).

Results of the current study do not align with previous work completed by McIntyre and Pfautsch (1982) when looking at the MRV's in both collegiate baseball and softball players.

McIntyre and Pfautsch (1982) wanted to investigate kinematic differences in same field hitting and opposite field hitting in collegiate baseball players. They defined same field hitting as a ball pitched towards the inside half of home plate towards the athlete swinging the bat which represents all middle and inside swing trials for the current study. Opposite field hitting represented a ball being pitched from the outside half of home plate representing the outside swing trials in the current study. Our study revealed that baseball's outside swing trials completed at the middle of their strike zone were faster statistically faster than swing trials completed at IH. OL swing trials were also faster than IH, and MH swing trials ($p<.05$).

MRV's for the softball swing trials over their respective strike zone revealed no statistical differences in bat speed for outside swing trials at any height in comparison to inside swing trials regardless of height. Results of McIntyre and Pfautsch (1982) indicated a greater linear bat velocity for same field (inside of home plate) hitting in comparison to opposite field hitting (outside of home plate). In examining RVBC of the baseball participants in the current study our results do align with work completed by McIntyre and Pfautsch (1982) in that our fastest velocity measures were completed towards the inside of home plate as indicated by our IH, IC, and IL regions of the strike zone when looking at the baseball players in the current study. The softball athletes in the current study could have had more time swinging a bat at a ball placed in varying regions of their respective strike zone that could help partially explain why there was no major difference in MRV between inside and outside swing trials among softball players used. Baseball players used in the current study spend a great deal of time swinging a bat towards the outside of their respective strike zone as that is a preferred pitching location for an outside pitcher hoping that the hitter will overextend himself leading to a possible strikeout.

Our study also does not align with the bat linear velocity numbers found by Escamilla et al. (2009a) which revealed that bat linear velocity trials collected during the study was 30 m/s in the adult hitters in which six participants played at the collegiate level and the other six competed at the professional level. Results of our study indicate a bat an average bat velocity of 38.81m/s over the nine regions of their respective strike zone. The overall MRV velocity over the nine regions of the strike zone for the softball participants was 34.23 m/s. Differences in these results could be based on the current study asked participants to make contact with a ball placed on a tee in comparison to the study completed by Escamilla et al (2009a) asked participants to swing at a ball from a pitching machine.

Regarding TD between MRV and RVBC there was no statistical difference among any of the nine regions of the strike zone for both baseball and softball players. These results align with previous work completed by Williams et al. (2017) showed no statistical difference in time between MRV and RVBC using a variety of WU implements including using a normal game bat ($p>.05$) when a ball was placed on a tee in a position of their choosing. The current study suggests that both baseball and softball athletes do not have an area within their respective strike zone where the time difference in MRV and RVBC are not statistically different ($p>.05$).

To our knowledge, this is the first study that has examined changes in BABC along with BAMRV in collegiate baseball and softball players. Our study revealed that the swing trials performed towards the top of their respective strike zone had a lower angle considering the top of the tee represented a relative 0° with the ground. The lower tee positions represented swing trials in the middle and bottom of their strike zone causing the bat to have a more downward angle of at ball contact as seen in the current study. The magnitude of BAMRV was not as drastic as BABC but there were some statistically significant differences seen (Tables 9,10,11).

7. Conclusion

In conclusion, it is evident that hitting kinematics changes in different areas of the strike zone when looking at the angle of the bat at maximal velocity and at ball contact. This study also shows differences in MRV for collegiate baseball and softball players. Both athlete and sport coach can use this data to work on hitting technique and bat speed depending on where he or she is deficient in comparison to an area(s) of strength. This information can also be used to establish what would be considered an ideal bat angle for both baseball and softball so both sport coaches and athletes can practice achieving the ideal bat angle at a given region of the strike zone to maximize the overall surface area of the bat for ball contact not only in collegiate populations but in other populations as well.

MANUSCRIPT II

EXAMINING CHANGES IN FULL BODY KINEMATICS IN VARIOUS REGIONS OF THE STRIKE ZONE IN COLLEGIATE BASEBALL AND SOFTBALL PLAYERS

1. Introduction

Baseball and softball have over 50,000 participants who compete against each other within the collegiate setting (Association, 2017). Collegiate athletics is built on developing a winning tradition with the hopes of competing for a conference or national championship. Research has been developed with the hope of finding effective ways to increase sport specific performance such as hitting by increasing bat speed along with achieving an ideal bat angle when ball contact is made by examining swing kinematics (Escamilla et al., 2009a; Escamilla et al., 2009; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1985a, 1986; Milanovich & Nesbit, 2014; Nathan, 2000; Nicholls et al., 2003; Race, 1961; Welch et al., 1995; C. C. Williams et al., 2017). Increasing an individual's bat speed along with having the ideal bat angle at ball contact has been shown to be important factors of one's batting performance (Miller & Shay, 1964; Scott, 1963).

Work by Welch et al. (1995) along with Messier and Owen (1986) wanted to investigate the effects of various striding and stances had on bat speed in high level baseball and softball players. Welch et al. (1995) utilized professional baseball players and they found out the longer amount of time participants spent during the stride phase of their swing resulted in a greater increase in bat velocity (Welch et al., 1995). The investigation completed by Messier and Owen utilized a total of seven collegiate softball players performing three different striding techniques to examine changes in bat speed. Participants were asked to swing only at balls pitched within the top half of their respective strike zone using either a parallel, open, or closed stance as each participant approach contact with the ball. Results of this study revealed a greater ground reaction force utilizing the closed stance technique however in terms of bat speed there were no statistical differences among the three striding techniques ($p>.05$) (Messier & Owen, 1986).

An investigation by Escamilla et al. (2009a) examined the differences in full body kinematics in hitting a baseball among skilled youth and professional baseball players. All participants were classified as being skilled by having a batting average of at least .300 (Coop DeRenne, 2007; Coop DeRenne et al., 2008; Race, 1961). After participants completed an on-deck warm-up (WU), each participant was asked to swing at balls pitched on the inner half of their strike zone. Results of this study indicated a greater amount of time spent in the stride phase of the swing .4± .07 seconds in the professional baseball hitters in comparison to the youth hitters at .29±.06 seconds ($p<.01$). Having an increase in stride time for the professional hitters led to a greater angular velocity for the lead elbow and knee as they approached extension in addition to having a greater upper torso angular velocity compared to the younger participants ($p<.01$). This increase in time spent during the stride phase of their swing resulted in a 5m/s increase in bat speed for the professional hitters compared to the youth hitters ($p<.01$).

Previous work by Williams et al. (2017) used various weighted implements and examined the acute changes in bat swing kinematics among collegiate baseball players. Participants were counterbalanced to utilize one of four differently weighted implements during their on-deck WU, mimicking what they would do prior to an at bat situation. When each participant completed their respective on-deck WU they were instructed to maximally swing a bat and make contact with a ball on a tee in a position comfortable for each participant. Results of this study revealed no significant differences any of the kinematic variables of interest regarding angle of the bat or bat speed ($p>.05$). There were significant intra-class correlations among all four WU implements among the variables of interest showing the commonality in all kinematic variables of interest. ($p<.001$) (C. C. Williams et al., 2017).

Evidence based research examining changes in bat swing kinematics have asked participants to swing at a ball placed on a tee in a position of their choosing or making contact with a ball from a pitching machine in a predetermined position in standardizing swing trials. During a game situation, however this is not ideal considering an opposing pitcher can place a ball in a batter's strike zone. The strike zone is defined as a region that starts above the batter's knee cap and extends upward below the base of the number of a batter's jersey. The strike zone also extends the entire width of home plate as defined by the National Collegiate Athletic Association (NCAA) (Paronto, 2014). Hitting coaches typically break the strike zone into 9 distinct regions and to our knowledge no one has examined three-dimensional (3D) full-body kinematics of either a baseball or softball swing in each of these regions. A large portion of batting practices utilize individuals hitting a ball placed on a tee in varying positions. Understanding how the body moves within these various regions of the strike zone can help baseball and softball players approach ball contact more efficiently to help maximize measures of batting performance of bat speed and bat angle at ball contact.

2. *Methodology*

2.1 Experimental Approach to the Problem

This study used a total of 26 NCAA division I baseball (n=13) and softball players (n=13) between the ages of 18 to 25. Meetings with the players and sports coaches of both teams took place explaining the rationale of the current study and then recruited willing participants. Participants filled out a physical activity readiness questionnaire (PAR-Q) and were free of musculoskeletal injuries. Participants also had at least one year of resistance training experience in order to complete the current study.

The instrumentation utilized for the current study will be a Vicon Nexus 3D motion capture system (Oxford, UK) equipped with 8 near-infrared T-Series cameras. This system was used to record kinematic trajectories of retroreflective markers at a sampling rate of 200Hz which has been utilized in previous research designs (Fleisig et al., 2002; Milanovich & Nesbit, 2014; Nakata et al., 2013; Nakata et al., 2012; Nicholls et al., 2003; Southard & Groomer, 2003). In order to quantify the 3D motion of this data, a global coordinate system must be established in order to properly record the trajectories of each individual's swing trials. Defining the global coordinate system is based on the Flesig et al. (2002) manuscript, quantifying the Z-direction as the vertical projection upward. The X-direction will be defined as the vector in which all participants swung their bat as they approach contact within different areas of his or her strike zone. The cross product of X and Z will be used to define the Y-direction (Fleisig et al., 2002). Cameras will be calibrated and have an image error rate of less than 0.1.

A repeated measure, counter-balanced design using a within-subjects factor will be used. All participants will visit the Applied Biomechanics Laboratory (ABL) once over the course of their fall sport season. A description of the experimental procedures for each visit is provided below. The participants will come into the ABL based on their class schedule and complete the protocol before baseball or softball practice. Each participant will be asked to fill out a physical activity readiness questionnaire (PAR-Q) and sign the University informed consent after one of the investigators explains what will be taking place in the lab.

In order to distinguish anatomical differences among the participant's anthropometrics will be taken such as height, weight, leg length, and widths of the shoulder, elbow, hand, knee, and ankle. A total of 39 retroreflective markers were affixed to specific anatomical landmarks using a modified, full body Helen Hayes marker system. In addition to this marker system, two custom models for both the bat and tee will be used to track bat kinematic variables of interest (See figure 5 for marker locations). After all markers were secured, participants were asked to perform their traditional on-deck WU simulating what will be done prior to an at-bat situation for a game for a period of two minutes.

Upon completion of the on-deck WU, a short rest period will be given to mimic the time a batter walks into the box for an at bat situation. Athletes will complete all swing trials on a hitting mat with an outline of their respective batter's box and a diagram of home plate. The participants will then swing a SB specific to their sport 15 times within the nine regions of his or her strike zone: inside high (IH), inside center (IC), inside low (IL), middle high (MH), middle center (MC), middle low (ML), outside high (OH), outside center (OC), and outside low (OL) as they approach contact with a ball on a tee. The NCAA defines the strike zone as the entire width of home plate in which the bottom of the strike zone begins just below the knee cap and extends up towards the bottom of the number (Paronto, 2014). A description of where the tee was placed based on an inside, middle and outside swing trial is displayed in Figure 7.

Each maximal swing attempt will be randomized in a different region of the strike zone to mimic ball delivery by a pitcher during an at-bat situation. Each person's strike zone will vary depending upon his or her height along with stance of the specific batter. A ball placed on a tee in a comfortable position for the participant to make contact with the ball in the middle of home plate will be the center of the strike zone. From there we can adjust the tee to either edge of home plate along with raising or lowering the tee to mimic either the top or bottom of their respective strike zone. Each swing trial will be separated by a period of 20 seconds to simulate the time between pitches during a game situation (Potteiger, Blessing, & Wilson, 1992). A ten-minute rest period will be provided after the 15th swing followed by another set of 15 maximal swing attempts in a counterbalanced order. This process will continue until they have completed a total of 45 swings, totaling five swing trials within each of the nine regions of their respective strike zone.

3. Data Analysis

Each swing will be broken into four distinct events and over three phases based on previous work completed by Escamilla et al. (2009a) and Shaffer et al. (1993). The first event of the swing begins with the lead foot leaves the ground which begins the stride phase of the swing. The stride phase of the swing ends when the toe of the lead foot reestablishes contact with the ground representing the 2nd event of the swing. The point at which the lead toe reestablishes contact with the ground until the bat reaches a perpendicular position with the ground (3rd event) is known as the transition phase. The point at which the bat is perpendicular with the ground through bat-ball contact (4th event) is known as the swing phase (Escamilla et al., 2009a; Shaffer et al., 1993). The point at which bat-ball contact is made will be defined as the first frame where deformation of the tee occurs from the bat when ball contact has been made (C. C. Williams et al., 2017).

A forth order Butterworth filter was used to smooth the data as shown in previous literature (Escamilla et al., 2009a; Welch et al., 1995). One trial from each of the nine regions of their respective strike zone was selected based on the visibility of marker present to complete full body kinematic analysis. Due to marker dropout, two softball participants were removed from the analysis to have a total sample of 11 softball participants. The main event of interest was examining possible changes in full body kinematics specifically stride limb arm and leg at bat-ball contact. Angles of interest included the stride leg hip, and knee angles along with stride leg arm of shoulder, elbow, and wrist angles.

4. Statistical Analysis

For our statistical analysis, SPSS 21 statistical software will be used using a pre-determined alpha level of .05 using a series of 1 (condition) x (9 regions of strike zone) within subject's factor repeated measures analysis of variance (ANOVA) on all full body kinematic variables of interest (hip, knee, shoulder, elbow and wrist angles). If there is a violation of Mauchly's test of sphericity, a Greenhouse-Geisser correction will be used to determine significance. If a significant main effect is found, Least Square Difference (LSD) was used to determine pair wise differences among the variables of interest.

5. Results

5.1 Baseball Stride Leg Kinematics

Results of this analysis revealed a nonsignificant main effect when examining changes at in flexion/ extension angle of the stride hip at bat-ball contact (p=.365) over the nine regions of their respective strike zone. There were nonsignificant differences in abduction/ adduction and internal/external rotation angles of the stride leg hip at ball contact respectively (p=.080), (p=.485). There was no significant difference in terms of knee flexion/ extension angle differences over the nine regions of the strike zone at bat-ball contact (p=.180).

5.2 Baseball Stride Arm Kinematics

There was no significant main effect finding for flexion/ extension angle (p=.562), abduction/adduction angle (p=.518) of the stride shoulder at bat-ball contact over the nine regions of the strike zone. There was a significant main effect for internal/ external rotation angle of the shoulder at bat-ball contact over the nine regions of their respective strike zone. Pairwise comparisons revealed significant differences in internal rotation of the shoulder at bat-ball contact of trials completed towards the IH of their respective strike zone at 9.02 ± 26.67° in comparison to OC swing trials 149.30 ± 32.30° (p=.013). There was a greater internal rotation angle at the shoulder in trials completed in OC 149.30± 32.30° and OL 121.28 ± 39.3° in comparison to IC swing trials 45.79± 29.51° respectively (p=.004), (p=.042). There was also a greater internal rotation angle at bat-ball contact of the stride shoulder found in OH 89.64±33.97 (p=.043), OC swing trials 149.30 ± 32.30° (p=.013), and OL 121.28 ± 39.3° (p=.008) when compared to MH swing trials 3.71±38.48°. There was also a greater internal rotation angle at bat-ball contact of the shoulder in OL 121.28 ± 39.3° swing trials in comparison to MC swing trials 23.86± 46.51°(p=.037). Internal rotation angle at the shoulder was also greater in OC swing trials 149.30 ± 32.30° in comparison to ML swing trials 71.05 ± 27.27° (p=.023). Shoulder angle kinematics at ball contact can be seen in figures 10-12 under Appendix B: Figures.

A significant main effect was found for elbow flexion angle at bat-ball contact (p<.001). Pairwise comparisons revealed a greater elbow flexion angle at bat-ball contact for trials completed at the top end of their respective strike zone (IH: 63.02± 4.24°, MH: 61.15 ± 3.75°, OH: 58.04 ± 3.44°) when compared to trials completed at the bottom of their strike zone (IL: 54.10 ± 3.65°, ML: 55.86 ± 3.32°, OL: 48.82± 2.85°) (p<.01). There was greater elbow flexion at ball contact in swing trials completed in the IH (63.02± 4.24°) region of their strike zone in comparison to OC swing trials (52.20±3.25°) (p=.003). There was a greater elbow flexion angle at ball contact in IC swing trials (60.73± 3.72°) in comparison to IL (54.10 ± 3.65°), ML(55.86 ± 3.32°), and OL (48.82± 2.85°) swing trials (p<.05). MH swing trials exhibited a greater elbow flexion angle at ball contact (61.15 ± 3.75°) in comparison to OH (58.04 ± 3.44°) and OC (52.20±3.25°) swing trials (p<.05). There was also a greater elbow flexion angle at ball contact in trials completed in the MC of their respective strike zone in comparison to IL(54.10 ± 3.65°), OC (52.20±3.25°), and OL (48.82± 2.85°) swing trials (p<.01). ML swing trials yielded a greater elbow flexion angle at ball contact (55.86 ± 3.32°) when compared to OL swing trials (48.82± 2.85°) ($p<.001$). Changes in elbow angle at ball contact can be seen in Figure 13.

There was no significant main effect for flexion/ extension angle of the wrist at bat-ball contact ($p=.345$), along with abduction/ adduction angle ($p=.256$), or internal/ external rotation ($p=.082$). Figures for baseball full body kinematics can be found under Appendix B, Figure 14.

5.3 Softball Stride Leg Kinematics

After removing two participants from full body kinematic analysis, there was no significant main effect difference observed when looking at hip angle difference angles at ball contact regarding flexion/extension angle ($p=.169$), abduction/ adduction angle ($p=.233$), and internal rotation angle ($p=.453$) over the nine regions of the strike zone. There was also no difference in knee flexion/ extension angle at bat-ball contact over the nine regions of the strike zone ($p=.068$).

5.4 Softball Stride Arm Kinematics

In analyzing the angle of the shoulder at bat-ball contact, there was no significant main effect of shoulder flexion angle ($p=.194$), adduction angle ($p=.295$), and internal rotation angle ($p=.230$) over the nine regions of the strike zone. There was a significant main effect for elbow flexion at bat-ball contact ($p<.001$). Pairwise comparisons revealed swing trials completed IH of their respective strike zone had greater elbow flexion (76.59± 4.52°) in comparison to the other eight regions of the strike zone: IC: 73.49 ± 4.57° ($p<.05$), IL: 67.36 ± 4.88° ($p=.012$), MH: 72.10± 4.64° ($p<.05$), MC: 67.17± 4.66° ($p<.01$), ML: 63.03± 3.48° ($p<.001$), OH: 63.55± 3.92° ($p<.01$), OC: 57.61± 3.46° ($p<.001$), OL: 54.76± 3.13° ($p<.001$). IC swing trials also exhibited a greater elbow flexion angle (73.49 ± 4.57°) in comparison to IL: 67.36 ± 4.88° ($p<.05$), MC: 67.17± 4.66° ($p<.05$), ML: 63.03± 3.48° ($p<.001$), OH: 63.55± 3.92° ($p<.01$), OC: 57.61± 3.46°

(p<.001), OL: 54.76± 3.13° (p<.001). There was a greater elbow flexion at ball contact for MH swing trials (72.10± 4.64°) when compared to MC: 67.17± 4.66° (p<.05), ML: 63.03± 3.48° (p<.01), OH: 63.55± 3.92° (p<.01), OC: 57.61± 3.46° (p<.001), OL: 54.76± 3.13° (p<.001). MC swing trials had a greater elbow flexion angle 67.17± 4.66° when compared to OC: 57.61± 3.46° (p<.01), OL: 54.76± 3.13° (p<.01). ML swing trials (63.03± 3.48°) also had a greater elbow flexion at ball contact when compared to OL swing trials 54.76± 3.13° (p=.009). Results revealed a non-significant main effect when examining changes in wrist extension (p=.353), adduction (p=.444), and internal rotation (p=.662) angle at bat-ball contact among various regions of the strike zone in collegiate softball players.

6. Discussion

The results from our study are quite novel in nature reporting full body kinematic differences at bat-ball contact among collegiate baseball and softball players in various regions of the strike zone specifically looking at the stride arm and leg at bat-ball contact. In looking at kinematics on both stride arm and leg we have similar results when looking at the angle of the knee at bat-ball contact as seen in Escamilla et al. (2009a). The angle of the stride knee at bat-ball contact was 11±4° for the adult hitters (professional) and 15±11° for youth baseball players reported by Escamilla et al. (2009a). The baseball players in the current study had knee angles ranging from 8.6° to 12.6° over the nine regions of the strike zone. Softball participants in the current study also had similar knee angles ranging from 10.6° to 15.1° over the nine regions of the strike zone at bat-ball contact. Welch et al. (1995) reported similar knee flexion angles at bat-ball contact of the stride leg at bat-ball contact in 25 professional baseball players. The mean knee flexion of the stride leg at bat-ball contact in these professional baseball players was (15±9°) (Welch et al., 1995) which is similar to what was found in the current study for both baseball and softball groups. This in turn supports that changes in lead knee flexion angle at bat-ball contact is comparable across with youth, collegiate, and professional baseball players. This study also shows that there are minimal differences in stride leg knee flexion angle in collegiate softball players when comparing knee flexion angles across youth, college, and professional baseball players (Escamilla et al., 2009a; Welch et al., 1995).

To our knowledge, this is one of the first studies examining stride leg and arm differences at bat-ball contact in collegiate baseball and softball players in various regions of the strike zone. Our study showed greater internal rotation of the shoulder at bat-ball contact for trials completed and they approached a greater degree of elbow extension towards the outside of their strike zone in comparison to trials completed in the middle or inside of their strike zone. This could be explained by the coaching technique the hitting coach taught this group of baseball participants. Outside of this statistical difference in stride arm/ leg kinematics, there was no other statistical differences seen in the current study when looking at the hip, shoulder, and wrist among both baseball and softball participants. Part of this can be explained in the very large standard deviations each of these angles were at ball contact telling us the wide variability and differences in hitting technique across each participant has as he or she approaches contact with a ball over the nine regions of the strike zone.

Our study however does not align with work completed by Escamilla et al (2009a) or Welch et al (1995) regarding elbow kinematics at bat-ball contact with both baseball and softball players. The current study showed greater elbow flexion for trials completed towards the inside third of home plate (IH, IC, IL) for both baseball and softball players. There was less elbow flexion at ball contact the further away the ball was placed on the tee in regions in the middle and outside of corner of the strike zone along with the trials completed in the center and bottom of each region of the strike zone for both groups. The study completed by Escamilla et al. (2009a) had six collegiate and six professional baseball players recorded a mean stride arm elbow angle at bat-ball contact of 18±6°. These athletes were asked to swing at baseballs pitched from a machine towards the inside of half of home plate and a region lying between the bottom of the number on the participant's jersey towards the waist (Escamilla et al., 2009a). Based on this information we can compare the data in regions of the strike zone including IH, IC, IL, MH, MC, and ML for both groups. Comparing data from our current study trials showing the greatest amount of elbow flexion for baseball and players at ball contact was when the tee was placed IH of their respective strike zone respectively (63.02±15.3°) (76.59±15.0°).

The investigation completed Welch et al (1995) examined full body kinematics of hitting a baseball in 25 right handed professional baseball players. Participants completed trials with a ball being placed on a tee of their choosing in the middle of home plate (Welch et al., 1995) which would be the MC region of the strike zone in the current study. Results of this investigation revealed that the elbow flexion angle at bat-ball contact was (37±8°). Relating this angle difference to the current study we can compare the elbow flexion angles completed in the MC region of the strike zone for both baseball and softball. The mean elbow flexion angle at MC for baseball was (58.7±7°) followed by (67.2°) for the softball group in the same position.

The differences reported by Escamilla at al. (2009a) and Welch et al. (1995) compared with our findings could be based on changes in swing techniques made by the various hitting coaches across all of these investigations. The hitting coaches in the earlier studies could have taught their athletes to approach full elbow extension with the hope to square the bat up to expose as much of the bat to make contact with the ball. The current participants had a greater stride arm elbow flexion angle at ball contact for swing trials placed on the inside of their respective strike zone followed by less flexion approaching elbow extension the further away the ball was placed towards the outside of their respective strike zone. Having a greater elbow flexion in trials completed towards the inside of bat-ball contact for both baseball and softball caused an increase in velocity of the bat at ball contact. This can be explained by Newton's 1st Law of Motion which states every object remains at rest of in uniform motion unless changed by an outside force. Newton's angular law of inertia is quantified by an objects mass and the axis of rotation known as the radius of gyration. If one shortens the radius of gyration and brings it closer to an objects center of mass, you lower the overall inertia needed to move that object. Having the elbow flexed causes a decrease in the radius of gyration and thus decreases this objects resistance inertia allowing the bat to travel faster exhibited in this study (see Figures 8-9) in comparison to the adult hitters in Escamilla et al. (2009a) at 30±2 m/s.

Another possibility to explain these differences in stride arm elbow flexion at bat-ball contact is where the participants set up in the batters box to complete the swing trials. The investigation by Welch et al. (1995) had each participant line up comfortably onto two force plates and then had the tee placed in a position comfortable for the participant to hit a line drive up the middle of the field. Investigations by Escamilla et al. (2009a) asked participants to swing at pitched baseballs from a machine that were placed on the inside half of home plate in a region below the base of the numbers and above the waist with no mention of stance position prior to completing each swing trial (Escamilla et al., 2009a). With participants having prior knowledge of what to expect and what type of pitches to swing at could have allowed these participants to make adjustments to best position themselves for the given trial such as sitting further back in the batters box prior to an inside swing trial. The current study asked all participants to set their stance up to home plate to mimic facing an opposing pitcher in a at-bat situation and had no prior knowledge of where the next trial took place under the tee was moved and set accordingly prior to performing the next trial. In addition each swing trial was counterbalanced regarding position of the tee placed among the nine regions of their respective strike zone with having each trial separated by a period of 20 seconds as seen in game situations.

7. Conclusion

Baseball and softball players spend a great deal of time working on generating an effective swing motion to generate the most amount of speed while exposing the greatest amount of surface area of the bat with the hope of making successful contact with the ball. Hitting a ball on a tee is a common technique and widely utilized across baseball and softball populations of varying age and skill level. This study was designed to examine changes in full body kinematics on both the stride leg and arm over various regions of the strike zone with the hope of finding the most effective swing with the hope of increasing batting performance.

With any study there are certain limitations of the study that must be considered when interpreting these results. The first of which is that all of the swing trials were completed in a lab setting and each of the swing trials were not “true” game situation swings. Each participant completed each swing trial by hitting a ball placed on a tee in designated regions of the strike zone without facing an opposing pitcher and taking into consideration the decision on whether or not to swing at a given pitch i.e. ball or strike and then swinging at that given pitch. To our knowledge this is the first study that has examined other various joint angle changes at bat ball contact regarding abduction/ adduction, internal/ external rotation of stride hip, shoulder, and wrist in collegiate baseball and softball players in various regions of the strike zone. Caution should be used in examining the angle differences of these joints until future research is completed to examine and compare these changes. We acknowledge that these changes at bat-ball contact were non-significant (angle of hip, shoulder, wrist) in nature based on the wide variability in each individual's swing. Improving the efficiency of hitting kinematics can improve both bat speed and the angle of the bat at ball contact. Establishing hitting patterns and positions of the each person's stance and swing can help both the coach and athlete in achieving a higher increase in one's batting performance.

MANUSCRIPT III

EXAMINING CHANGES IN LOWER EXTREMITY ELECTROMYOGRAPHY IN VARIOUS REGIONS OF THE STRIKE ZONE IN COLLEGIATE BASEBALL AND SOFTBALL PLAYERS

1. Introduction

Within the realm of collegiate athletics, there are collectively 50,000 men and women who compete in collegiate baseball and softball (Association, 2017). One of the main outcomes within athletics is to simply win with the chance to compete for either a conference or national championship. Clinical professionals have established evidence based literature finding ways to maximize an athlete's batting performance in terms of bat speed and bat angle in their respective sport (Escamilla et al., 2009a; Escamilla et al., 2009; Katsumata, 2007; Mcintyre & Pfautsch, 1982; Messier & Owen, 1984, 1985a, 1986; Milanovich & Nesbit, 2014; Nathan, 2000; Nicholls et al., 2003; Race, 1961; Welch et al., 1995; C. C. Williams et al., 2017). Research also has examined changes in electromyography (EMG) as one completes a baseball swing (Nakata et al., 2013; Nakata et al., 2012; Shaffer et al., 1993).

One of the foundational studies to examine changes in upper and lower extremity musculature was completed by Shaffer, Jobe, Pink, and Perry in 1993. The investigators in this study recruited 18 professional baseball players and used fine wire electrodes to examine electrical activity of the triceps, posterior deltoid, serratus anterior, and supraspinatus muscles. The use of surface electrodes was placed on the erector spinae, vastus medialis, biceps femoris, and semimembranosus. Maximum muscle test (MMT) and baseline EMG signals were recorded prior to having each participant complete a WU until they were comfortable with swinging a bat at six pitched fastballs. Investigators in this study broke down the swing into 4 distinct phases wind-up, pre-swing, swing, and follow-through. Results of this study revealed that hamstring activity of the biceps femoris and semimembranosus reached the highest percentage of MMT at 154% and 157% during the pre-swing phase. The gluteus maximus reached its highest percentage of MMT during the pre-swing phase as well. Vastus medialis oblique reached its highest percentage of MMT during the mid-swing phase of the swing at 107% (Shaffer et al., 1993).

Work by Nakata, Miura, Yoshie, and Kudo (2012); along with Nakata et al. (2013) looked at changes in lower extremity muscle activity while participants were either swinging a baseball swing or checking their swing. The investigators wanted to see the firing sequence differences in the lower extremity between 10 skilled and 10 un-skilled baseball players. Surface electrodes were placed on the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius and the signals were digitized to 1,000Hz. Maximal voluntary isometric contractions (MVIC's) were on the aforementioned muscles of interest and tracked muscle activity by breaking the swing into seven distinct phases (waiting, shifting of body weight, stepping, landing, swing, impact, and follow through). Each participant was asked to perform a total of 60 trials with 45 of them being maximal swing trials. The other 15 swing trials, participants were asked to check their swing to mimicking a pitch thrown outside his or her strike zone (Dee Abrahamson, 2013; Paronto, 2014). Results of this study revealed a higher percent activation of MVIC in the skilled baseball players over the novice baseball players in the rectus femoris, biceps femoris, tibilais anterior, and the medial gastrocnemius when participants swung a bat with maximal effort ($p<.05$) (Nakata et al., 2013). Results also indicated a shorter peak latency when participants checked their swing compared to completing a maximal swing trial in the biceps femoris, tibialis anterior, and medial gastrocnemius ($p<.05$) (Nakata et al., 2012).

The aforementioned research designs examined lower extremity musculature while participants completed either a baseball swing or checked their swing. It is important to note that these studies asked participants to make contact with a pitched ball in a position of their choosing by either a machine or by an experimenter swing (Nakata et al., 2013; Nakata et al., 2012;

Shaffer et al., 1993). Knowing where the ball is not realistic in a game situation considering an opposing pitcher can throw a ball in an individual's strike zone.

The strike zone is defined as a region right below the bottom of a player's jersey and ends right above the top of their knee when he or she sets up in their respective stance. The strike also extends the entire width of home plate (Paronto, 2014). The strike zone can be divided into 9 distinct regions and to our knowledge no one has examined changes in lower extremity muscle activity as it relates to collegiate baseball and softball players swinging a bat in each one of these nine distinct areas specifically on the stride leg. Understanding lower extremity firing pattern can allow both sport and strength coach the information necessary to both correct batting technique and train the musculature responsible for generating an individual's swing.

The purpose of this manuscript is to examine changes in lower extremity musculature as it relates to collegiate baseball and softball players swinging in different areas of their respective strike zone. The musculature of interest will be the gluteus maximus (GM), vastus medialis oblique (VMO), semitendinosus (MH), medial gastrocnemius (MG), and tibilais anterior (TA) of the lead/ stride leg of each participant. We suspect there to be changes in muscle activity during the four distinct phases of the swing and as the swing trajectory changes throughout the nine regions of an athlete's strike zone.

2. Methodology

2.1 Experimental Approach to the Problem

This study design is comparing lower leg muscle activity as it relates to the nine distinct regions and throughout a swing in collegiate baseball and softball players. The use of a Vicon Nexus motion capture system will be utilized to break down the distinct phases of the swing along with recording all EMG data of interest. Motion capture systems have been shown to be reliable in terms of what they analyze along with being used in previous swing analysis research (Bonnechere et al., 2014; Fleisig et al., 2002; Milanovich & Nesbit, 2014; Tsushima et al., 2003; C. C. Williams et al., 2017). The current design used 13 current baseball and 13 softball intercollegiate athletes who completed one experimental trial during their fall season.

2.2 Participants

Thirteen (age:19.69± 1.18 years, height: 184 ± 6.16cm, mass: 93.32± 9.8kg) NCAA division I baseball players along with 13 NCAA division I softball players (age: 19.46± 1.33years, height: 171.31± 9.13cm, mass: 73.05± 8.1kg) participated in the current study. These participants were classified as being free from musculoskeletal injury after filling out a physical activity readiness questionnaire (PAR-Q) along with having at least one year prior of resistance training experience prior to the study. Meetings with sport coaches and players took place prior to the study to let them be aware of all benefits and risks prior to testing. All participants signed a University informed consent approved by the University Institutional Review Board (IRB) with the following experimental protocol.

2.3 Procedures

A Vicon Nexus 3D motion capture system (Oxford, UK) equipped with 8 near-infrared T-Series cameras were utilized to record all EMG variables of interest. In order to properly distinguish the phases of the swing a modified, full body Helen Hayes marker system along with two custom models were created for both the bat and tee. Sampling rate was set at 200Hz on 47 retroreflective markers from the aforementioned kinematic models. Prior to testing, a global coordinate system was put in place to properly track each retroreflective marker to distinguish the phases of the swing to record all EMG measures of interest. A global coordinate system was put into place to accurately quantify the three-dimensional motion of each swing trial. The Z-direction was defined as the vertical projection upward. The Y-direction was defined as the vector in which all participants completed their swing trials as they approached contact with a ball placed on tee in various regions of their respective strike zone. The cross-product of both Y and Z directions was used to determine the X-direction. Defining the current global coordinate system has been used in previous swing analysis research (Fleisig et al., 2002; C. C. Williams et al., 2017)).

The current study design utilized a traditional hitting tee and standard bat (SB) based on their respective sport. A SB weight for collegiate baseball cannot be more than three units less than the length of the bat (Paronto, 2014). The current study utilized a bat that is 33inches long and weigh 30 ounces or 34 inches and weigh 31 ounces for baseball participants. For softball, their SB cannot weigh more than 38 ounces and cannot be longer than 34 inches (Dee Abrahamson, 2013). The softball players in the current study used either a 34in/ 24oz or a 33in/23oz bat. Participants completed one laboratory visit lasting no more than two hours in duration where they were aware of all risks and benefits prior to signing a University informed consent approved by the University IRB. Investigators asked all participants to maintain their normal activities of daily living in terms of hydration and nutrition status.

The experimental protocol was completed around participant's class and practice times during the fall semester. Anthropometric measurements of the ankle, knee, shoulder, and hand were taken prior to testing. Upon completion of paperwork, participants were prepped for EMG procedures.

This process began by shaving if necessary, abrading, and cleaning the skin with alcohol pads at the sites for electrode placement on the lower extremity. Surface EMG signals will be recorded using sliver chloride monopolar surface electrodes. The ground electrode was placed on the tibial plateau. From there, participants will complete 3 sets 5-second maximal voluntary isometric contractions (MVIC) that will measure muscle activity of lower extremity muscles (gluteus maximus, medial quadriceps, medial hamstrings, tibialis anterior, and medial gastrocnemius(MG)) with their stride leg used during their swing trials. Participants were asked to maximally extend their hips to obtain the MVIC of the gluteus maximus. Participants were asked to forcefully extend their stride leg into a pad to obtain the medial quadriceps (MQ) MVIC. Following MVIC of the quadriceps, participants flexed maximally into the same pad to obtain MVIC's of the medial hamstrings (MH). In order to obtain the MVIC of the tibialis anterior (TA), participants secured their dominant foot in a strap and be asked to maximally dorsiflex. From there, participants were asked to maximally plantar flex into the ground to obtain the MVIC for the medial gastrocnemius (MG). Participants were also asked to stand and forcefully extend their stride leg while keeping the knee extended to get the MVIC of the gluteus maximus (GM). Once all EMG procedures are completed, participants were escorted over to the table where retroreflective markers will be placed on anatomical landmarks to track whole body kinematics as well as bat kinematics.

Considering everyone's strike zone is different depending on their set-up of their respective height along with his or her height. To standardized each participant's strike relative to their height, the top of the strike zone will be defined as 6 inches above their belt line. The bottom of the strike zone will be defined as the top of the knee and the difference between these two points will be the middle of their respective strike zone. The strike zone also covers the entire width of home plate therefore, the tee will be placed at different regions of home plate to mimic an inside, middle, and outside pitch (Figure 6). The regions of each respective strike zone are as follows: inside high (IH), inside center (IC), inside low (IL), middle high (MH), middle center (MC), middle low (ML), outside high (OH), outside center (OC), and outside low (OL).

A counterbalanced design was implemented to determine the tee position for each maximal swing trial. After all of the markers were securely placed, each participant completed a 2 minute on-deck WU mimicking what they would do prior to an at bat situation. Once their on-deck WU was complete, a short rest period took place allowing for each participant to get set in their respective batting stance. Participants were asked to set up relative to home plate and to never adjust to the tee as they would in a game situation. Each participant was asked to maximally swing and make contact with a ball placed on a tee in various positions of their respective strike zone. After each trial, a period of 20 seconds elapsed to mimic the time between each pitch and allowed the investigators to place the tee in another position within their strike zone. At the conclusion of the 15th maximal swing, a 10-minute wash-out period was implemented followed by another on deck WU. The maximal swing protocol was repeated until there was a total of 45 recorded trials, having a total of five swing trials within the nine regions of each participant's strike zone.

3 Data Analysis

The swing was broken into three distinct phases and four specific events based on previous work by Shaffer et al. (1993) and Escamilla et al. (2009). The first event began when each participant's lead (stride) foot left the ground which started the stride phase of the swing. The stride phase ended when the lead toe reestablishes contact with the ground representing the 2nd event of the swing. The point at which the lead foot reestablishes contact with the ground up to the point where the bat reaches a perpendicular position with the ground (3rd event) represents the transition phase of the swing (Escamilla et al., 2009a; Shaffer et al., 1993). The swing phase of the swing begins when the bat is perpendicular with the ground and ends when bat-ball contact is made (Escamilla et al., 2009a; Shaffer et al., 1993) which will be defined as the frame in which deformation of the tee occurred when bat-ball contact was made (C. C. Williams et al., 2017).

EMG analysis was recorded using Noraxon® Telemyo software synced with a Vicon Nexus motion capture system. Raw EMG will be collected at 1,000Hz, a fourth order Butterworth filter was used to smooth the data. The data was also rectified prior to statistical analysis.

4 Statistical Analysis

Results for the current study will be analyzed using SPSS 22 statistical software with a predetermined alpha level of .05. A series of 3 (phases of swing) x 9 (regions of the strike zone) within subject's factor repeated measures analysis of variance (ANOVA) was used on each stride leg muscle of interest (GM, H, MG, Q, TA) for both percent activation and mean muscle activity. If there is a violation of Mauchly's test of sphericity, a Greenhouse-Geisser correction will be used to determine significance. If a significant main effect is found, Least Square Difference (LSD) was used to determine pair wise differences among the variables of interest.

5 Results

5.1 Baseball % Activation and Mean Muscle Activity

Results of this study indicated a significant main effect for percent activation for GM, H, MG, Q, and TA over the three phases of the swing ($p<.05$). There was a significant increase in percent activation of the GM in the transition phase: 60.89±25.47% in comparison to the stride phase of the swing 19.31±8.55% ($p=.035$). There were significant differences observed in H percent activation across all three phases: stride phase: 45.90±14.3%, transition phase:

68.33±17.65% and swing phase: 160.29±21.94% ($p<.05$). Significant differences in percent activation were also seen in the MG across all three phases as well: 18.05±4.34%, transition phase: 100.29±36.89% and swing phase: 164.39±63.63% as well (p<05). Percent activation in the Q was also observed across all three phases of the swing as well: stride phase: 4.07±.464, transition phase: 25.58±5.24% and swing phase: 18.84±3.42% ($p<.05$). The TA also exhibited significant differences in percent activation throughout the swing: stride phase: 7.04±1.68%, transition phase: 15.19±3.72% and swing phase: 20.33±4.18% ($p<.05$). Differences in percent activation over the three phases of the swing can be found in Figure 23.

Results of this study also indicated a significant main effect of mean muscle activity of the stride throughout the various phases of the swing (stride, transition, swing) in the GM, H, MG, Q and TA among collegiate softball players ($p<.05$). Significant differences concerning the aforementioned muscles and phases of the swing can be seen in Table 9. There was no significant main effect for mean muscle activity on the aforementioned stride muscles of interest (GM, H, MG, Q, and TA) throughout the various regions of the strike zone in collegiate baseball players ($p>.05$).

5.2 Softball %Activation and Mean Muscle Activity

Results of this investigation for softball players who participated in the current study revealed a significant main effect for percent activation of the GM, H, MG, and Q over the three phases of the swing ($p<.05$). Significant differences were seen in percent activation of the GM over the three phases of the swing: stride: 33.82 ± 7.2 %, transition: 77.57 ± 17.17 %, swing: 100.16 ± 25.53% ($p<.05$). Significant differences were also seen in percent activation of the MH between the stride phase: 31.5± 4.54% and the swing phase: 89±10.01% ($p<.05$) along with differences between the transition phase: 38.99±5.8% and swing phase: 89±10.01% ($p<.05$).

Significant differences were also seen in the MG across all three phases of the swing: stride; 26.14±4.77%, transition: 69.47± 12.02%, swing: 183.35± 30.93% ($p<.01$). There were significant differences seen in the Q of the stride leg over the three phases of the swing: stride: 6.48±1.44%, transition: 21.23±2.75% and swing phase: 17.05±2.57% ($p<.05$). Significant differences were seen in percent activation in the TA between the stride phase: 9.41 ± 2.82% and the transition phase 25.69±7.23% ($p=.004$), but no statistical difference when comparing the swing phase percent activation of the TA ($p>.05$) (See Figure 7).

Results also indicated a significant main effect on mean muscle activity of the stride throughout the various phases of the swing (stride, transition, swing) in the GM, H, MG, Q and TA among collegiate softball players ($p<.05$). Significant differences concerning the aforementioned muscles and phases of the swing can be seen in Table 10.

There was also a significant main effect for percent activation across areas of the strike zone only in the GM ($p<.05$). Significant differences in percent activation of the GM was higher in the MH (74.45±17.79), MC (71.64±15.98%), OH (78.05±18.07%), OC (82.37±17.60%), and OL (70.40±14.58%) swing trials in comparison to IH (60.69±13.47%) swing trials ($p<.05$). ML swing trials had a significantly lower percent activation of the GM (60.99±14.03%) when compared to OC swing trials (82.37±17.60%). OC swing trials had a higher GM percent activation (82.37±17.60%) when compared to OL (70.40±14.58%) swing trials ($p=.011$). There were no other significant main effect differences across the strike zone for the other four stride leg muscles ($p>.05$).

In terms of mean muscle activity, there was no significant main effect difference in mean muscle activity in the stride leg over the nine regions of the strike zone in the MH, MG, Q, and TA among collegiate softball players($p>.05$). There was a significant main effect difference in mean muscle activity in the GM over the nine regions of the strike zone. There was a higher mean muscle activity in IC (225.75±29.15 mV), MH (269.23±4.14 mV), MC (259.84±84 mV), OH (277.83±34.68 mV), OC (296.75±34.07 mV), and OL (264.86±28.19 mV) swing trials in comparison to IH (225.75±29.15 mV) swing trials ($p<.05$). Higher mean muscle activity in the GM was seen in OH (277.83±34.68 mV), OC (296.75±34.07 mV), and OL (264.86±28.19 mV) swing trials in comparison to IL (217.26± 28.63 mV) swing trials ($p<.05$). There was a higher mean muscle activity seen in the GM during OC (296.75±34.07 mV) when compared to ML (241.87± 30.07 mV) ($p=.003$). OC swing trials had a higher mean muscle activity of the GM (296.75±34.07 mV) in comparison to OL swing trials (264.86±28.19 mV) ($p<.05$).

6 Discussion

In this study, we aimed to investigate differences in percent activation and mean muscle activity of stride leg musculature (GM, H, MG, Q, TA) throughout various phases of the swing (stride, transition, swing) in addition, to examining possible changes in various regions of the strike zone in collegiate baseball and softball players. This study revealed increases in both percent activation and mean muscle activity in both of populations over the three phases of the swing. Percent activation and mean muscle activity was the highest during the swing phase for both baseball and softball players for the H, MG, and TA on the stride leg. The Q had a higher peak activation and mean muscle activity for both baseball and softball during the transition phase of the swing. Baseball players that completed the study had a higher percent activation and mean muscle activity of the GM during the transition phase of the swing instead of the swing phase as exhibited by the softball players in the current study.

Our results are comparable to what Nakata et al. (2013) found when they examined changes in lower limb electromyography between skilled and unskilled baseball players.

Investigators found the greatest percent activation based on percentage of MVIC was at impact for the stride musculature of the rectus femoris (RF), biceps femoris (BF), TA, and MG (Nakata et al., 2013). The same can be said for our study for both the TA and MG was the highest in terms of percent activation and mean muscle activity during the swing phase where contact of the ball occurred. We chose to examine changes in electrical activity of both the vastus medialis and semitendinosus for their role in extending and flexing the knee respectively. The percent activation of the H in the current study was a little higher during the swing phase at 160.29±21.94% in comparison to 120% found by Nakata et al (2013). This could possibly suggest a greater contribution of the semitendinosus in comparison to the biceps femoris however; considering both of these muscles were not measured to compare against we can only speculate to the overall contribution both of these knee flexors play in the swing for both baseball and softball players. The H percent activation found in softball players was 89±10.01% during the swing phase.

To date, this is the first study to examine both percent activation and mean muscle activity in the stride leg in elite level, collegiate softball players. Unfortunately, to our knowledge, there is not any current literature we can use to compare our values outside of previous research that was completed in a male population. The current study showed a similar trend for increases in both percent activation and mean muscle activity of the GM, H, MG, Q, and TA as the baseball players in this study.

To our knowledge, this is also the first study that has examined differences in both percent activation and mean muscle activity in various regions of an athlete's strike zone for both collegiate baseball and softball players. Our results found a significant difference in percent activation of the GM over the course of the strike zone in collegiate softball players specifically within trials completed in the top inside corner (IH) of the strike zone along with the bottom of an individual's strike zone. Percent activation of the GM was lowest in IH (60.69±13.47%) swing trials followed by ML (60.99±14.03%), and (70.40±14.58%). This lowered percent activation of the GM in these regions of the strike zone could possibly be explained partly by the changes in muscle activity taking place in the trunk and upper extremity musculature based on where the ball was placed on the tee. However; considering we did not examine electromyography on the trunk or trail leg during the current investigation we can only speculate as to why this occurred. Another thought of why we saw changes in GM percent activation over the strike zone is due to having over a majority of the population being freshmen and sophomores. Swinging a bat is considered a very complex movement to generate the optimal amount of power while taking into consideration spatial accuracy of making contact with the ball. Younger athletes potentially have not had near as much time spent practicing the proper sequencing of their swing in various regions of the strike zone in comparison to older more experienced athletes.

With regard to the rest of the stride leg musculature of interest (H, MG, Q, TA), there was no difference in percent activation or mean muscle activity throughout the various regions of the strike zone for both baseball and softball players ($p>.05$). This could be related to the copious amount of time allotted for these individuals to practice these swings as the NCAA has set guidelines of when these athletes can practice (Dee Abrahamson, 2013; Paronto, 2014).

A current limitation of the current study was we cannot truly replicate how both collegiate baseball and softball players swing during a "game situation". Participants in the current study were asked to hit a ball placed on tee in various regions of their strike zone which is a very common batting practice technique implemented by both of the current sports teams.

Unfortunately, during a game situation, these athletes have to take into consideration swing a bat based on the where the ball is placed by an opposing pitcher along with reacting to a given pitch as whether or not to swing at that given pitch within their respective strike zone ie. strike/ ball. Future research can examine changes in one's swing with a live pitcher as seen during a game situation.

7 Conclusion

This study examined changes in stride leg electromyography in various regions of the strike zone in collegiate baseball and softball players. The present study confirms that swinging a bat for both baseball and softball is a very complex, sequential motion in order to achieve the desired outcome of maximal bat speed while making contact with a ball in a game situation. This study can help both players and coach better understand the firing patterns of their stride leg as they practice swinging a bat as they make contact with a ball placed on a tee.

Our data suggests a greater percent muscle activation and mean muscle activity of stride leg musculature in both the transition and swing phase while one is swinging a bat. This data can also provide the information necessary to get an athlete to "buy in" to a strength and conditioning program that maximizes movement patterns designed to improve bilateral and unilateral strength needed in swinging a bat effectively (Nakata et al., 2013; Szymanski et al., 2007).

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APPENDICES

APPENDIX A: TABLES

Table 1: Baseball Participant Characteristics

Age	19.69± 1.8 yrs
Height (cm)	184.31± 6.16 cm
Mass (kg)	93.32± 9.80 kg
Batter Stance	Left (n=8), Right (n=5)

Table 2: Softball Participant Characteristics

Age	19.46± 1.3 yrs
Height (cm)	171.31± 9.14 cm
Mass (kg)	73.05±8.10 kg
Batter Stance	Left (n=3), Right (n=10)

Table 3: MRV for Inside Strike Zone Swing Trials among Baseball/ Softball Participants

MRV for Inside Swing Trials: Baseball — MRV for Inside Swing Trials: Softball

Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
IH	38.5	1.9	IC	-4.95	0.1*	IH	33.57	0.8	IC	-.36	0.2
			IL	-1.02	0.2*				IL	-.996	0.3
			MH	-.039	0.2				MH	-1.15	1.2
			MC	-.850	0.2				MC	-.67	0.2
			ML	-.807	0.3				ML	-1.04	0.2
			OH	-.549	0.2				OH	-.051	0.5
			OC	-.750	0.1*				OC	-.750	0.3
			OL	-1.13	0.2*				OL	-.957	0.2
Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
IC	39.	2	IH	.495	0.1*	IC	33.937	0.75	IH	.360	0.2
			IL	-.52	0.1				IL	-.636	0.2
			MH	.455	0.1				MH	-.794	1.1
			MC	-.356	0.2				MC	-.311	0.1
			ML	-.312	0.2				ML	-.682	0.1*
			OH	-.054	0.2				OH	.309	0.5
			OC	-.255	0.1				OC	-.390	0.2
			OL	-.631	0.2				OL	.596	0.1
Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
IL	39.5	2.3	IH	1.02	0.2*	IL	34.57	0.68	IH	.996	.3
			IC	.524	0.1				IC	.636	.2
			MH	.979	0.2*				MH	-.158	1.4
			MC	.168	0.2				MC	.325	.26
			ML	.212	0.2				ML	-.046	.2
			OH	.469	0.1				OH	.945	.6
			OC	.269	0.1				OC	.247	.2
			OL	-.107	0.1				OL	.04	.2

*(p<.05)

Table 4: MRV for Middle Strike Zone Swing Trials among Baseball/ Softball Participants

MRV for Middle Swing Trials: Baseball						MRV for Middle Swing Trials: Softball					
Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
MH	38.56	0.61	IH	.039	0.2	MH	34.73	1.43	IH	1.15	1.3
			IC	-.455	0.1				IC	.794	1.2
			IL	-.979	0.2*				IL	.16	1.2
			MC	-.811	0.3				MC	.48	1.1
			ML	-.767	0.3				ML	.11	1.1
			OH	-.510	0.2				OH	1.10	1.2
			OC	-.710	0.1				OC	.405	1.1
			OL	-1.086	0.2*				OL	.198	1.1
Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
MC	39.38	0.63	IH	.850	0.3	MC	34.25	0.75	IH	.671	0.2
			IC	.356	0.2				IC	.311	0.1
			IL	-.168	0.2				IL	-.325	0.3
			MH	.811	0.3				MH	-.483	1.1
			ML	.044	0.2				ML	.37	0.1
			OH	.301	0.2				OH	.62	0.6
			OC	.101	0.2				OC	-.079	0.25
			OL	-.275	0.2				OL	-.285	0.18
Mean MRV (m/s)		SE	Mean Difference (m/s)		SE	Mean MRV (m/s)		SE	Mean Difference (m/s)		SE
ML	39.33	39.33	IH	.807	0.3	ML	34.62	0.71	IH	1.04	0.2
			IC	.312	0.2				IC	.682	0.1*
			IL	-.212	0.2				IL	.046	0.2
			MH	.767	0.3				MH	-.112	1.1
			MC	-.044	0.2				MC	.371	0.1
			OH	.258	0.2				OH	.991	0.5
			OC	.057	0.2				OC	.292	0.2
			OL	-.319	0.2				OL	.086	0.2

*($p<.05$)

Table 5: MRV for Outside Strike Zone Swing Trials among Baseball/ Softball Participants

MRV for Outside Swing Trials: Baseball — MRV for Outside Swing Trials: Softball

	Mean MRV (m/s)	SE		Mean Difference (m/s)	SE		Mean MRV (m/s)	SE		Mean Difference (m/s)	SE
OH	39.07	0.6	IH	.549	0.2	OH	33.629	0.7	IH	.051	0.5*
			IC	.054	0.2				IC	-.309	0.5
			IL	-.469	0.1				IL	-.945	0.6
			MH	.510	0.2				MH	-1.103	1.2
			MC	-.301	0.2				MC	-.620	0.6
			ML	-.258	0.2				ML	-.991	0.5
			OC	-.201	0.1				OC	-.699	0.5
			OL	-.577	0.1				OL	-.905	0.5
	Mean MRV (m/s)	SE		Mean Difference (m/s)	SE		Mean MRV (m/s)	SE		Mean Difference (m/s)	SE
OC	39.27		IH	.750	0.1*	OC	34.327	0.6	IH	.750	0.3
			IC	.255	0.1				IC	.390	0.2
			IL	-.269	0.1				IL	-.247	0.2
			MH	.710	0.1				MH	-.405	1.1
			MC	-.101	0.2				MC	.079	0.2
			ML	.057	0.2				ML	-.292	0.2
			OH	.201	0.1				OH	.699	0.5
			OL	-.376	0.1				OL	-.207	0.2
	Mean MRV (m/s)	SE		Mean Difference (m/s)	SE		Mean MRV (m/s)	SE		Mean Difference (m/s)	SE
OL	39.65	0.6	IH	1.13	0.6*	OL	34.534	0.7	IH	.957	0.2
			IC	.631	0.2				IC	.596	0.1
			IL	.107	0.09				IL	-.040	0.2
			MH	1.09	0.5*				MH	-.198	1.1
			MC	.275	0.2				MC	.285	0.19
			ML	.319	0.2				ML	-.086	0.21
			OH	.577	0.1				OH	.905	0.56
			OC	.376	0.1				OC	.207	0.1

*(p<.05)

Table 6: BABC and BAMRV for Inside Strike Zone Swing Trials among Baseball and Softball

BABC Inside Swing Trials						BAMRV Inside Swing Trials					
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
IH	49.191	2.1	IC	-7.5440	1.7†	IH	46.74	2.4	IC	-8.0060	2.27
			IL	-11.2720	2.0†				IL	-10.0540	3.07
			MH	7.0530	2.2				MH	6.4030	3.27
			MC	-3.3580	2				MC	-3.5800	2.42
			ML	-8.6860	2.2*				ML	6.1900	3.4
			OH	*6.4180*	*2.4*				*OH*	*6.1920*	*3.08*
			OC	-0.7000	2.2				OC	-1.5750	2.78
			OL	-5.581	2.4				OL	-11.019	4.93
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
IC	56.735	2.7	IH	7.544	1.7	IC	54.75	3.0	IH	8.006	2.27
			IL	-3.729	2.3				IL	-2.049	2.97
			MH	14.596	1.8†				MH	14.409	2.4†
			MC	4.185	1.8				MC	4.43	1.88
			ML	-1.142	2.2				ML	1.488	3.12
			OH	13.961	2.3†				OH	14.198	3.2*
			OC	6.843	2.4				OC	6.43	2.79
			OL	1.962	3				OL	-3.013	5.01
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
IL	60.464	2.8	IH	11.272	2.0†	IL	56.8	3.2	IH	10.054	3.07
			IC	3.729	2.3				IC	2.049	2.97
			MH	18.325	3.2†				MH	16.457	3.0†
			MC	7.914	3.2				MC	6.474	3.75
			ML	2.587	3.0				ML	3.536	2.72
			OH	17.69	3.5†				OH	16.246	4.35*
			OC	10.572	3.3				OC	8.479	3.98
			OL	5.691	3.4				OL	-0.965	5.27

†($p<.01$)
*($p<.05$)

Table 7: BABC and BAMRV for Middle Strike Zone Swing Trials among Baseball and Softball

BABC Middle of Strike Zone Swing Trials						BAMRV Middle of Strike Zone Swing Trials					
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
MH	42.13	3.6	IH	-7.053	2.2	MH	40.34	3.8	IH	-6.403	3.2
			IC	-14.596	1.8†				IC	-14.409	2.4†
			IL	-18.33	3.2†				IL	-16.457	3.0†
			MC	-10.411	1.3†				MC	-9.983	2.3*
			ML	-15.738	2.3†				ML	-12.92	1.9†
			OH	-0.635	1.4				OH	-0.211	3.2
			OC	-7.753	1.9*				OC	-7.979	2.6
			OL	-12.634	2.6†				OL	-17.422	5
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
MC	52.55	3.3	IH	3.358	2	MC	50.32	3.3	IH	3.58	2.4
			IC	-4.185	1.8				IC	-4.426	1.8
			IL	-7.914	3.2				IL	-6.474	3.7
			MH	10.411	1.3†				MH	9.983	2.3*
			ML	-5.327	2.5				ML	-2.938	3.
			OH	15.103	1.6†				OH	9.772	2.7*
			OC	7.986	1.9				OC	2.004	1.1
			OL	3.104	2.9				OL	-7.439	5.0
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
ML	57.88	2.1	IH	8.686	2.2*	ML	53.26	3.1	IH	6.518	3.4
			IC	1.142	2.2				IC	-1.488	3.1
			IL	-2.587	3.0				IL	-3.536	2.7
			MH	15.738	2.3†				MH	12.921	1.9†
			MC	5.327	2.5				MC	2.938	3.1
			OH	15.103	2.2†				OH	12.71	3.7
			OC	7.986	1.6†				OC	4.942	2.8
			OL	3.104	1.6				OL	-4.501	4.6

† (p<.01)
* (p<.05)

Table 8: BABC and BAMRV for Outside Strike Zone Swing Trials among Baseball and Softball

BABC Outside of Strike Zone Swing Trials						BAMRV Outside of Strike Zone Swing Trials					
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
OH	42.77	3.33	IH	-6.418	2.4	OH	40.5	3.93	IH	-6.192	3.1
			IC	-13.961	2.3†				IC	-14.198	3.2†
			IL	-17.69	3.5†				IL	-16.246	4.4*
			MH	0.635	1.4				MH	0.211	3.2
			MC	-9.776	1.6†				MC	-9.772	2.3*
			ML	-15.103	2.2†				ML	-12.71	3.7
			OC	-7.118	1.3†				OC	-7.768	2.7
			OL	-11.999	2.3†				OL	-17.211	5.6
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
OC	49.891	2.85	IH	0.7	2.2	OC	48.32	3.38	IH	1.575	2.7
			IC	-6.843	2.4				IC	-6.43	2.7
			IL	-10.572	2.1*				IL	-8.479	3.9
			MH	7.753	1.9				MH	7.979	2.6
			MC	-2.658	1.9				MC	-2.004	1.8
			ML	-7.986	1.6†				ML	-4.942	2.8
			OH	7.118	1.3†				OH	7.768	2.7
			OL	-4.881	1.6				OL	-9.444	5.1
Mean Bat Angle (°)		SE	Mean Difference (°)		SE	Mean Bat Angle (°)		SE	Mean Difference (°)		SE
OL	54.773	49.4	IH	5.581	2.4	OL	57.76	4.898	IH	11.019	4.9
			IC	-1.962	2.9				IC	3.013	5.01
			IL	5.691	3.4				IL	0.965	5.6
			MH	12.634	2.6†				MH	17.422	4.9
			MC	2.223	2.9				MC	7.439	5.0
			ML	-3.104	1.6				ML	4.501	4.6
			OH	11.999	2.3†				OH	17.211	5.5
			OC	4.881	1.6				OC	9.44	5.1

† (p<.01)
* (p<.05)

Table 9: Mean Muscle Activity (mV) of Stride Leg in Baseball Players over various phases of swing

Mean Muscle Activity (mV) of Stride Leg Musculature: Baseball			
Muscle	**Stride**	**Transition**	**Swing**
Gluteus Maximus	0.12863±.0187	0.305395±.0461*	0.337464±.0453*
Quadriceps	0.109425±.0097	0.438486±.0475*	0.305971±.0289*†
Hamstrings	0.120254±0120	0.17032±.0280	0.028019±.0289*†
Gastrocnemius	0.09853±.0068	0.270663±.0274*	0.686606±.0712*†
Tibialis Anterior	0.19514±.0196	0.55878±.0658*	0.955925±.1460*†

(*) Significant difference from stride phase ($p<.01$)
(†) Significant difference from transition phase ($p<.01$)

Table 10: Mean Muscle Activity (mV) of Stride Leg in Softball Players over various phases of swing

Mean Muscle Activity (mV) of Stride Leg Musculature: Baseball			
Muscle	Stride	Transition	Swing
Gluteus Maximus	0.10413±.0147	0.033112±.0568*	0.305164±.0501*
Quadriceps	0.101784±.0081	0.653663±0958*	0.095884±.0803*
Hamstrings	0.179733±.0597	0.279285±.0678*	0.604556±.0623*†
Gastrocnemius	0.096148±.0078	0.499618±.1132*	0.747436±.1282*
Tibialis Anterior	0.154639±.0108	0.332488±.0275*	0.502947±.0379*†

(*) Significant difference from stride phase ($p<.05$)
(†) Significant difference from transition phase ($p<.05$)

APPENDIX B: FIGURES

Figure 1. Represents recommended bat for an individual to use based on age and weight of Athlete (Slugger, 2017).

SIZING INFORMATION

WEIGHT	HEIGHT									
	3'-3'4"	3'5"-3'8"	3'9"-4'	4'1"-4'4"	4'5"-4'8"	4'9"-5'	5'1"-5'4"	5'5"-5'8"	5'9"-6'	6'1"-over
Under 60 Lbs	26"	27"	28"	29"	29"					
61 - 70	27"	27"	28"	29"	30"	30"				
71 - 80		28"	28"	29"	30"	30"	31"			
81 - 90		28"	29"	29"	30"	30"	31"	32"		
91 - 100		28"	29"	30"	30"	31"	31"	32"		
101 - 110		29"	29"	30"	30"	31"	31"	32"		
111 - 120		29"	29"	30"	30"	31"	31"	32"		
121 - 130		29"	30"	30"	30"	31"	32"	33"	33"	
131 - 140		29"	30"	30"	31"	31"	32"	33"	33"	
141 - 150			30"	30"	31"	31"	32"	33"	33"	
151 - 160			30"	31"	31"	32"	32"	33"	33"	33"
161 - 170				31"	31"	32"	32"	33"	33"	34"
171 - 180						32"	33"	33"	34"	34"
over 180							33"	33"	34"	34"

MOST POPULAR LENGTH BY AGE						
AGE	5-7	8-9	10	11-12	13-14	15-16
LENGTH	24"-26"	26"-28"	28"-29"	30"-31"	31"-32"	32"-33"

Figure 2. Phases of a baseball swing. This figure represents the four distinct phases of a baseball swing based on windup, pre-swing, swing, and follow through (Shaffer et al., 1993).

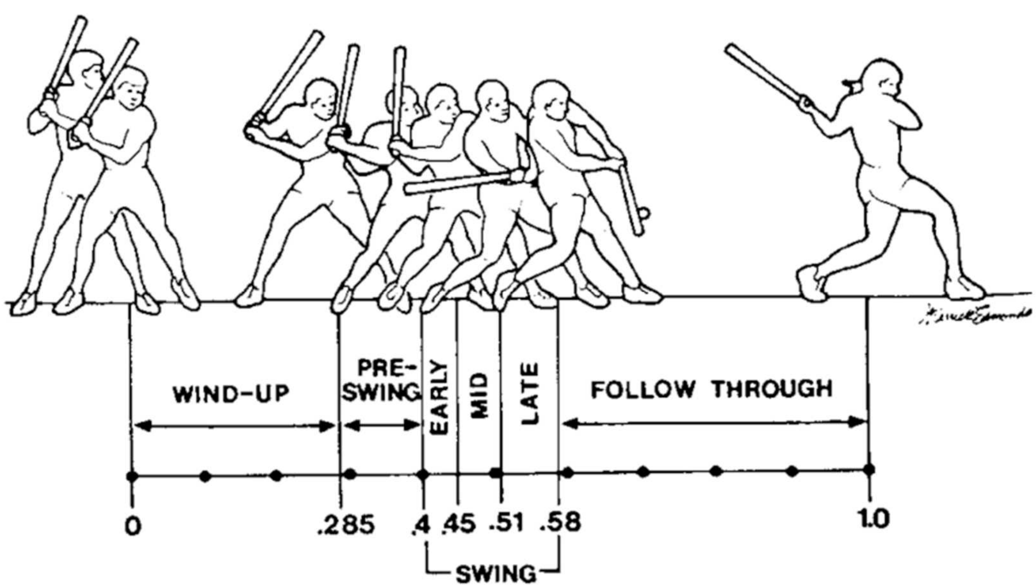


Figure 3. Three different striding techniques utilized by the lead leg and foot position as participants approached contact with softballs from a pitching machine for a right handed batter (Messier & Owen, 1986)

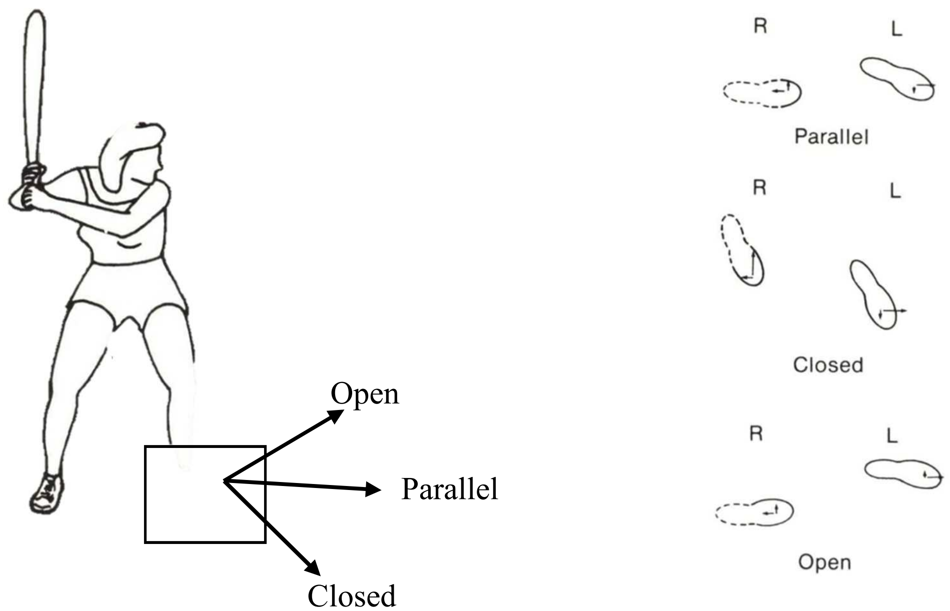


Figure 4. Phases of the swing used to quantify lower extremity EMG in work completed by (Nakata et al., 2013; Nakata et al., 2012)

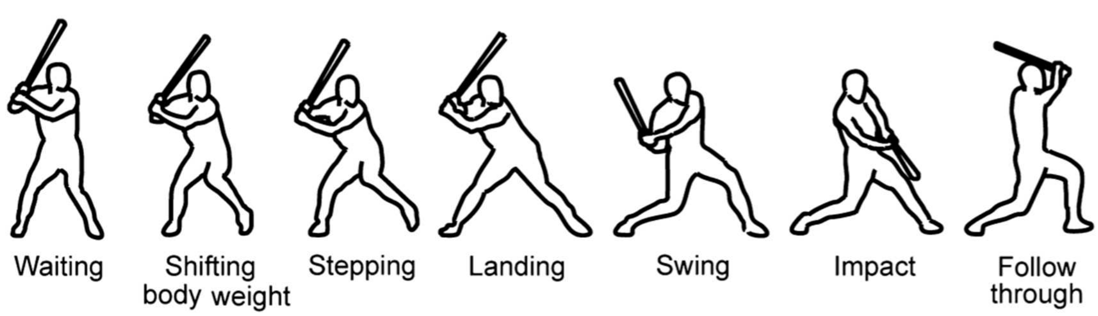


Figure 5. Modified Helen Hayes full body marker system and custom made bat and tee marker locations, (●) represent retroreflective markers.

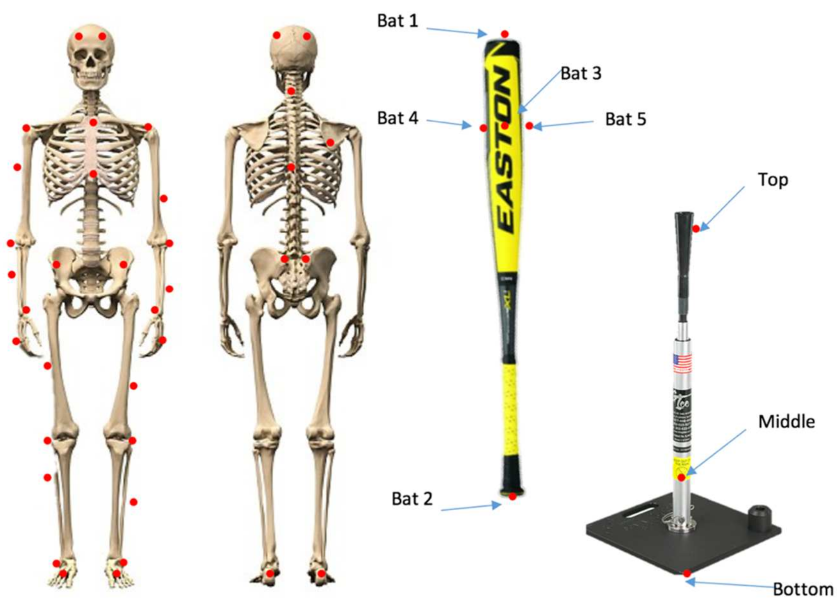


Figure 6. Diagram of the strike zone as defined by the NCAA rulebook (Paronto, 2014)

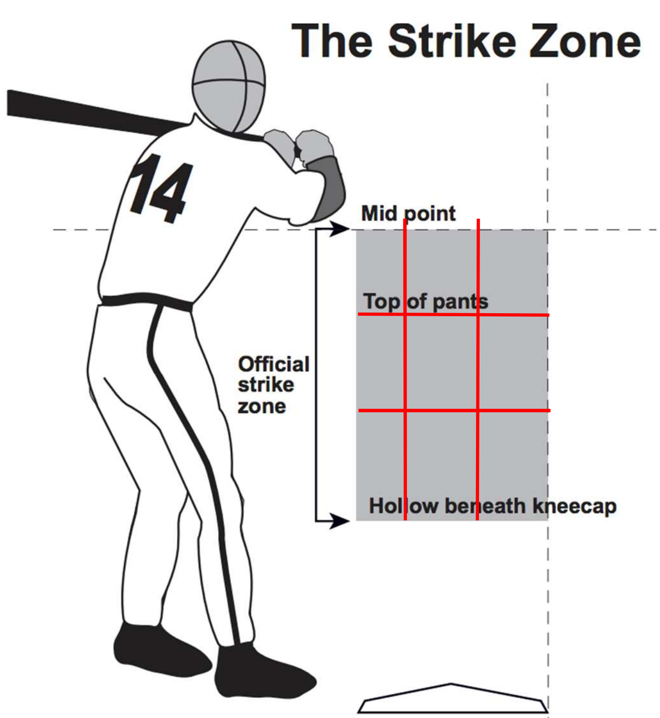


Figure 7. Tee position for an inside, middle, and outside pitch for a right-handed batter.

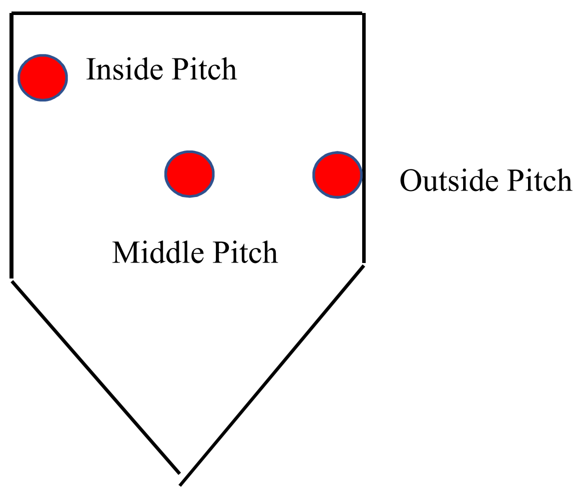
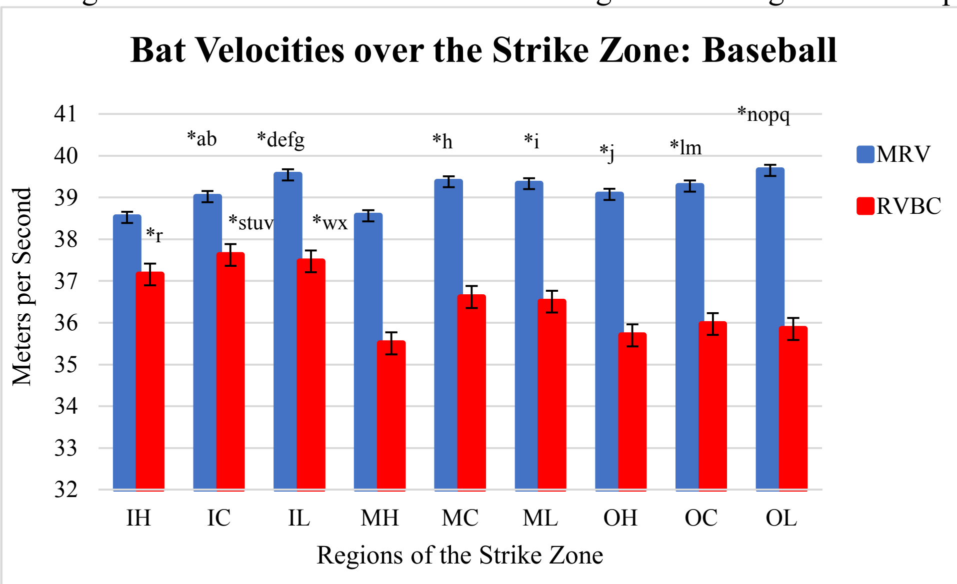
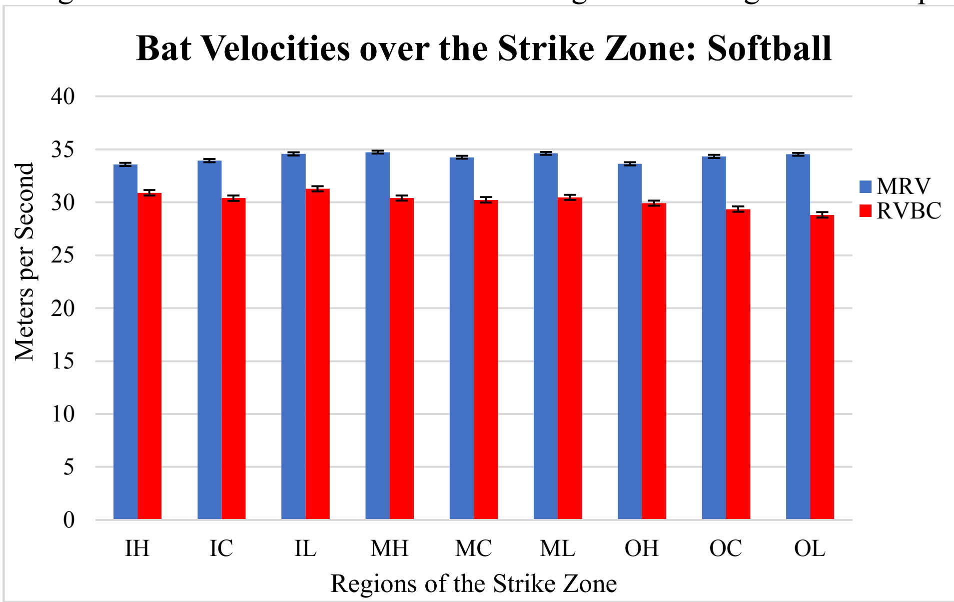


Figure 8. Changes in MRV and RVBC over the nine regions in collegiate softball players



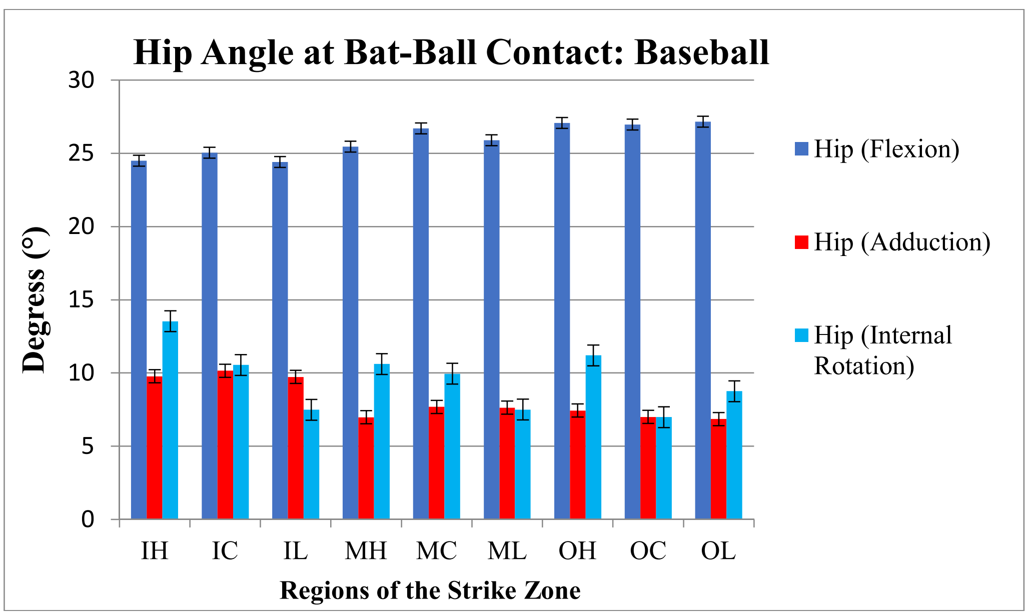
(*) Significant Difference (p<.05) across strike zone
Post-hoc comparisons significant differences between (p<.05): [a] IC & IH, [b] IC &MH [c] IC&OL [d] IL& IH [e] IL&IC [f] IL&MH [g] IL &OH [h] MC&IH, [i] ML&IH, [j] OH&MH, [k] OC&IH, [l] OC&MH [m] OC & OL ,[n] OL& IH, [o] OL& IC, [p] OL&MH [q] OL&OH [r] IH&OH [s] IC&MH [t] IC& OH [u] IC&OC [v] IC& OL [w] IL& MH [x]IL&OH [y] [z]

Figure 9. Changes in MRV and RVBC over the nine regions in collegiate softball players



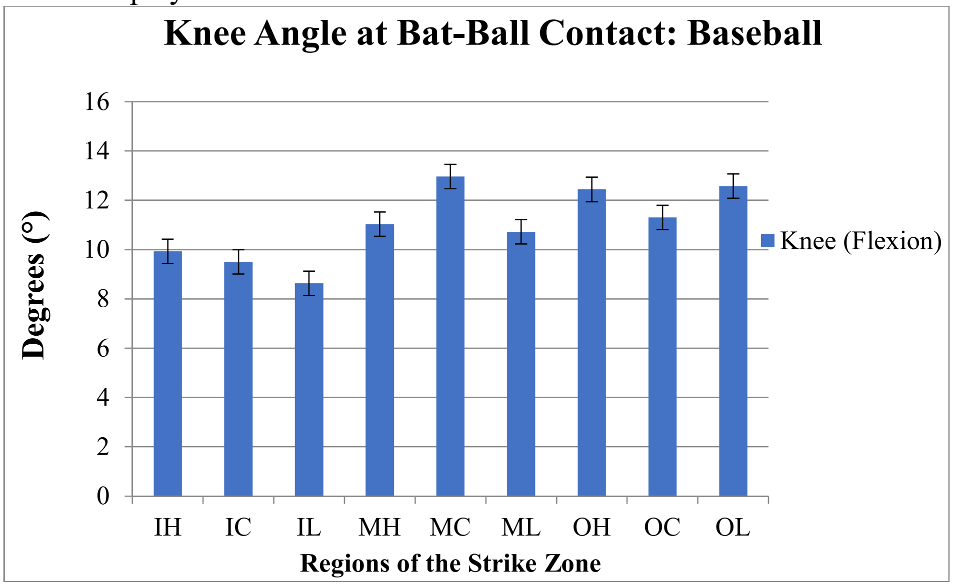
All values presented (p>.05)

Figure 10. Changes in hip angle in various regions of the strike zone among collegiate baseball players



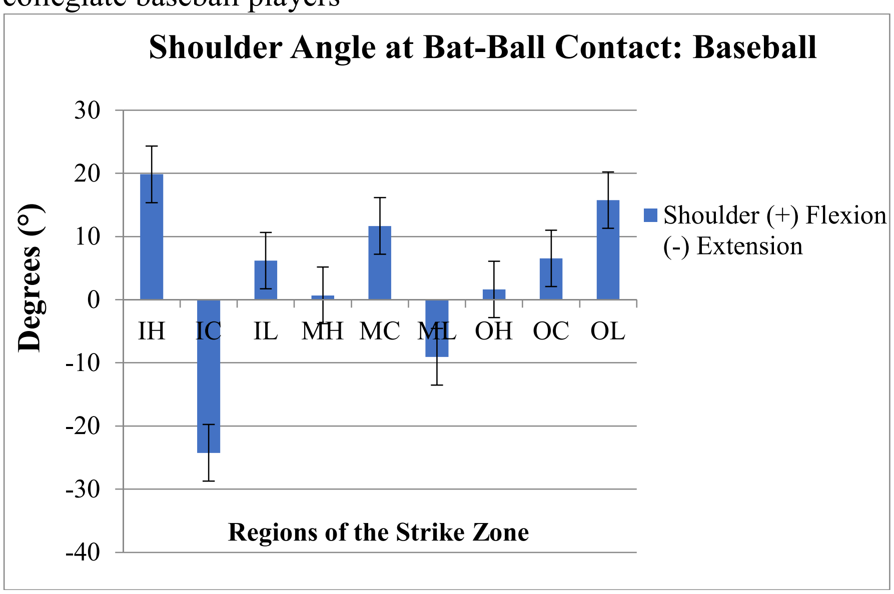
All values presented (p>.05)

Figure 11. Changes in knee flexion angle at bat ball contact in various regions of the strike zone in collegiate baseball players



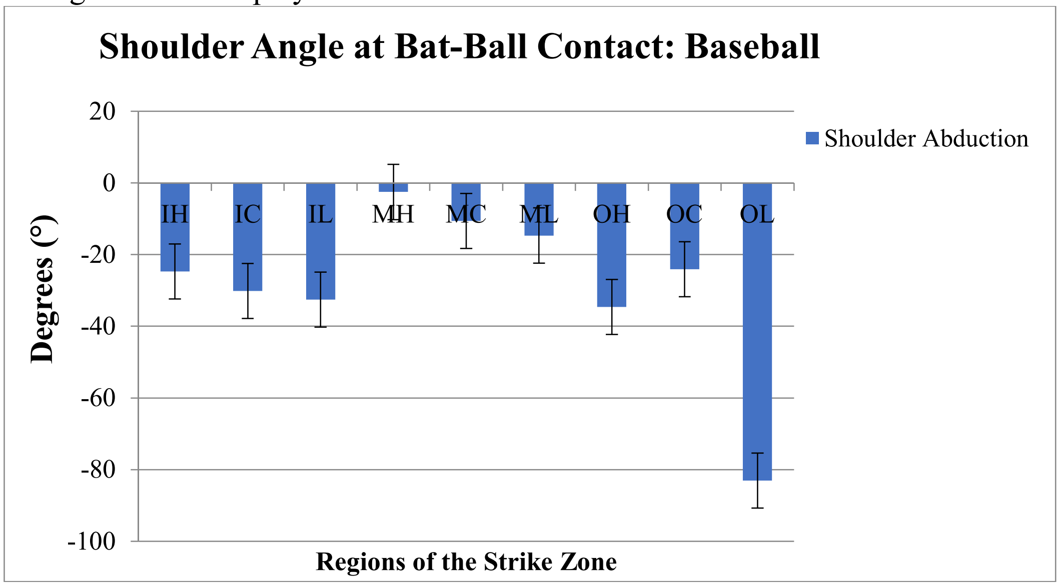
All values presented (p>.05)

Figure 12. Changes in shoulder flexion/ extension angle at ball contact in various regions of the strike zone in collegiate baseball players



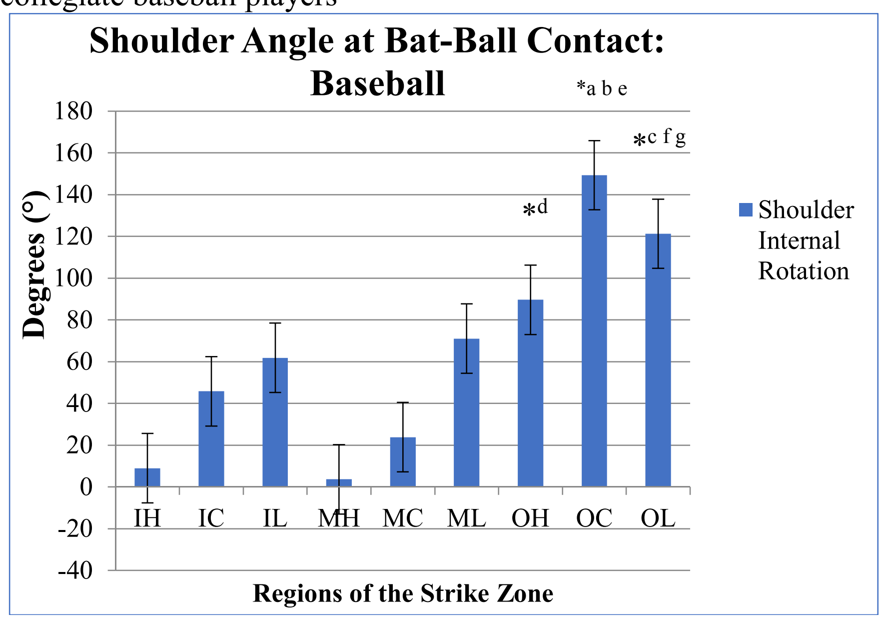
All values presented (p>.05)

Figure 13. Changes in shoulder abduction angle at ball contact in various regions of the strike zone in collegiate baseball players



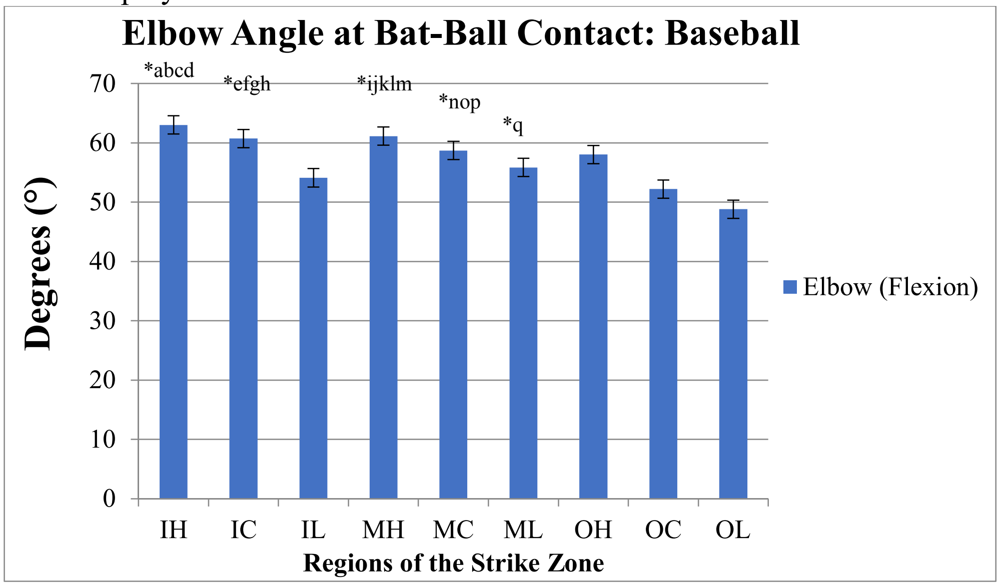
All values presented (p>.05)

Figure 14. Changes in shoulder internal rotation angle at ball contact in various regions of the strike zone in collegiate baseball players



(*) Significant Difference (p<.05) across strike zone
Post-hoc comparisons significant differences between (p<.05): [a] IH & OC, [b] IC &OC [c] IC&OL [d] MH& OH [e] MH&OC [f] MH&OL [g] MC &OL [h]

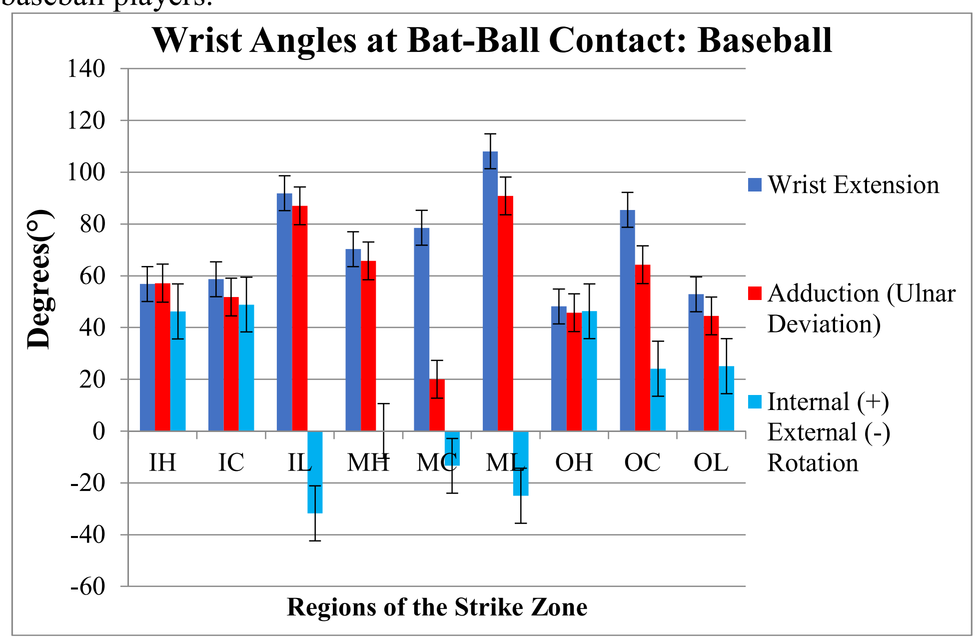
Figure 15. Changes in elbow flexion angle at ball contact in various regions of the strike zone in collegiate baseball players



(*) Significant Difference (p<.05) across strike zone

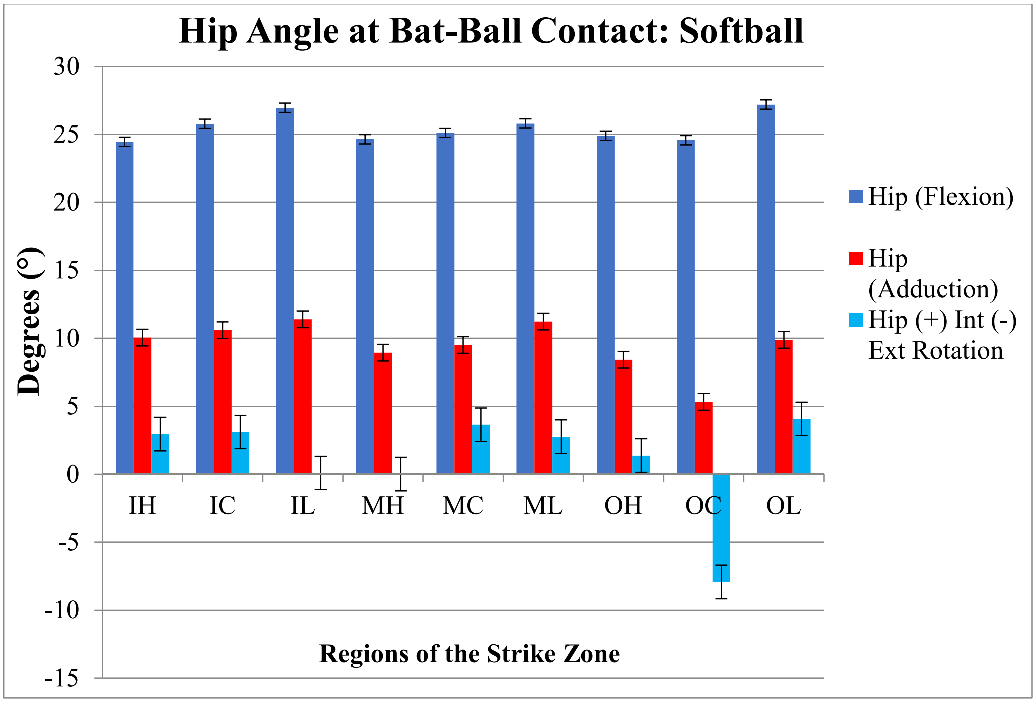
Post-hoc comparisons significant differences between (p<.05): [a] IH & IL, [b] IH &ML, [c] IH&OC [d] IH& OL, [e] IC&IL, [f] IC&ML, [g] IC &OC, [h] IC&OL, [i] MH&IL, [j] MH&ML, [k] MH&OH, [l] MH&OC [m] MH & OL , [n] MC& IL, [o] MC& OC, [p] MC&OL [q] ML&OL

Figure 16. Changes in wrist angle at ball contact in various regions of the strike zone among collegiate baseball players.



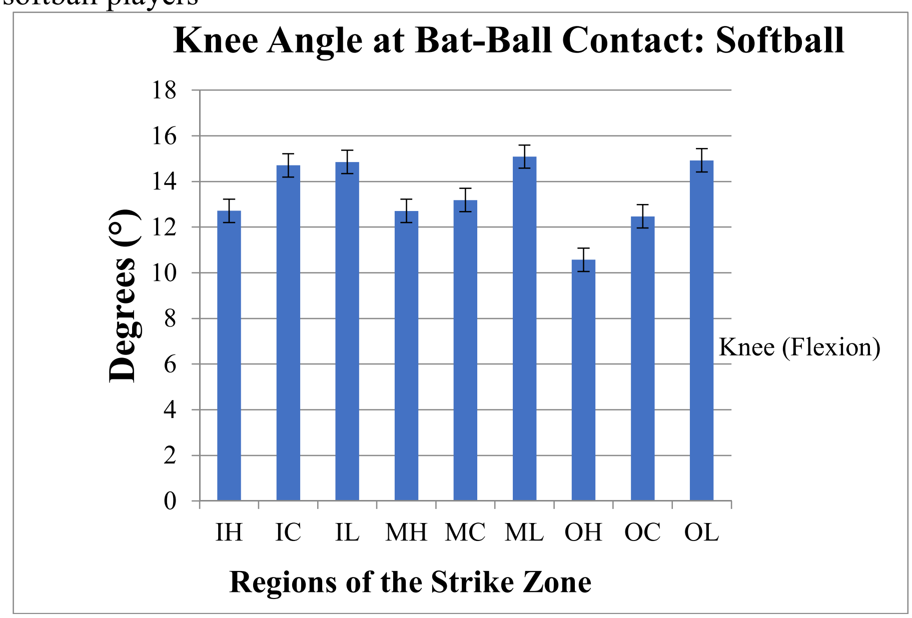
All values presented (p>.05)

Figure 17. Changes in hip angle in various regions of the strike zone among collegiate softball players



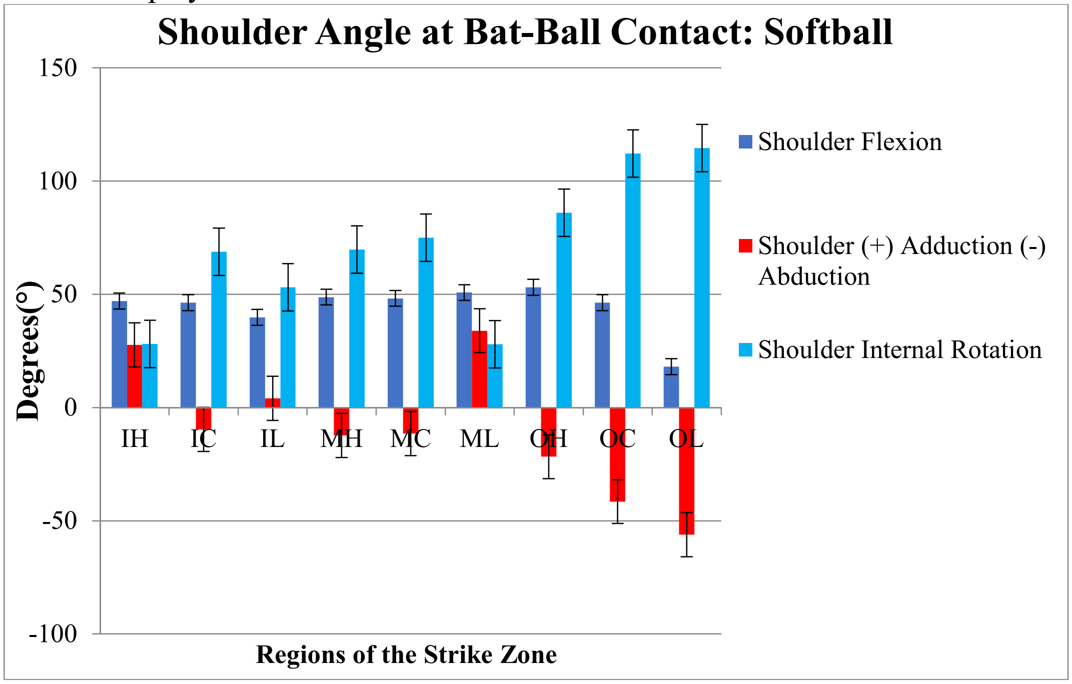
All values presented (p>.05)

Figure 18. Changes in knee flexion angle at bat ball contact in various regions of the strike zone in collegiate softball players



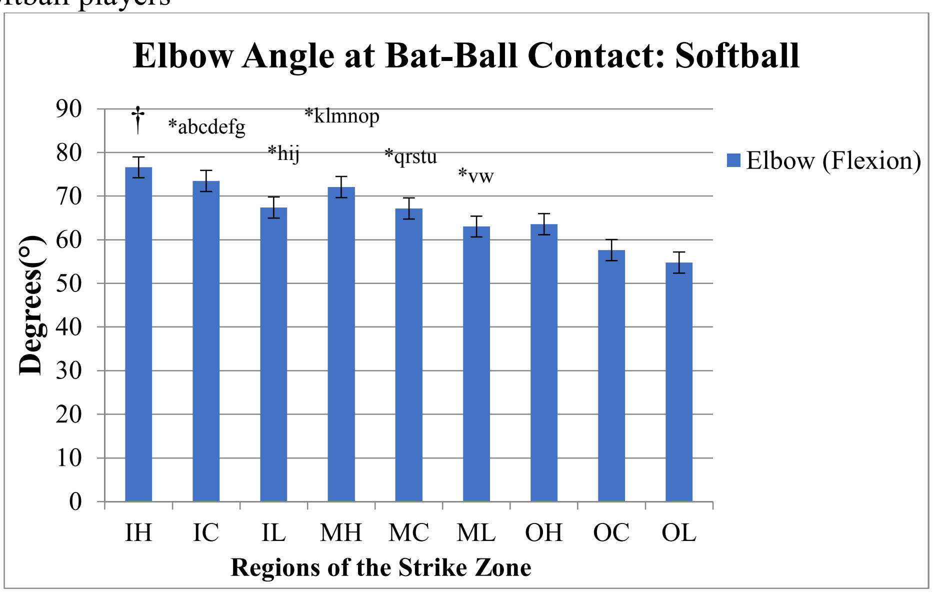
All values presented (p>.05)

Figure 19. Changes in shoulder angle at bat ball contact in various regions of the strike zone in collegiate softball players



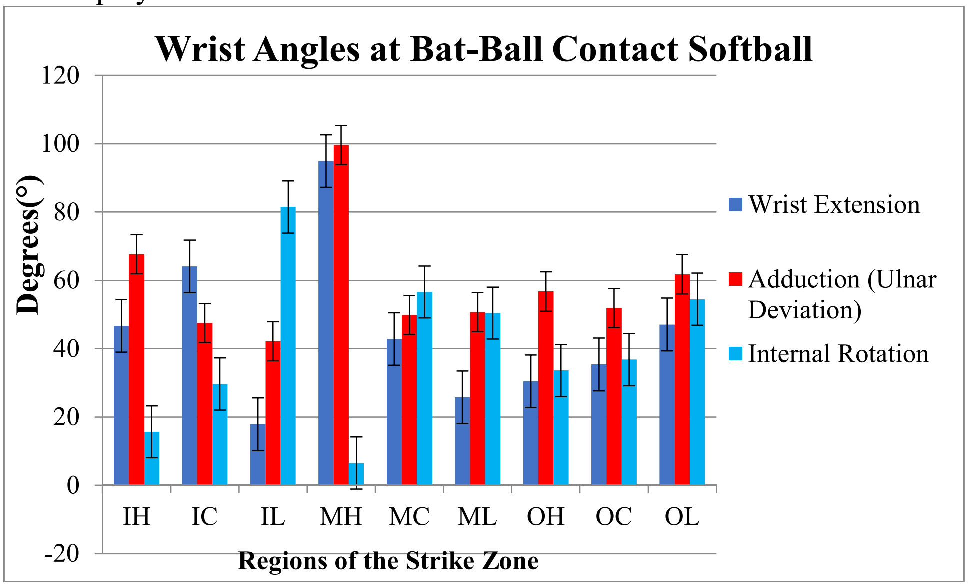
All values presented (p>.05)

Figure 20. Changes in elbow flexion angle at ball contact in various regions of the strike zone in collegiate softball players



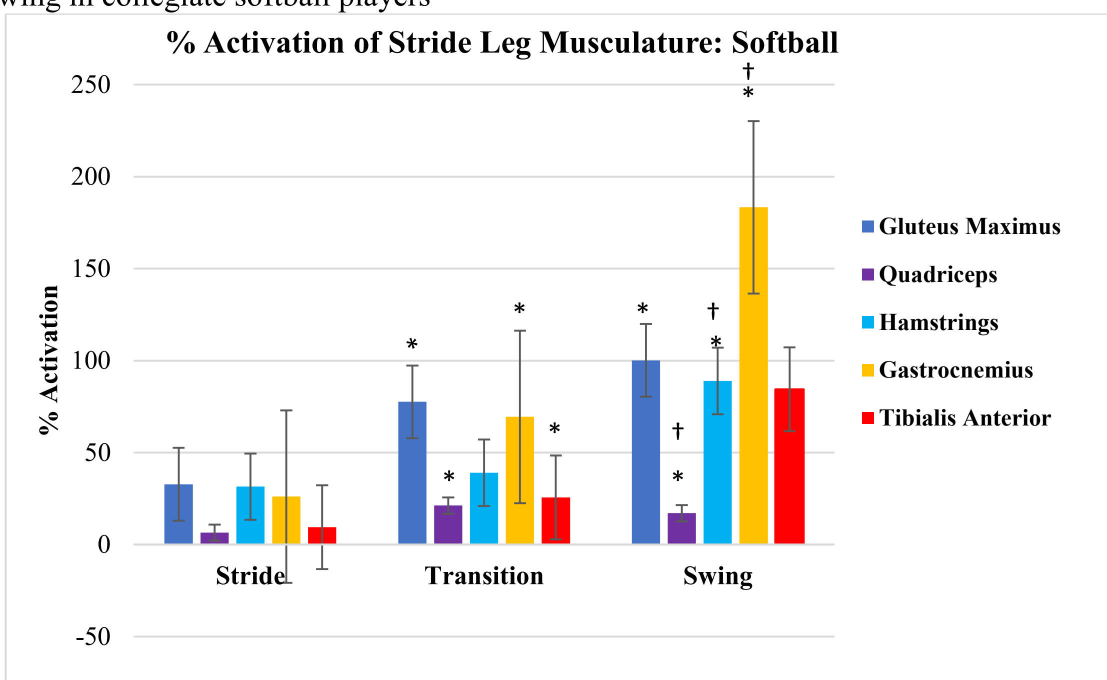
(*) Significant Difference (p<.05) across strike zone
(†) Different across entire strike zone (p<.05)
Post-hoc comparisons significant differences between (p<.05): [a] IC & IH, [b] IC &IL, [c] IC&MC [d] IC& ML, [e] IC&OH, [f] IC&OC, [g] IC &OL, [h] IL&IH, [i] IL&OC, [j] IL&OL, [k] MH&IH, [l] MH&MC [m] MH & ML ,[n] MH& OH, [o] MH& OC, [p] MH&OL [q] MC&IH [r] MC&ML [s] MC&OH [t] MC& OC [u] MC&OL [v] ML& IH [w] ML& OL

Figure 21. Changes in wrist angle at ball contact in various regions of the strike zone among collegiate softball players.



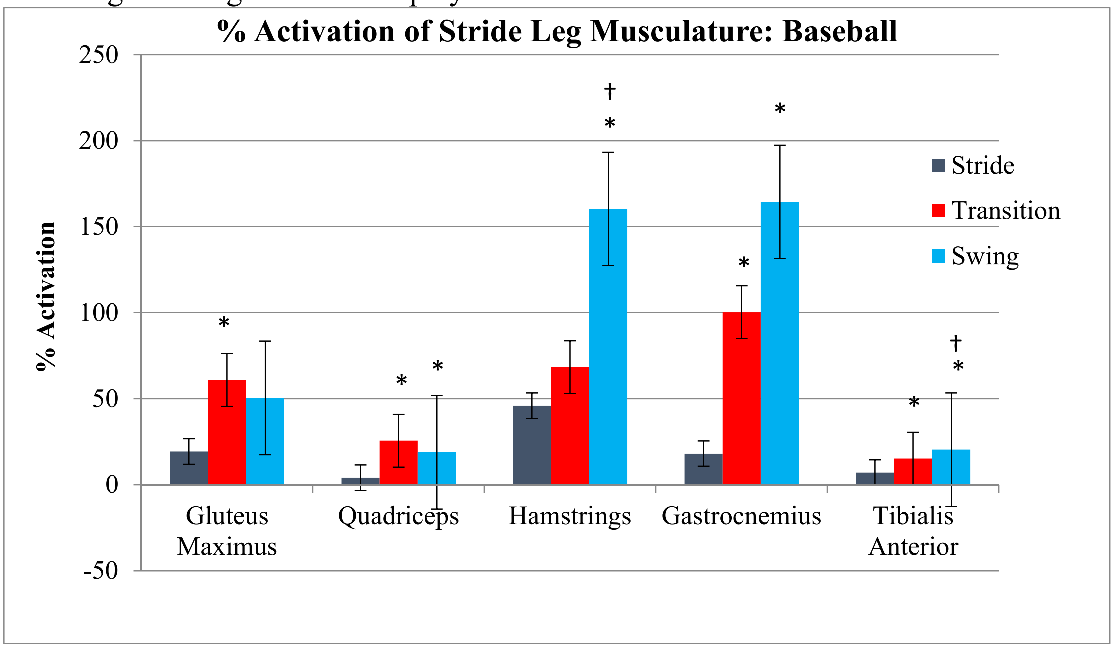
All values presented (p>.05)

Figure 22. Percent Activation of lower leg musculature of stride leg over the various phases of the swing in collegiate softball players



(*) Significant difference from stride phase (p<.05)
(†) Significant difference from transition phase (p<.05)

Figure 23. Percent Activation of lower leg musculature of stride leg over the various phases of the swing in collegiate baseball players



(*) Significant difference from stride phase (p<.05)
(†) Significant difference from transition phase (p<.05)

APPENDIX C: INFORMED CONSENT FORM

The University of Mississippi Institutional Review Board

Protocol # 18-011
Approval Date 09-20-17
Expiration date 09-19-18
Signature

Consent to Participate in Research

Study Title: Examining Changes in Bat Swing Kinematics in Different Areas of the Strike in Collegiate Baseball and Softball Players

Investigator
C. Caleb Williams, M.S., CSCS, USAW
Health, Exercise Science, Recreation Man.
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University, MS 38677
(352) 317-0544
ccwilli1@go.olemiss.edu

Faculty Sponsor
Martha Ann Bass, Ph.D.
Health, Exercise Science, Recreation Man.
232 Turner Center
PO Box 1848
University of Mississippi
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(662) 915-5563
mbass1@go.olemiss.edu

☐ By checking this box I certify that I am 18 years of age or older.

The purpose of this study

We want to determine how baseball swing changes after being exposed to a variety of weighted implements commonly used before on deck performance in baseball players.

What you will do for this study

The study requires 1 visit to the Applied Biomechanics Lab (Rm 240) at Turner Center. You will be asked to follow a brief orientation procedure presented by one of the investigators. The test will last no more than 2 hours. Exact procedures are addressed below:

1. Participants will fill out an informed consent before the experimental trial begins.
2. Investigators will check whether you meet the minimum standards for the study. If you do not fulfill the minimum standard, you will be dropped from the study and all information will be discarded immediately.
3. If you are eligible for the study, we will ask you be asked to use certain clothing for the study. Clothing will be provided by the Applied Biomechanics Lab.
4. We will obtain your height, weight, biological age and number of years engaging in physical activity.
5. Surface EMG signals will be recorded using sliver chloride electrodes on the following muscles (gluteus maximus, medial quadriceps, medial hamstrings, tibilias anterior, medial gastroc). For female participants, EMG electrode placement will be completed by a female co-investigator and supervised by a graduate faculty member.
6. Maximal voluntary isometric contractions will be completed on the aforementioned muscles.
7. Next, we will put reflective markers on your body to record your swing movements.

8. You will conduct a two-minute warm-up protocol composed of overhead and behind the back-stretching exercises to mimic a warm-up performed on deck before an at bat during a game.
9. After stretching, you will swing a standard softball bat five times.
10. You will then complete 15 maximal swings with a standardized bat after performing the general and on-deck warm-up. Rest periods will be set to 1 minute beginning at the end of the last warm-up swing. Swings with a standardized bat will be separated by 20 seconds to simulate time elapsed between pitches.
11. A ten-minute rest period will be provided after the 15th swing followed by another set of 15 maximal swing attempts in a randomized order after completion of their 2 minute on-deck WU. This process will continue until they have completed a total of 45 swings.

Videotaping / Audio-taping

We will record your movements while moving, by the motion capture system and a digital camera recording, which might consist of your face and/or body, for qualitative use only. This recording will be studied by the research team for use in the research project.

Time required for this study

This study will only have one session lasting no more than two hours

Possible risks from your participation

There is a risk however very unlikely of participants having an inversion ankle sprain when swinging a baseball bat. Considering participants in this study are collegiate baseball players and will be instructed by certified strength and conditioning specialists (CSCS) the risk of injury is minimal at best.

Benefits from your participation

This study can provide valuable information to both the player participating in this study as well as baseball and softball coaches. Information from this study can help sport coaches identify certain aspects of an individual's swing can be improved

Confidentiality

All information will be kept in a secure locked filing cabinet within the biomechanics lab. Data will also be protected via a secured desktop computer within the lab as well. Any information about you obtained from or for this research study will be kept as confidential (private) as possible. The records identifying your name will be (1) stored in a locked file cabinet and/or in a password-protected computer file, (2) kept separate from the rest of the research records, and (3) be accessible to only the researchers listed on the first page of this form and their staff. Your identity on the other research records will be indicated by a case number rather than by your name. You will not be identified by name in any publication of the research results unless you sign a separate form giving your permission (release).The key registry and identifiable videotapes will be destroyed after 2 years after the end of the study, which is expected to be spring semester, 2019).

Right to Withdraw
You do not have to volunteer for this study, and there is no penalty if you refuse. If you start the study and decide that you do not want to finish, just *tell the experimenter*. Whether or not you participate or withdraw will not affect your current or future relationship with the *Department of Health, Exercise Science and Recreation Management*, or with the University, and it will not cause you to lose any benefits to which you are entitled.

IRB Approval
This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions or concerns regarding your rights as a research participant, please contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all of your questions have been answered, you can inform us of your willingness to participate in the study or not.

Statement of Consent
I have read the above information. I have been given an unsigned copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

Signature of Participant ________________________________ Date __________

Printed name of Participant____

NOTE TO PARTICIPANTS: DO <u>NOT</u> SIGN THIS FORM

IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED

VITA

Charles Caleb Williams PhD, CSCS*D

Department of Health, Exercise Science and Recreation Management
The University of Mississippi
215 Turner Center, PO Bow: 1848
All American Drive, University, MS 38677
Email: ccwilli1@go.olemiss.edu
Cell Phone: (352) 317-0544

Education:

2014-Present	University of Mississippi Oxford, MS 38655	Pursing PhD in Kinesiology	**Anticipated Graduation Spring 2018**

Dissertation Title: Examining changes in bat swing kinematics in different areas of the strike zone in collegiate baseball and softball players

2012-2014	University of Pittsburgh Pittsburgh, PA 15260 (412) 624-4141	M.S. Health & Fitness	***Magna cum laude***
2010-2012	University of North Florida 1 UNF Drive Jacksonville Florida 32224 (904) 620-1000	B.S. Exercise Science	***Magna cum laude***
2008-2010	Florida Gateway College		***Overall GPA: 3.88***

University Employment History:

August 2014- Present	**Graduate Teaching Assistant/ Doctoral Student/ Applied Biomechanics Lab Student Researcher** Department of Health, Exercise Science and Recreation Management: University of Mississippi
August 2012- May 2014	**Graduate Teaching Assistant/ Graduate Student** Department of Health and Fitness: University of Pittsburgh

Curriculum Teaching Experience

The University of Mississippi: Courses were taught between Fall of 2014- Present

Undergraduate Courses

Primary Instructor

- **ES 447, Biomechanics Lab**
  An introductory course exposing students to concepts of mechanics as they apply to human movement- particularly those pertaining to exercise, sport, and physical activity.

Students obtain an understanding of the mechanical and anatomical principles that govern human motion and develop the ability to link the structure of the human body with its function from a mechanical perspective.

- **ES 446: Biomechanics of Human Movement (Guest Lectured): Applied Linear Kinetics**
  This course is designed to provide an introduction to the biomechanical principles of human movement. In addition to a basic understanding of forces, muscle mechanics, and material properties, the course also investigates static and dynamic analyses of motion, including kinetics and kinematics.

- **ES 402, Exercise Leadership**
  This course is an overview of educational concepts in leadership skills, exercise physiology, exercise technique and program design. This course allows students to the ability to implement strength and conditioning programs tailored towards an individual or group.

- **ES 396: Allied Health Terminology**
  This course offers an introduction to medical terms through an examination of their composition, focusing on prefixes, suffixes, word roots and their combined forms by review of each body system and specialty area. Use if this specialized language in a professional health care environment and in scholarly and professional writing is also emphasized.
- **ES 391, Trends and Topics in Exercise Science: Practical Skills in Strength and Conditioning**
  This course is designed to provide students with the knowledge base of how to properly structure and implement a program for a given clientele including athletic, recreational, and clinical populations. Students will also become proficient in how to properly perform and coach exercises within the field of strength and conditioning.

- **ES 346, Kinesiology**
  This course is designed to provide an advanced analysis of human functional anatomy, with primary emphasis being placed on the articular, skeletal, muscular, and nervous systems.

- **HP 203, First Aid CPR**
  This course acts as an introduction to safety instruction and practices as prescribed in the American Red Cross standards and advanced courses. Students learn to how to prevent accidents and to care for individuals in the event of an emergency. New methods of accident prevention, first aid techniques, and cardiopulmonary resuscitation (CPR) are taught with a hands-on approach.

- **HP 191, Personal and Community Health**

This course looks at health/wellness from various perspectives while covering topics such as cardiovascular fitness, resistance training, flexibility, nutrition, body composition, stress management and other present-day health care issues. Students learn to promote a healthier lifestyle for themselves and members of the community including the general layperson, recreational/active individuals and the organized athlete.

- **EL 151, Weightlifting**
  This course is designed to teach students basic lifting principles to minimize the risk of injury. Students will also perform exercises both aerobic and anaerobic in nature to maintain a lifetime of being physically active.

- **EL 124, Racquetball**
  An interactive activities course that is designed to teach the essential fundamentals and techniques of racquetball. Students are introduced to the history, rules/regulations, scoring, and basic strategy of the game.

- **ES 100, Introduction to Exercise Science (Guest Lectured)**
  An introduction to the faculty and courses in exercise science, with an emphasis on career planning and student development. Required for all exercise science majors during the first semester of program enrollment and recommended for anyone considering exercise science as a major.

Teaching Assistant

- **ES 446: Biomechanics of Human Movement**
  This course is designed to provide an introduction to the biomechanical principles of human movement. In addition to a basic understanding of forces, muscle mechanics, and material properties, the course also investigates static and dynamic analyses of motion, including kinetics and kinematics.

Co-Lab Research Director of the Applied Biomechanics Laboratory: Skills and equipment utilization

- Manage daily operations
- Manage and maintenance of laboratory equipment
- Research design and application
- Research design and application as primary investigator and assistant to full-time faculty members and other graduate students
- Utilizing 8 Vicon M2 cameras with a Vicon 612 Datastation (Vicon, Oxford, UK)
- Retroreflective markers (3M, St. Paul MN, USA)
- 3 force plates (Advanced Mechanical Technology, Inc., Watertown MA, USA)
- Competent in operating Power Plate Whole Body Vibration Platform (Performance Health Systems, Northbrook IL, USA)
- Competent in operating Dual-energy X-ray absorptiometry (DEXA)
- Neurocom® Equitest

Departmental Services

- Assist undergraduate students in selecting appropriate classes during group advising each semester.
- Undergraduate Independent Study Student Advisor
- Undergraduate Honor's Thesis Student Advisor: Mentored Mary Langford on Honor's Thesis Project: A Comparison of Warm-up Modalities on Upper Body Force Production Measures

The University of Pittsburgh Fall 2012-May 2014

Undergraduate Courses

Primary Instructor

- **PEDC 0340, Kettlebell and Conditioning**
  This class is designed to provide the student with a total body strength and cardiovascular workout utilizing kettle bell equipment and various strength and conditioning techniques. Emphasis is on circuit style or continuous training with the goal of progressively increasing the intensity and difficulty of the workout throughout the semester.

- **PEDC 0194, Sports Conditioning**
  This course includes sport specific training for a multitude of sports including plyometric, speed and agility training, resistance training and will incorporate different modes of aerobic training. This course focuses on how to train different types is related to the sport/event involved.

Assistant Instructor

- **HPA 1233, Principles of Strength and Conditioning**
  Instruction is provided describing the principles for development of pre-season, in-season and offseason strength and conditioning programs. Laboratory experiences will include the theory and techniques of operating strength training equipment.

The University of North Florida Fall 2010-May 2012

Undergraduate Courses

Assistant Instructor

- **APK 3115C, Practical Skills in Strength and Conditioning**
  Study of scientific principles and techniques related to strength and conditioning of the athletic population. Designed to provide a background for certification as a strengthening and conditioning specialist.

Professional Strength and Conditioning Presentations

- National Strength and Conditioning Association Mississippi State Clinic: Understanding Basic Joint Structure and Function of the Knee (Spring 2018)
- National Strength and Conditioning Association Mississippi State Clinic: Practically Implementing Concurrent and High Intensity Training within Sports Performance (Spring 2017)
- National Strength and Conditioning Association Mississippi State Clinic: Strength and Conditioning Considerations for the Female Athlete (Spring 2016)
- Olympic Strength Staff Lecture Series: Nutrition, Speed, and Agility Sessions, 3 Rivers ROTC Program, University of Pittsburgh (Fall 2012)

Research Funding

Gdovin, JR & Garner, JC
Kinematic Comparison of Cleat Type during Performance Movements
University of Mississippi Graduate Student Council Research Grant
Role: Graduate Research Assistant
Funding Request: $1000
Status: Funded, 2015-2016

Peer-Reviewed Journal Articles: Published/ Accepted: In Press

1. **Williams, CC**; Gdovin, JR; Wilson, SJ; Cazas-Moreno, VC; Eason, JD; Hoke, EL; Allen, CR; Garner, JC. The effects of various weighted implements on baseball swing kinematics in collegiate baseball players. Journal of Strength and Conditioning Research. (Accepted: In-Press), 2017
2. Wilson, SJ; **Williams, CC**; Gdovin, JR; Eason, JD; Chander, H; Wade, C; Garner, JC. The Influence of an Acute Bout of Whole Body Vibration on Human Postural Control Responses. Journal of Motor Behavior. Published online 23 October 2017: Pages 1-8
3. Allen, CA; Fu, YC; Cazás-Moreno, VC; Valliant, MW; Gdovin, JR, **Williams, CC**, Garner, JC. The effects of jaw clenching and a jaw alignment mouthpiece on force production. International Journal of Strength and Conditioning Research. (Accepted: In Press), 2017
4. **Williams, CC**, Gdovin JR, Allen, CR, Wilson, SJ, Cazás-Moreno, VL, Ossenheimer, C, Garner, JC. Strength and conditioning considerations for collegiate dance. Strength and Conditioning Journal April 38 (2): 88-95, 2016.
5. Cazás-Moreno, VC, Gdovin, JR, **Williams, CC**, Fu, YC, Allen, CR, Brown LE, Garner, JC. Influence of whole body vibration and specific warm-ups on force during an isometric mid-thigh pull. International Journal of Kinesiology and Sports Science. 3(4):31-39, 2015.

Peer-Reviewed Journal Articles: Under Review

1. Chander, H; Knight, AC; Garner, JC, Wade, C; Carruth, D; Wilson, SJ; Gdovin, JR; **Williams, CC**. Impact of Military Type Footwear and Load Carrying Workload on Postural Stability. Ergonomics (In-Review), 2017

2. Garner, JC, Wilson, SJ, Gdovin, JR, **Williams, CC**, Eason, JD, Hoke, EL, Chander, H, Williams, N, Wade, C. The Impact of Golf Specific Footwear on Human Balance. Journal of Sports Biomechanics. (In-Review), 2017
3. Gdovin, JR; **Williams, CC**; Wilson, SJ; Cazas-Moreno, VC; Eason, JD; Hoke, EL; Allen, CR; Chander, H; Wade, C; Garner, JC. The effects of athletic footwear on ground reaction forces during a side step cutting maneuver on artificial turf. Journal of Strength and Conditioning Research. (In-Review), 2017

Manuscripts in Preparation

1. **Williams, CC**; Godvin, JR; Wilson, SJ; Hill, CM; Luginsland, LA; Wade, C; Garner, JC. Changes in swing kinematics in collegiate softball players over a fall season. Journal of Strength and Conditioning Research (In-Preparation)
2. Gdovin, JR; Vicary, MK; **Williams, CC**; Wilson SJ; Chander, H; Wade, C; Garner, JC (2016). The effects of athletic footwear on ground reaction forces during a side step cutting maneuver in female collegiate soccer players (In-Preparation)

Abstracts/ Conference Presentations

1. Wilson SJ, Donahue PT, **Williams CC**, Hill CM, Luginsland LA, Waddell DE, Chander H, Garner JC. Lead Leg Recovery Responses Between Individuals Who Fall and Recover After an Unexpected Slip. *42nd American Society of Biomechanics (ASB) Annual Meeting*, Rochester, MN, USA.August 8-11 2018. *(In-Review)*
2. Garner JC, Donahue PT, **Williams CC**, Hill CM, Luginsland LA, Waddell DE, Chander H, Wilson SJ. Postural Control Measures Between Individuals Who Fall and Recover After an Unexpected Slip. *42nd American Society of Biomechanics (ASB) Annual Meeting*, Rochester, MN, USA. August 8-11 2018. *(In-Review)*
3. Hill CM, Wilson SJ, Mouser JG, Donahue PT, **Williams CC**, Chander H. Repeated Motor Control Testing Decreases Co-Contraction Index in Healthy Young Adults. *42nd American Society of Biomechanics (ASB) Annual Meeting*, Rochester, MN, USA. August 8-11 2018. *(In-Review)*
4. Hill CM, Wilson SJ, Mouser JG, **Williams CC**, Luginsland LA, Donahue PT, Chander H. Impact Of Repeated Balance Perturbations On Lower Extremity Mean Muscle Activity. Mid-south Biomechanics Conference , Memphis TN. February 22-23 2018.
5. **Williams, CC**; Gdovin JR; Wilson SJ; Hill CM; Donahue, PT; Luginsland LA; Eason JD; Yarbrough AL; Wade C; Garner JC. Examining changes in bat angle at ball contact in collegiate softball players over a fall softball season. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, Tennessee February 15-17th 2018
6. Luginsland LA, **Williams CC**, Gdovin JR, Wilson SJ, Donahue PT, Hill CM, Eason JD, Yarbrough AL, Wade C, Garner JC. *Changes in Bat Angle at Maximal Velocity in Collegiate Softball Players.* Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.

7. Donahue PT, Wilson SJ, **Williams CC**, Hill CM, Luginsland LA, and Garner JC. Positional Differences In Peak Power During Countermovement Vertical Jump In Professional Baseball Pitchers. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
8. Hill CM, Wilson SJ, Mouser JG, **Williams CC**, Luginsland LA, Donahue PT, Chander H. Impact Of Repeated Balance Perturbations On Lower Extremity Mean Muscle Activity. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
9. Wilson SJ, Hill CM, Mouser JG, **Williams CC**, Luginsland LA, Donahue PT, Garner JC, Chander H. Can Postural Responses Be Learned? Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
10. Garner JC, Hill CM, Wilson SJ, Mouser JG, **Williams CC**, Luginsland LA, Donahue PT, Chander H. Influence of Repeated Motor Control Tests on Proximal Lower Extremity Musculature Activation. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Chattanooga, TN. February 15-17 2018.
11. **Williams CC,** Gdovin JR, Wilson SJ, Hill CM, Luginsland LA, Eason JD, Smidebush MM, Yarbrough AL, Wade C, Garner JC. Changes in swing kinematics in collegiate softball players over a fall softball season. NSCA Annual Meeting, Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
12. Hill CM, **Williams CC,** Gdovin JR, Wilson SJ, Eason JD, Hoke EL, Donahue PT, Wade C, Garner JC. The effects of various weighted implements on perception and bat angle in collegiate baseball players. NSCA Annual Meeting, Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
13. **Wilson SJ**, Gdovin JR, Williams CC, Eason JD, Luginsland LA, Hill CM, Donahue PT, Hoke EL, Chander H, Garner JC. More Than a Foot Wedge – Golf Footwear and Postural Control. *NSCA Annual Meeting,* Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
14. Donahue PT, Jackson, PM, Wilson SJ, Gdovin JR, **Williams CC**, Luginsland LA, Hill CM, Studzinski DL, Guarascio JJ, Garner JC. Effect of Offseason Training on Countermovement Jump Velocity in Division I Football Athletes. NSCA Annual Meeting, Las Vegas, NV. July 12-15. National Strength and Conditioning Association.
15. **Williams CC**, Wilson SJ, Gdovin JR, Eason JD, Hoke EL, Luginsland LA, Hill CM, Donahue PT, Davis RE, Chander H, Wade C, Garner JC. The influence of golf specific footwear on whole body reaction times. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
16. Luginsland LA, Wilson SJ, Gdovin JR, **Williams CC,** Eason JD, Hoke EL, Hill CM, Donahue PT, Davis RE, Chander H, Wade C, Garner JC. The Acute Influence of Golf Specific Footwear on Balance Equilibrium Scores. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
17. Wilson SJ, Gdovin JR, **Williams CC,** Eason JD, Hoke EL, Luginsland LA, Hill CM, Donahue PT, Davis RE, Chander H, Wade C, Garner JC. The Effects of Golf Specific Footwear on Human Balance. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.

18. Hoke EL, Wilson SJ, Gdovin JR, **Williams CC**, Eason JD, Luginsland LL, Hill CM, Donahue PT, Chander H, Wade C, Green M, Garner JC. Acute effects of gold specific footwear on bilateral balance. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
19. Eason JD, Wilson SJ, Gdovin JR, **Williams CC**, Hoke EL, Luginsland LA, Hill CM, Donahue PT, Chander H, Wade C, Garner JC. The effects of golf shoe type on balance equilibrium scores. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18, 2017.
20. Gdovin JR, Wilson SJ, **Williams CC,** Eason JD, Hoke EL, Luginsland LA, Hill CM, Donahue PT, Davis RE, Chander H, Wade C, Garner JC. The acute effects of golf specific footwear on reaction time latencies. Southeast Chapter of the American College of Sports Medicine (SEACSM) Annual Meeting, Greenville, SC. February 16-18 2017.
21. **Williams CC,** Dabbs NC, Gdovin JR, Wilson SJ, Cazas-Moreno VL, Eason JD, Hoke EL, Fu YC, Wade C, Garner JC. The effects of various weighted implements on baseball swing kinematics in collegiate baseball players. NSCA Annual Meeting, New Orleans, LA. July 6-9. National Strength and Conditioning Association
22. Gdovin JR, **Williams CC**, Wilson SJ, Cazás-Moreno VL, Eason JD, Hoke EL, Fu YC, Wade C, Garner JC. The effects of American football cleats and soccer cleats on vertical jump performance. American Society of Biomechanics (ASB) Annual Meeting, Raleigh, NC. August 2-5 2016.
23. Wilson SJ, Gdovin JR, **Williams CC**, Eason JD, Chander H, & Garner JC. Applications of Whole Body Vibration: Are Spinal Modifications Playing a Role? 40th Annual Meeting of the American Society of Biomechanics, Raleigh, NC, August 2-5, 2016.
24. Eason JD, Wilson SJ, Gdovin JR, **Williams CC**, Hoke EL, Chander H, & Garner JC. Effects of whole body vibration on maximal voluntary isometric contraction and percent muscle activation during balance perturbations. 40th Annual Meeting of the American Society of Biomechanics, Raleigh, NC, August 2-5, 2016.
25. VL. Cazás-Moreno, JR Gdovin, **CC. Williams**, SJ Wilson, JC. Garner. Effects of lower body isometric strength after various warm-up protocols. SEACSM Annual Meeting, Greenville, SC. February 18-20, 2016. Southeast Chapter of the American College of Sports Medicine.
26. JR. Gdovin, H. Chander, C. Wade, SJ. Wilson, VL. Cazás-Moreno, **CC. Williams**, JC. Garner. Occupational footwear's effects on balance. SEACSM Annual Meeting, Greenville, SC. February 18-20, 2016. Southeast Chapter of the American College of Sports Medicine
27. **Williams CC.**, H. Chander, C. Wade, SJ. Wilson, VL. Cazás, JR. Gdovin, JC. Garner. Footwear design characteristic's impact on lower extremity muscle activity. SEACSM Annual Meeting, Greenville, SC. February 18-20, 2016. Southeast Chapter of the American College of Sports Medicine
28. Moreno-Cazas VL, Gdovin JR, Fu YC, **Williams CC**, Allen CR, Garner JC. The influence of an isometric warm-up and whole-body vibration on the rate of force development during an isometric clean pull. National Strength and Conditioning Association (NSCA) Annual meeting, Orlando, FL, July 7-11, 2015.
29. Gdovin JR, Moreno-Cazas VL, Fu YC, **Williams CC**, Allen CR, Garner JC. The influence of an isometric warm-up and whole-body vibration on power during an

isometric clean pull. National Strength and Conditioning Association (NSCA) Annual meeting, Orlando, FL, July 7-11, 2015.

30. **Williams, CC**, Moreno-Cazas VL, Fu YC, Gdovin JR, Allen CR, Garner JC. The influence of an isometric warm-up and whole-body vibration on peak force during an isometric clean pull. National Strength and Conditioning Association (NSCA) Annual meeting, Orlando, FL, July 7-11, 2015.
31. Moreno-Cazas VL, Chander, H, Allen, CR, Gdovin JR, **Williams CC**, Garner JC,. The influence of whole-body vibration on rate of force development during an isometric clean pull. SEACSM Annual Meeting, San Diego, CA, May 26-30, 2015. Medicine and Science in Sports and Exercise.
32. Moreno-Cazas VL, Chander, H, Allen, CR, Gdovin JR, **Williams CC**, Garner JC. The influence of whole-body vibration on rate of force development during an isometric clean pull. SEACSM Annual Meeting, Jacksonville, FL. February 12-14, 2015. Southeast Chapter of the American College of Sports Medicine.
33. Magyari PM, **Williams CC**, Anton M, Johnson C. Gender Effects on Dynamic Resistance Exercise. Med Sci Sports Exer. 44(5S):596, 2013.
34. M. Anton, C. Johnson, C**C. Williams** andP. Magyari.(2013). Variability in Resistance Training Repetitions Achieved at Specific Workloads by Gender. American College of Sports Medicine Southeast Regional Conference, Greenville, S.C.
35. **Williams CC.** and Peter Magyari (Faculty Mentor). (2012). Variability in Resistance Training Repetitions Achieved at Specific Workloads. Poster Presentation. American College of Sports Medicine Southeast Regional Conference. Undergraduate Student Research Competition, Jacksonville, FL.
36. Magyari PM and **Williams CC**. Impact of Load on Resistance Training Circuit Volume and Energy Expenditure. *Med Sci Sports Exer*. 44(5S):863, 2012.
37. Wight, J.T., **Williams, CC**., Magyari, P.M. (2012). Does the number of repetitions achieved for the bench press predict the number of repetitions achieved for other common resistance training exercises? Annual Meeting of the American Society of Biomechanics, Gainesville, FL.
38. **Williams CC.** and Peter Magyari (Faculty Mentor). (2011). Resistance Training Repetition Variability at Specified Intensities. Florida Statewide Student Research Symposium.
39. **Williams CC.** and P. Magyari (Faculty Mentor). (2011). Variability in Resistance Training Repetitions Achieved at Specific Workloads. 10th Annual Scholars Transforming Academic Research Symposium (STARS). Jacksonville, FL.
40. **Williams CC**& Magyari P (Faculty Mentor). (2011). Resistance Training Repetition Variability at Specified Intensities. Brooks College of Health Faculty and Student Research Poster Presentation Day.

Research Collaborations

- Missouri State University, Department of Kinesiology
- Troy University, Department of Kinesiology and Health Promotion
- Mississippi State University, Department of Kinesiology
- University of North Florida, Department of Exercise Science

Academic Accomplishments/Awards

- Received Ryan Malone Memorial Assistantship: University of Mississippi Fall 2014-Present
- Earned Graduate Teaching Assistantship: University of Pittsburgh Fall 2012- May 2014
- Graduated Magna Cum Laude from the University of Pittsburgh
- Graduated Magna Cum Laude from the University of North Florida
- Nominated for the University of North Florida "Senior Service Award"
- UNF Presidents list 2 semesters
- UNF Dean's list 2 semesters
- Spring 2011: Awarded Florida Transfer Scholarship
- Fall 2008: Awarded Florida Bright Future Scholarship
- Fall 2008: Awarded Esther King Memorial Scholarship

Strength and Conditioning Coaching Experience:

Volunteer Assistant Strength and Conditioning Coach
University of Mississippi: August 2014-Present
Supervisor: Chas Ossenheimer, Ben Fleming: Assistant Strength and Conditioning Coaches

- Work with strength staff implementing programs for Baseball, Softball, Volleyball, and Rebelette Dance

Graduate Strength and Conditioning Intern
Carnegie Mellon University: January 7, 2014- May 2014
Supervisor: Alan DeGennaro Head Strength and Conditioning Coach

- Work with strength staff implementing programs for various sports teams.

Graduate Strength and Conditioning Intern
University of Pittsburgh: August 2012-December 13, 2013
Supervisors: Kim King Olympic Director/ Tim Beltz Head Basketball Strength and Conditioning

- Work with the Olympic Strength Staff implementing programs for 16 sports

Strength and Conditioning Intern
University of Tennessee: May 2012-July 31st, 2012
Supervisor: Ron McKeefery Director of Strength and Conditioning

- Helped Administer Strength and Conditioning Summer Football Program

Strength and Conditioning Intern
University of Florida: May 2011- August 2011
Supervisor: Paul Chandler Assistant Strength and Conditioning Coach

- Helped Administer Strength and Conditioning Summer Programs for Football, Baseball, Volleyball, and Track and Field

Student Assistant Strength Coach

University of North Florida: May 2010-May 2012
Supervisor: Wesley Brasseal Head Strength and Conditioning Coach

- Helped Administer and Implement Strength and Conditioning Programs for 17 sports
- Designed and Implemented Programs for Cross Country, Swimming & Diving, Track and Field (Throwers, Vaulters)

Assistant Weightlifting Coach
Union County High School: Lake Butler, Florida: January 2009-May 2010
Supervisor: Andrew Zow

- Designed and implemented weightlifting programs for high school strength athletes competing in Olympic and Powerlifting movements.

<u>Professional Memberships</u>

- Professional Member for the National Strength and Conditioning Association:(Spring 2012- Present)
- State of Mississippi Student Representative for the National Strength and Conditioning Association: (Spring 2016- Present)
- Member of Southeast American College of Sports Medicine: (Spring 2015-Present)

<u>Certifications:</u>

National Strength and Conditioning Association
Certified Strength and Conditioning Specialist: May 2012-Present
Certification #: 7247820638

American Red Cross/ First Aid
Instructor Certified: Spring 2015- Present

American Red Cross Association
CPR/AED Healthcare Provider 2009-Present

<u>Relevant Coursework</u>

The University of Mississippi

<u>Biomechanics</u>:

- ES 632 Advanced Structural Kinesiology
- ES 620 3D Kinematics/Kinetics Modeling
- ES 612 Instrumentation and Analysis in Biomechanics
- ES 609 Motor Control and Learning
- ES 548 Biomechanics of Injury
- ES 512 Foundations of Biomechanics

<u>Exercise Physiology</u>:

- ES 620 Selective Topics in Exercise Science - Strength and Conditioning
- ES 618 Advanced Muscle Physiology
- ES 611 Exercise Physiology I

Statistical Coursework:

- PHAD 795 Special Topics in Pharmacy Administration: Longitudinal Modeling
- PHAD 781 Applied Multivariate Analysis (Audit)
- PHAD 780 General Linear Modeling
- PSY 704 Quantitative Methods in Psychology II
- HP 626 Statistical Analysis I

Additional Coursework:

- HP 695 Human Health and Illness
- ES 652 Advanced Individual Study: Changes in softball swing kinematics over a fall season
- NHM 619 Sports Nutrition

Athletic Experience:

Olympic Weightlifter and Powerlifter: 2008-Present