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DIFFERENCES IN THE MUSCLE ACTIVITY FOR BASEBALL HITTERS OF VARYING SKILL

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Ethan M. Stewart, Student

Dr. Robert Shapiro, Major Professor

Dr. Heather Erwin, Director of Graduate Studies
DIFFERENCES IN THE MUSCLE ACTIVITY FOR BASEBALL HITTERS OF VARYING SKILL

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Education at the University of Kentucky

By

Ethan Michael Stewart
Lexington, Kentucky

Advisor: Dr. Robert Shapiro, Professor of Kinesiology

Lexington, Kentucky

2017

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ABSTRACT OF THESIS

DIFFERENCES IN THE MUSCLE ACTIVITY FOR BASEBALL HITTERS OF VARYING SKILL

INTRODUCTION: Muscle activity and timing of the swing phases may contribute to the differences we see in athletes at different skill levels. The purpose of this study is to analyze the differences between mean muscle activity, peak muscle activity and time to peak muscle activity for select muscles in the lower extremity as well as the differences between start times for swing phases and bat velocity prior to impact for a skilled and recreational group. METHODS: Twelve healthy subjects were split into two groups based on competitive level and analyzed hitting off of a tee. RESULTS: No significant differences were seen between muscle activity or the start time for the landing and swinging between groups. The skilled group did have a faster time to peak muscle activation for the front leg biceps femoris (p = 0.024), start the shifting (p = 0.12) and stepping (p = 0.11) phases significantly earlier as well as had a higher bat velocity prior to ball contact (p = 0.42) than the recreational group. CONCLUSION: Mean and peak muscle activity trends to be lower for skilled hitters than recreational hitters. Evidence of the skilled group starting the shifting and stepping phase earlier as well as having a higher bat velocity prior to impact could be important in separating hitters into skill level.

KEYWORDS: Baseball, Electromyography, Biomechanics, Lower Extremity, Hitting

Ethan Stewart
July 27th, 2017
DIFFERENCES IN THE MUSCLE ACTIVITY FOR BASEBALL HITTERS OF VARYING SKILL

By
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Dr. Robert Shapiro
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July 27, 2017
ACKNOWLEDGEMENTS

The following thesis is individual work; however, it did benefit from several individuals. First, my thesis chair, Dr. Robert Shapiro, helped to guide me every step of the way. He was able to provide feedback throughout the entire process and the completion of this project would not have been possible without him. Next, I would like to thank the other members of my committee: Dr. Timothy Butterfield and Dr. Ben Johnson. They were both available to answer any questions and provide feedback that proved crucial to the completion of the final product. Finally, I would like to thank anyone who assisted with data collections or processing, specifically Megan Smidebush. This project would not have been completed without their help.
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CHAPTER ONE: INTRODUCTION

The introduction section provides background information about the topic of baseball hitting and muscle activity. It provides justification for the importance of the study.

Introduction

Baseball batting has been defined as the most difficult skill in sports with a thirty percent success rate considered elite performance (3, 8, 22). The success rate of batting depends on the player’s ability to use spatial and temporal information to hit the ball on the “sweet spot” of the bat (22). During the course of a game, the pitcher will use an assortment of pitches to test the batter’s ability to use that spatial and temporal data to successfully contact the ball.

There are multiple measurements that have been used to analyze the swing including ground reaction forces (GRF) (9, 15, 21, 32), movement kinematics and kinetics (4, 5, 7, 8, 13, 14, 18, 19, 21, 24, 27, 32) and surface electromyography (sEMG) (17, 22, 23, 26). Dowling and Flesig (5) found that higher level hitters have significantly higher bat velocities when compared to youth hitters. In 1986, Hirano (13) was able to differentiate between hitters of different skill by finding that the higher skilled hitters had a higher bat velocity just prior to impact when compared to their lesser skilled counterpart. Inkster et al. (14) was able to differentiate between skill levels for twenty sub elite baseball hitters. Splitting the hitters into two groups of ten based on three qualified coaches’ ratings and batting average, it was found that the skilled group exhibited a significantly higher bat velocity.
Using sEMG, Kitzman (17) looked at six muscles from the upper extremity and trunk, but no muscles of the lower extremity, for two skilled vs unskilled hitters. Based on the findings of his study, Kitzman suggested that strengthening the triceps brachii of the lead arm would increase force transfer to the bat. Broer et al. (2) investigated seventeen upper extremity, fourteen lower extremity and three trunk muscles in one unskilled hitter. Their findings suggested that the abdominal muscles are important for trunk stabilization. Kauffman et al. (16) using four collegiate baseball players looked at the biceps and triceps activity and were unable to show the advantage of swinging with a weighted bat. Shaffer et al. (26) investigated twelve muscles in the lower extremity, upper extremity and trunk of eighteen professional baseball players to find percentage of MMT (maximum muscle test) at specific points in the swing and concluded that the lower extremity was important for generating the power during the swing. Nakata et al. (22) has the most comprehensive lower extremity sEMG study. Using ten skilled and ten novice baseball players, Nakata et al. (22) looked at the Rectus Femoris (RF), Biceps Femoris (BF), Tibialis Anterior (TA) and Medial Gastrocnemius (MG) of both the lead and back leg. Nakata et al. (22) found differences in peak muscle activation between the lead leg RF, BF and MG as well as back leg BF, TA and MG for the two groups. It was also found that skilled players started the shifting, stepping and landing phases significantly earlier than the novice group while starting the swinging phase significantly later. Nakata et al. (22) while comparing groups did not look at the time it took to get to the peak muscle activation. With the knowledge of muscle activity, time to peak muscle activity, start time of swing phases, and bat velocity prior to impact differences in skill level, it could be possible to further train baseball players of lesser skill.
Previous research has shown that there are differences in peak muscle activity in the lower extremity and start times for the swing phases for novices and skilled baseball hitters. Previous research has also shown that hitters of varying skill level have a significantly different bat velocity just prior to ball contact with the higher skilled hitters being faster. Therefore, the purpose of this study is to investigate differences in peak muscle activity, mean muscle activity, time to peak muscle activity, start time for the swing phases, and bat velocity prior to impact between hitters who currently play or previously played at the varsity collegiate level versus players who play recreationally and never at the collegiate varsity level. It is hypothesized that the skilled group will have higher values for the peak muscle activity, and bat velocity prior to impact while also starting the shifting, stepping, and landing phase earlier and swinging phase later than the recreational group. With no previous research being reported on mean muscle activity or time to peak muscle activity we hypothesize that there will be differences with the skilled group having higher mean muscle activity and getting to their peak muscle activity earlier.
CHAPTER TWO: METHODOLOGY

The methodology section provides information on the specific steps conducted to complete the study. Information regarding research design, participants, data collection procedures, instruments used and statistical analysis are all contained in this section. These steps are crucial in the investigation of mean and peak muscle activity, time to peak muscle activity, start time for swing phases, and bat velocity between groups.

Experimental Design

This study was a laboratory based, two-group, prospective-observational study. The independent variable was skill level. The dependent variables included peak muscle activation, mean muscle activation, and time to peak muscle activation for the six muscles tested, start time for the swing phases and bat velocity prior to ball contact.

Participants

Participants were recruited using a convenience sample of the university area. Physical flyers as well as word of mouth were utilized as means to recruit subjects. Participants had to be between the ages of 18-30 years and competitively active in baseball during the year. Skilled subjects were defined as those that currently compete or previously competed at the varsity collegiate level (NCAA or NAIA) while recreational players were those who play baseball competitively but never on the collegiate varsity level. Subjects were excluded from the study if they were experiencing any pain that would hinder them from playing baseball competitively, had experienced an injury that has hindered them from playing baseball in the last three months, or if they were not comfortable swinging a bat inside of the laboratory setting. Twelve subjects were included in this study with six subjects in the skilled group (25.83 ± 3.06 years, 1.78435
± 0.07 m, 91.78 ± 3.58 kg) and six subjects in the recreational group (21.5 ± 2.17 years, 
1.75 ± 0.03 m, 81.55 ± 8.01 kg).

Procedures

Participants were required to come to the lab for one visit for this study. All 
subjects, when qualified to participate, had the data collected over a single session in the 
laboratory.

Testing Session

As participants arrived to the Biodynamics Laboratory, the procedures involved 
during the study were explained prior to their data collection. All participants were asked 
to read and sign an informed consent form approved by the Institutional Review Board at 
the University of Kentucky. Basic demographic data including age, height, weight, sex 
and current competitive level was acquired before any testing began and a physical 
activity readiness questionnaire (PAR-Q) was filled out to ensure the subject’s ability to 
participate.

Maximum Voluntary Isometric Contraction Testing

An MVIC for each muscle being studied was obtained for each subject prior to 
completing the swing analysis. Each subject had bipolar surface electrodes placed over 
the lead leg biceps femoris, tibialis anterior and medial gastrocnemius as well as the 
back-leg rectus femoris, biceps femoris and medial gastrocnemius. A ground electrode 
was placed over the patella. Prior to electrode placement, the skin was shaved and 
cleansed to decrease electrical impedance. After placement of the electrodes, muscle 
specific tests were conducted to find the MVIC. Each MVIC test consisted of one
familiarization test followed by three actual trials. The table below shows the muscles tested, location for electrode placement and the test to calculate MVIC based on SENIAM guidelines (12).

**Table 1.1:** List of muscles tested, placement of electrodes and specific test to obtain MVIC.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Location of Surface Electrode</th>
<th>MVIC Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrocnemius</td>
<td>Electrodes need to be placed at the 1/3 of the line between the head of the fibula and the heel.</td>
<td>Plantar flexion of the foot with emphasis on the pulling the heel upward more than pushing the forefoot downward.</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>The electrodes need to be placed at ½ of the line between the ischial tuberosity and the lateral epicondyle of the tibia.</td>
<td>Leg curl against resistance at the ankle.</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>The electrodes need to be placed at 1/3 of the line between the tip of the fibula and the tip of the medial malleolus.</td>
<td>Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot in inversion without extension of the great toe.</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>The electrodes need to be placed at ½ of the line from the anterior spina iliaca superior to the superior part of the patella.</td>
<td>Leg extension with resistance above the ankle.</td>
</tr>
</tbody>
</table>

Swing Analysis

Prior to performing the swing analysis, each participant was fitted with standardized neutral running shoe (Nike, 602171404, Beaverton, OR) to wear for the entire data collection. Participants were then fitted with twenty-five retro-reflective markers on the following landmarks: right and left ASIS & PSIS, right and left medial &
lateral knee, right and left medial & lateral malleoli, right and left lateral heel, right and left proximal & distal heel, right and left 1st & 5th metatarsal head, right and left toe, and an offset marker on the right foot. In addition, rigid body clusters of 5 markers was placed on the right thigh, while rigid body clusters of 4 markers were placed on the right shank, and left thigh and shank. The bat was fitted with two markers while the ball was fitted with retro-reflective tape to serve as a marker.

The swing analysis was completed using two force plates (Bertec, Columbus, OH) recording at 1000 Hz, 6 Eagle and 4 Raptor Motion Analysis cameras (Motion Analysis Corp, Santa Rosa, CA) recording at 200 Hz, and six surface electromyography sensors (Delsys, 6480731, Natick, MA) recording at 1000 Hz. A static image of each participant was captured to identify the anatomical locations of the markers. After a warm-up period with 10 swings to become acclimated to the lab, participants were instructed to swing five times while marker trajectory, force, and sEMG data were collected.

The swing was broken down into seven phases: waiting, shifting, stepping, landing, swinging, impact and follow-through. The waiting phase was defined as the time before the shifting phase. The shifting phase was defined as the point in which the back-leg rectus femoris activity increased three standard deviations from the baseline. The stepping phase was defined as the point in which the front foot left the ground and when it returned, the landing phase began. The swinging phase was defined as the point in which the bat started to move downward toward the ball, impact occurred at ball contact and follow-through for one second after contact.
Data Processing

Marker trajectory data was tracked using Cortex software (Motion Analysis Corp., Santa Rosa, CA). Data processing including filtering and calculating joint/segment angles was conducted using Visual 3D software (C-Motion Inc., Germantown, MD). Raw marker trajectory data were filtered using a fourth order low-pass Butterworth filter with a cut-off frequency of 13 Hz. An X-Y-Z cardan sequence (sagittal-frontal-transverse) was used to quantify joint angles, in which the distal segment is expressed relative to the proximal segment. All sEMG data were filtered using Noraxon myoRESEARCH 3.10 (Noraxon U.S.A. Inc., Scottsdale, AZ). Raw sEMG signal were filtered using a finite impulse response with 101 points using Hamming window and smoothed with a root-mean-square moving average of 10 ms per window. MVIC values were obtained using a 100 ms window to find the highest average of each trial and averaging them together. sEMG data obtained during the swing were analyzed to find the peak and mean muscle activity using the MVIC obtained for each muscle of each specific subject for three swings and then averaged. Time to peak muscle activity from the start of the shifting phase were found using the peak muscle activity and relating it to ball contact. Data were then averaged for each group to compare.

Statistical Analysis

Peak muscle activity, mean muscle activity, time to peak muscle activity and start time for swing phases and bat velocity were all compared between groups using independent samples t-test. Multiple correlation analyses were run to look at correlation between mean muscle activity and bat velocity as well as peak muscle activity and bat
velocity. All statistical analysis were performed using SPSS statistical software (SPSS Inc., Chicago, IL) with a significance level of $p < 0.05$. 
CHAPTER THREE: RESULTS

The results section presents the findings of the study, including ANOVAs, independent t-tests, and correlation analyses that were conducted on the data collected. The results give insight into differences that could exist between mean and peak muscle activity, time to peak muscle activation, start time for swing phases and bat velocity.

Results

Mean values and standard deviations for the mean muscle activity for each muscle in each group can be found in Table 3.1. All data are presented in terms of %MVIC. The independent samples t-test comparing mean muscle activity between skill groups, see Table 3.2, found there were no statistically significant differences between groups. A visual representation of the differences seen between the means for mean muscle activity between groups can be found in Figure 3.1. Although no significant differences were seen, five of six muscles tested were active less in the skilled group than the recreational group.

Table 3.1: Mean muscle activity (Mean ± SD) for all six muscles tested for each group.

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Recreational</th>
<th>Skilled</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris (MVIC)</td>
<td>43.48 ± 9.86</td>
<td>33.53 ± 9.87</td>
<td>0.111</td>
</tr>
<tr>
<td>Gastrocnemius (MVIC)</td>
<td>49.49 ± 9.36</td>
<td>33.67 ± 17.80</td>
<td>0.083</td>
</tr>
<tr>
<td>Tibialis Anterior (MVIC)</td>
<td>32.18 ± 11.59</td>
<td>32.37 ± 10.93</td>
<td>0.977</td>
</tr>
<tr>
<td><strong>Back Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris (MVIC)</td>
<td>31.43 ± 8.65</td>
<td>21.01 ± 8.12</td>
<td>0.057</td>
</tr>
<tr>
<td>Gastrocnemius (MVIC)</td>
<td>47.09 ± 8.05</td>
<td>36.67 ± 16.28</td>
<td>0.190</td>
</tr>
<tr>
<td>Rectus Femoris (MVIC)</td>
<td>60.37 ± 20.88</td>
<td>37.16 ± 29.59</td>
<td>0.148</td>
</tr>
</tbody>
</table>
Table 3.2: Independent samples t-test table for mean muscle activity from SPSS.

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Front Leg Biceps Femoris</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.263</td>
<td>.618</td>
<td>1.747</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>1.747</td>
</tr>
<tr>
<td>Front Leg Gastrocnemius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>4.12</td>
<td>.070</td>
<td>1.927</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>1.927</td>
</tr>
<tr>
<td>Front Leg Tibialis Anterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.006</td>
<td>.942</td>
<td>-.029</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>-0.029</td>
</tr>
<tr>
<td>Back Leg Biceps Femoris</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.001</td>
<td>.975</td>
<td>2.153</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>2.153</td>
</tr>
<tr>
<td>Back Leg Gastrocnemius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>2.88</td>
<td>.121</td>
<td>1.405</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>1.405</td>
</tr>
<tr>
<td>Back Leg Rectus Femoris</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>1.570</td>
</tr>
</tbody>
</table>
Figure 3.1: Graph of mean muscle activity for all six muscles tested for each group.

Mean values and standard deviations for the peak muscle activity for each muscle in each group can be found in Table 3.3. All data are presented in terms of % MVIC. The independent samples t-test comparing peak muscle activity between skill groups, see Table 3.4, found there were no statistically significant differences between groups. A visual representation of the differences seen between the means of peak muscle activity between groups can be found in Figure 3.2. Although no significant differences were found, five of six muscles were found to be active less in the skilled group.
Table 3.3: Peak muscle activity (Mean ± SD) for all six muscles tested for each group.

<table>
<thead>
<tr>
<th></th>
<th>Recreational</th>
<th>Skilled</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>126.80 ± 47.02</td>
<td>120.52 ± 72.76</td>
<td>0.863</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>144.43 ± 35.54</td>
<td>96.95 ± 41.85</td>
<td>0.060</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>97.68 ± 47.68</td>
<td>109.78 ± 43.14</td>
<td>0.655</td>
</tr>
<tr>
<td><strong>Back Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>123.20 ± 39.86</td>
<td>87.94 ± 22.79</td>
<td>0.089</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>139.06 ± 23.71</td>
<td>102.06 ± 37.13</td>
<td>0.067</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>158.78 ± 62.75</td>
<td>93.62 ± 86.32</td>
<td>0.166</td>
</tr>
</tbody>
</table>

Table 3.4: Independent samples t-test table for peak muscle activation from SPSS.

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of ...</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td><strong>Front Leg Biceps Femoris</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.422</td>
<td>.531</td>
<td>.178</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td>.178</td>
</tr>
<tr>
<td><strong>Front Leg Gastrocnemius</strong></td>
<td>.292</td>
<td>.601</td>
<td>2.118</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td>2.118</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front Leg Tibialis Anterior</strong></td>
<td>.002</td>
<td>.964</td>
<td>-.461</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td>-.461</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Biceps Femoris</strong></td>
<td>1.425</td>
<td>.260</td>
<td>1.881</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td>1.881</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Gastrocnemius</strong></td>
<td>.197</td>
<td>.666</td>
<td>2.057</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td>2.057</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Rectus Femoris</strong></td>
<td>.035</td>
<td>.855</td>
<td>1.496</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td>1.496</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mean values and standard deviations for the time to peak muscle activity for each muscle in each group can be found in Table 3.5. All data are presented in ms in with respect to ball contact being 0 ms. The independent samples t-test comparing time to peak muscle activity between skill groups, see Table 3.6, found there were only a significant difference for the front leg biceps femoris.
Table 3.5: Time to peak muscle activity (Mean ± SD) for all six muscles tested for each group.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Recreational</th>
<th>Skilled</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris (ms relative to contact)</td>
<td>-53.89 ± 25.07</td>
<td>-83.89 ± 11.63</td>
<td>0.024*</td>
</tr>
<tr>
<td>Gastrocnemius (ms relative to contact)</td>
<td>-36.33 ± 224.74</td>
<td>-147.22 ± 198.29</td>
<td>0.509</td>
</tr>
<tr>
<td>Tibialis Anterior (ms relative to contact)</td>
<td>43.33 ± 305.24</td>
<td>115.55 ± 153.13</td>
<td>0.616</td>
</tr>
<tr>
<td><strong>Back Leg</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps Femoris (ms relative to contact)</td>
<td>-136.11 ± 96.92</td>
<td>-161.11 ± 18.09</td>
<td>0.548</td>
</tr>
<tr>
<td>Gastrocnemius (ms relative to contact)</td>
<td>-161.11 ± 39.25</td>
<td>-55.56 ± 201.20</td>
<td>0.236</td>
</tr>
<tr>
<td>Rectus Femoris (ms relative to contact)</td>
<td>198.33 ± 211.44</td>
<td>77.78 ± 201.98</td>
<td>0.336</td>
</tr>
</tbody>
</table>
*Denotes significance at P < 0.05 level

Table 3.6: Independent samples t-test for time to peak muscle activation from SPSS.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Levene’s Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td><strong>Front Leg Biceps Femoris</strong></td>
<td>.594</td>
<td>.459</td>
<td>-2.659</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front Leg Gastrocnemius</strong></td>
<td>.005</td>
<td>.945</td>
<td>-.686</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Front Leg Tibialis Anterior</strong></td>
<td>2.137</td>
<td>.175</td>
<td>.518</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Biceps Femoris</strong></td>
<td>3.584</td>
<td>.088</td>
<td>.621</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Gastrocnemius</strong></td>
<td>3.254</td>
<td>.181</td>
<td>-1.261</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Back Leg Rectus Femoris</strong></td>
<td>.295</td>
<td>.599</td>
<td>1.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean values and standard deviations for the start time for each phase for each group can be found in Table 3.7. All data are referenced in ms to contact, with contact representing 0 ms. The ANOVA comparing start time of each swing phase between skill groups resulted in a significance F value, see Table 3.8, so independent t-tests were run to determine which phases were significantly different between groups. The results showed differences between the recreational and skilled hitters for both the shifting and the
stepping phase at the p < 0.05 level (see Table 3.7). The skilled group starts shifting and stepping phase significantly earlier than the recreational group.

Table 3.7: Start time for each phase of the swing (Mean ± SD) for the four phases of the baseball swing for each group.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Recreational</th>
<th>Skilled</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shifting (ms before contact)</td>
<td>-655.56 ± 90.08</td>
<td>-897.22 ± 170.72</td>
<td>0.012*</td>
</tr>
<tr>
<td>Stepping (ms before contact)</td>
<td>-483.06 ± 68.41</td>
<td>-608.28 ± 67.74</td>
<td>0.011*</td>
</tr>
<tr>
<td>Landing (ms before contact)</td>
<td>-308.06 ± 71.39</td>
<td>-285.28 ± 50.15</td>
<td>0.54</td>
</tr>
<tr>
<td>Swinging (ms before contact)</td>
<td>-237.78 ± 47.93</td>
<td>-191.15 ± 26.65</td>
<td>0.68</td>
</tr>
</tbody>
</table>

*Denotes significance at P < 0.05 level

Table 3.8: Independent samples t-test for start time for each phase of the swing from SPSS.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>df</td>
</tr>
<tr>
<td></td>
<td>Shifting</td>
<td>Equal variances assumed</td>
<td>2.747</td>
</tr>
<tr>
<td></td>
<td>Stepping</td>
<td>Equal variances assumed</td>
<td>.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equal variances not assumed</td>
<td>3.110</td>
</tr>
<tr>
<td></td>
<td>Landing</td>
<td>Equal variances assumed</td>
<td>.608</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equal variances not assumed</td>
<td>-.640</td>
</tr>
<tr>
<td></td>
<td>Swinging</td>
<td>Equal variances assumed</td>
<td>5.101</td>
</tr>
</tbody>
</table>

Mean values and standard deviations for bat velocity prior to impact for each group can be found in Table 3.9. All velocity data are presented in m/s. The skilled group exhibited a significantly greater bat velocity prior to impact than the recreational group at the p < 0.05 level (see Table 3.9).
Table 3.9: Bat velocity prior to impact (Mean ± SD) for each group.

<table>
<thead>
<tr>
<th>Bat Velocity (m/s)</th>
<th>Recreational</th>
<th>Skilled</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28.65 ± 1.57</td>
<td>30.91 ± 1.76</td>
<td>.042*</td>
</tr>
</tbody>
</table>

*Denotes significance at P < 0.05 level

Table 3.10 shows the SPSS output for the multiple correlation analysis run between mean muscle activation and bat velocity. Positive correlations were seen between the front leg biceps femoris and front leg gastrocnemius and back leg biceps femoris, the front leg gastrocnemius and back leg biceps femoris and back leg gastrocnemius, and the front leg tibialis anterior and back leg rectus femoris. No correlations were seen between any mean muscle activity and bat velocity; however, the trend seen is that all muscles other than front leg tibialis anterior have a negative correlation with bat velocity.

Table 3.10: SPSS output for multiple correlation analysis between mean muscle activity (% MVIC) and bat velocity (m/s).

<table>
<thead>
<tr>
<th></th>
<th>Front Leg Biceps Femoris</th>
<th>Front Leg Gastrocnemius</th>
<th>Front Leg Tibialis Anterior</th>
<th>Back Leg Biceps Femoris</th>
<th>Back Leg Gastrocnemius</th>
<th>Back Leg Rectus Femoris</th>
<th>Bat Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlations</td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>N</td>
<td>Pearson Correlation</td>
</tr>
<tr>
<td>Front Leg Biceps Femoris</td>
<td>.622*</td>
<td>.031</td>
<td>12</td>
<td>.641*</td>
<td>.025</td>
<td>12</td>
<td>-150</td>
</tr>
<tr>
<td>Front Leg Gastrocnemius</td>
<td>.624*</td>
<td>.956</td>
<td>12</td>
<td>.515*</td>
<td>.015</td>
<td>12</td>
<td>-140</td>
</tr>
<tr>
<td>Front Leg Tibialis Anterior</td>
<td>.018</td>
<td>-.141</td>
<td>12</td>
<td>.956</td>
<td>.015</td>
<td>12</td>
<td>.035</td>
</tr>
<tr>
<td>Back Leg Biceps Femoris</td>
<td>.678*</td>
<td>.294</td>
<td>12</td>
<td>.354*</td>
<td>.063</td>
<td>12</td>
<td>.273</td>
</tr>
<tr>
<td>Back Leg Gastrocnemius</td>
<td>.357*</td>
<td>.552*</td>
<td>12</td>
<td>.063</td>
<td>.063</td>
<td>12</td>
<td>.391</td>
</tr>
<tr>
<td>Back Leg Rectus Femoris</td>
<td>.458*</td>
<td>.551*</td>
<td>12</td>
<td>.332</td>
<td>.063</td>
<td>12</td>
<td>-.401</td>
</tr>
<tr>
<td>Bat Velocity</td>
<td>-.150*</td>
<td>-.281*</td>
<td>12</td>
<td>.035</td>
<td>.292</td>
<td>12</td>
<td>.196</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).
Table 3.11 shows the SPSS output for the multiple correlation analysis run between peak muscle activation and bat velocity. Correlation were only seen between front leg gastrocnemius and back leg gastrocnemius. No correlations were seen between peak muscle activity and bat velocity.

Table 3.11: SPSS output for multiple correlation analysis between peak muscle activity (% MVIC) and bat velocity (m/s).

<table>
<thead>
<tr>
<th></th>
<th>Correlations</th>
<th>Front Leg Biceps Femoris</th>
<th>Front Leg Gastrocnemius</th>
<th>Front Leg Tibialis Anterior</th>
<th>Back Leg Biceps Femoris</th>
<th>Back Leg Gastrocnemius</th>
<th>Back Leg Rectus Femoris</th>
<th>Bat Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Leg Biceps</strong></td>
<td>Pearson Correlation</td>
<td>1.00</td>
<td>.157</td>
<td>-.030</td>
<td>.477</td>
<td>.098</td>
<td>.055</td>
<td>.149</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.627</td>
<td>.927</td>
<td>.911</td>
<td>.761</td>
<td>.864</td>
<td>.864</td>
<td>.644</td>
</tr>
<tr>
<td><strong>Front Leg Gastrocnemius</strong></td>
<td>Pearson Correlation</td>
<td>.157</td>
<td>1.00</td>
<td>.051</td>
<td>.452</td>
<td>.592</td>
<td>.220</td>
<td>-.102</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.627</td>
<td>.874</td>
<td>.140</td>
<td>.043</td>
<td>.492</td>
<td>.752</td>
<td>.840</td>
</tr>
<tr>
<td><strong>Front Leg Tibialis Anterior</strong></td>
<td>Pearson Correlation</td>
<td>-.030</td>
<td>.051</td>
<td>1.00</td>
<td>.291</td>
<td>.447</td>
<td>.511</td>
<td>.020</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.927</td>
<td>.874</td>
<td>.358</td>
<td>.145</td>
<td>.909</td>
<td>.952</td>
<td>.120</td>
</tr>
<tr>
<td><strong>Back Leg Biceps Femoris</strong></td>
<td>Pearson Correlation</td>
<td>.477</td>
<td>.452</td>
<td>.291</td>
<td>1.00</td>
<td>.517</td>
<td>.261</td>
<td>-.066</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.117</td>
<td>.140</td>
<td>.358</td>
<td>.085</td>
<td>.530</td>
<td>.840</td>
<td>.840</td>
</tr>
<tr>
<td><strong>Back Leg Gastrocnemius</strong></td>
<td>Pearson Correlation</td>
<td>.988</td>
<td>.592</td>
<td>.447</td>
<td>.517</td>
<td>1.00</td>
<td>.544</td>
<td>-.564</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.761</td>
<td>.043</td>
<td>.145</td>
<td>.085</td>
<td>.909</td>
<td>.067</td>
<td>.056</td>
</tr>
<tr>
<td><strong>Back Leg Rectus Femoris</strong></td>
<td>Pearson Correlation</td>
<td>.955</td>
<td>.220</td>
<td>.511</td>
<td>.201</td>
<td>.544</td>
<td>1.00</td>
<td>-.498</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.864</td>
<td>.492</td>
<td>.090</td>
<td>.530</td>
<td>.067</td>
<td>.160</td>
<td>.100</td>
</tr>
<tr>
<td><strong>Bat Velocity</strong></td>
<td>Pearson Correlation</td>
<td>.149</td>
<td>-.102</td>
<td>.020</td>
<td>-.066</td>
<td>-.564</td>
<td>-.498</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.644</td>
<td>.752</td>
<td>.952</td>
<td>.840</td>
<td>.056</td>
<td>.160</td>
<td>.120</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).

Summary

While the results show that there are no significant differences between groups for mean and peak muscle activity, it can be seen that muscle activity trends to be lower for both in the skilled group. There were no significant differences time to peak muscle activity and start times for the landing and swinging phase between groups. Significant differences between groups were found for the shifting and stepping phase as well as bat velocity. Correlations between mean muscle activity were found for the front leg biceps
femoris and front leg gastrocnemius and back leg biceps femoris, the front leg
gastrocnemius and back leg biceps femoris and back leg gastrocnemius, and the front leg
tibialis anterior and back leg rectus femoris. Correlations were also found between peak
muscle activity for the front leg gastrocnemius and back leg gastrocnemius.
CHAPTER FOUR: DISCUSSION

The discussion section interprets the findings reported in chapter three as well as list possible limitations to the study. The intention of the discussion section is to add new knowledge to the topic of baseball hitting by interpreting the results found for the mean and peak muscle activity, time to peak muscle activation, start times for swing phases and bat velocity between the two groups.

Discussion

The goal of this study was to investigate the differences between mean and peak muscle activity, time to peak muscle activity, start time for swing phases, and bat velocity before contact between recreational and skilled baseball hitters. Our aim was to use the differences seen in this study found between skill groups to help train lesser skilled hitters to become better. Contrary to our hypothesis, there were no differences seen between mean and peak muscle activity, time to peak muscle activation, or time to the landing and swinging phase for the swing. However, statistical differences were seen during the shifting and stepping phase of the swing as well as bat velocity prior to impact.

No statistical significances were found when comparing mean muscle activity for each muscle between groups. No previous research has looked at and compared mean muscle activity between skill levels. Although, no statistical differences were found between the skilled and recreational group in this study, differences between other skill levels could be present. The recreational group in our study had all exhibited skill when hitting a baseball. If this study had looked at novice baseball players, there is a chance differences could have been seen. It is important to note that the trends were for skilled hitters to have lower mean muscle activation for the front leg biceps femoris and
gastrocnemius as well as the back leg biceps femoris, gastrocnemius and rectus femoris which is opposite of the hypothesized outcome. The small sample size for the two groups could explain for the lack of significance between the mean muscle activity. With greater sample size, it could be seen that there are significant differences in mean muscle activity. Differences in mean muscle activity between the groups tested could be due to the fact that the skilled group started their swing earlier, thus giving them a greater amount of time that their muscles were active and bringing the mean activity down. Positive correlations were found between the front leg biceps femoris and front leg gastrocnemius and the back leg biceps femoris, front leg gastrocnemius and back leg biceps femoris and the back leg gastrocnemius, and front leg tibialis anterior and the back leg rectus femoris. The correlations show that as muscle activity increases for one of those muscles then it will for the other as well. This also means that when the skilled hitters have lower muscle activity for one of the muscles the correlated muscle will also be lower.

The results for peak muscle activation between our two groups disagrees with that of previous research (22). Nakata et al. (22) reported significant differences between the front leg biceps femoris, gastrocnemius, and tibialis anterior as well as back leg biceps femoris, gastrocnemius and rectus femoris for skilled baseball hitters and novices. The novices were defined as individuals who had not had prior training in swinging a bat. The lack of statistical significance in this study could be due to the fact that all players were around the same age and were well versed with the art of hitting a baseball. The lack of significance for peak muscle activity could be due to the relatively small sample size. In previous research, the skill levels were very well defined between novices and
skilled, but in this study both groups were skilled to some degree. Combining that with the low sample size could be a key factor in why statistical differences were not seen. The data has a trend for the skilled group to have lower peak muscle activity in the front leg biceps femoris, and gastrocnemius as well as the back leg biceps femoris, gastrocnemius, and rectus femoris. The lower peak values for those muscles in the skilled group could be due to the fact that skilled level hitters are better conditioned and stronger than the recreational group thus needing to activate their muscles less to generate power. The positive correlation found between the front leg gastrocnemius and back leg gastrocnemius for peak muscle activity means that as one of them increases of decreases the other will do the same.

With no previous research comparing time to peak muscle activation before groups it is important to note that no significant differences were found for five of the muscles tested. The lack of statistical significance in the lead leg gastrocnemius, and tibialis anterior as well as the back leg biceps femoris, gastrocnemius, rectus femoris suggests that time to peak muscle activation is not a contributing factor to differences in skill level for hitting for the groups tested. Furthermore, the large standard deviations seen suggests that it is not something that is consistent among skill levels. The lead leg biceps femoris, however, showed very low standard deviations among skill groups and was found to be significantly different between groups. The skilled group got to the peak muscle activity for their lead leg biceps femoris and this could be an influence on determining skill but the other five muscles are not.

The results to our study show significant difference between the shifting and stepping phase of the baseball swing but not the landing and swinging phase when
comparing recreational and skilled baseball hitters. Nakata et al. (22) when comparing novices and skilled hitters found that the skilled hitters started the shifting, stepping and landing phase earlier while starting the swinging phase later than the novice group. The differences in results seen could be due to the fact that our recreational group consisted of hitters that were familiar with the ability to hit a baseball and could be similar in overall skill to our skilled group. The skilled group started the shifting and stepping phase significantly earlier than the recreational group which suggests that differences in those phases could lead to differences in skill level for the groups tested. As competition level increases, both batter skill and pitcher skill increases. Differences in the start times for shifting and stepping suggest that as hitters advance in competition level, they adjust the start of their swing to accommodate for the quicker reaction time needed to make ball contact.

Bat velocity has been shown to be higher for higher skilled groups when looking at professional hitters (13, 14). It has also been found that higher skilled hitters (professional hitters) have higher bat velocities than lesser skilled hitters (also professional hitters) (5). The skilled group in our study was found to have a significantly faster bat velocity prior to impact than their recreational counterpart. The findings for bat velocity comparing skill suggests that bat velocity does appear to relate to skill level. Multiple correlation analyses were run to determine if bat velocity were correlated to mean or peak muscle activity but no statistical significances were found. However, a trend was seen that all of mean muscle activity except for front leg tibialis anterior had a negative correlation with bat velocity meaning that as mean muscle activity decreases, bat velocity will increase.
Limitations

There are several limitations that should be noted in this study. sEMG sensors and marker placement error are always present. To control for this, a single investigator applied all sensors and markers to avoid inter-tester variability. Errors involving skin movement artifact should also be noted as markers were placed directly on skin and do not truly represent the bony landmarks.

Subject’s adherence to directions could also limit this study. All subjects were asked to avoid any strenuous activity for the twenty-four hours prior to data collection to help avoid muscle fatigue. Non-adherence to this request could lead to misinterpretations of both MVIC and muscle activations during the swing. It was assumed that all subjects avoided strenuous activity.

The subject’s exertion level during the MVIC testing and the swing trials is another potential limitation. Each subject was asked to give their full effort when performing the tests for MVIC but this could not be controlled. It was assumed that all subjects were giving full effort when performing all tasks for this study.

Only having six subjects in each group is another possible limitation. Lack of sample size could be reason for not seeing statistical significance for certain variables. In order to protect the study from type I error and increase power, muscle activity, time to peak muscle activity and start times for swing phases were ran through ANOVAs to test for significance. If the F value proved significant, independent means t-test were run to determine which variables were statistically different.
CHAPTER FIVE: CONCLUSIONS

The conclusions section contains a final summary of the study, conclusions based on the results of the study, and recommendations for future research. Conclusions based on the findings of mean and peak muscle activity, time to peak muscle activity, start time for swing phases and bat velocity can be found below.

Summary

Although there are apparent divisions between highly skilled baseball hitters and lower skilled hitters, the true reasons for the difference remain unknown. The relationship between bat velocity and different skill levels as well as peak muscle activity and start time for swing phases is known for skilled hitters versus novices. Therefore, this study compared those components between a skilled group that played at the varsity level collegiately versus a recreational group that stayed competitive but not on a varsity collegiate level team. Based on our findings, muscle activity does not appear to contribute to the differences between the skill levels tested, but skilled hitters tend to have lower peak and mean muscle activity. The large standard deviation for both groups and lack of significant differences when looking at time to peak muscle suggests that it does not contribute to differences seen in the skill levels tested. The results also showed that there were no significant differences between the start times of the landing of swinging phase which means it may not contribute to differences seen in our skill levels. Lack of statistical significance can represent that there are no differences seen or also that the small sample size did not provide enough data points to become significant.

The results of this study did find significant differences in the start times for the shifting and stepping phase which could contribute to the difference between the skill
levels tested. By starting the shifting phase earlier, the skilled group has more time to prepare for the swing. In turn, the skilled group is also able to start their stepping phase earlier, because of their ability to have their swinging phase start before the unskilled group. Being able to start these phases earlier gives the skilled group the ability to adjust for any pitch and gives them more time to generate power for the swing. It was also found that the two skill levels had significantly different bat velocities prior to ball impact. The higher bat velocity for the skilled group could be due to the fact that they have more time to generate power in the swing by starting the swinging and stepping phase before the recreational group. This too could contribute to the difference between the two skill levels tested in this study.

Conclusion

The results of the study suggest that the difference between the skilled group tested and the recreational group could be due to less muscle activity needed, the timing of specific phases of the swing as well as bat velocity. The trend for skilled hitters to have lower mean and peak muscle activity while having higher bat velocity suggest that those hitters are better at generating power, and could be better conditioned.

Recommendations for Future Research

In the future, it would be helpful to analyze the variables tested with both more subjects and more variation in skill level. The current study looked at players that had played recreationally through college and varsity in college, but did not include any professional hitters. Having a greater variation of skill level could be an important factor in finding the differences that actually exist between skill levels. Knowing the exact way energy is transferred in the baseball swing would be helpful in the development of young
or lesser skilled hitters. Additionally, it would be helpful to analyze the kinematics of the upper and lower extremities to try to find differences that could contribute to the difference seen in skill between the two groups. Doing so would lead to more information on the baseball swing and could give insight to what contributes to the skill level of hitters.
Appendix A: Marker Set

- RHAN
- LHAN
- RLWR
- LLWR

- LPSI
- RPSI
- RLWR
- RHAN
- LTAT
- LTPT
- LBAT
- LBPT
- RMMA
- LLMA
- LMMA
- RMKN
- LLKN
- RLKN
- LMKN
- R5MH
- RTOE
- R1MH
- L5MH
- LTOE
- L1MH

〇 Tracking Marker
〇 Anatomical Marker
Appendix B: Model Definition

Pelvis:

A CODA pelvis was used to create the pelvic coordinate structure. The plane was defined using the RASI and LASI and the midpoint between the RPSI and LPSI. The medio-lateral (X) axis was defined as the midpoint between the RASI and LASI toward the RASI. The vertical (Z) axis was defined as the perpendicular to the plane created by the ASIS and PSIS markers. The antero-posterior (Y) axis was defined as the cross-product of X and Z axis with positive being anterior.

Thigh:

A plane was formed using the hip joint center created by the CODA pelvis and the medial knee marker (RMKN or LMKN) and lateral knee marker (RLKN or LLKN). The vertical (Z) axis was defined as the vector beginning at the midpoint between the medial and lateral knee markers pointing toward the hip joint center with that being the positive. The antero-posterior (Y) axis was defined as the perpendicular to the plane created by the medial and lateral knee with the positive being anterior. The medio-lateral (X) axis was defined as the cross-product of the Z and Y axis with the positive being directed to the right. Tracking markers for the thigh were five markers on the right (RTAT, RBAT, RBPT, RTPT, and RMID) and four markers on the left (LTAT, LBAT, LBPT, and LTPT).

Shank:

A plane was formed using the medial knee marker (RMKN or LMKN) and lateral knee marker (RLKN or LLKN) and the medial ankle marker (RMAN or LMAN) and lateral
ankle marker (RLAN or LLAN). The vertical (Z) axis was defined as the vector forming at the midpoint or the medial and lateral ankle markers toward the midpoint of the medial and lateral knee markers with that being the positive. The antero-posterior (Y) axis was defined as the perpendicular to the plane created by the medial and lateral knee and ankle with the positive being anterior. The medio-lateral (X) axis was defined as the cross-product of the Z and Y axis with the positive being directed to the right. Tracking markers for the shank were four markers (RTAS or LTAS, RBAS or LBAS, RBPS or LBPS, and RTPS or LTPS).

Foot:

The vertical (Z) axis was defined as the vector forming at the RDHE or LDHE and pointing toward the RPHE or LPHE with that being the positive. The antero-posterior (Y) axis was defined as the vector originating at the RDHE or LDHE and going towards the midpoint between the R1MH or L1MH and the R5MH or L5MH with the positive being the anterior. The medio-lateral (X) axis was defined as the cross-product of the Z and Y axis with the positive being directed to the right. Tracking markers for the foot included RPHE or LPHE, RDHE or LDHE, RLHE or LLHE, and RTOE or LTOE.

Bat:

The vertical (Z) axis was defined as the vector forming at the TBAT and pointing towards the midpoint of the RHAN or LHAN and RLWR or LLWR with that being positive. The antero-posterior (Y) axis was defined as the perpendicular to the plane created by the TBAT and midpoint of the RHAN or LHAN and RLWR and LLWR with the positive being anterior. The medio-lateral (X) axis was defined as the cross-product
of the Z and Y axis with positive being directed left. Tracking markers for the bat included TBAT, MBAT, and RHAN or LHAN.
Appendix C: Expanded Literature Review

Studies of Electromyography for Baseball Hitting

Although baseball batting has been studies since the early 1960s, only a handful of studies have looked in to the muscle activation. The first study of electromyography (EMG) in the baseball swing was carried out by Kitzman in 1964(17). Looking at two professional and two novice baseball players, Kitzman investigated the pectoralis major, latissimus dorsi and triceps brachii during the swing. The results of this study showed that these muscles were active in early parts of the swing but not so much as the swing progressed. These findings led them to come to the conclusion that other muscles not studied were responsible for the movement later in the swing.

Broer and Houlz in 1967 (2) looked at one unskilled baseball batter during the swing. After their study, they concluded that the abdominal muscles were very important throughout the swing to keep the trunk stabilized. Kauffman and Grennisen (16) decided to test the idea that weighted bats affected muscle activity during the swing in 1973. Contrary to their hypothesis, no differences were found in the muscle activity when swinging the weighted bats before their at-bat. These findings supported their conclusion that using a weighted bat before going to the plate has no significant benefits to the player.

In 1993 Shaeffer et al. (26) used 18 professional baseball players to look at twelve muscles throughout the swing. Dividing the swing in to four phases (wind-up, pre-swing, swing, and follow-through), fine wire electrodes were used to look at the triceps, posterior deltid, supraspinatus and middle serratus anterior of the lead arm along with
the gluteus maximus of the back leg and surface electrodes to look at the vastus medialis obliques, semimembranosus and biceps femoris of the back leg as well as the erector spinea (lead and trail) and abdominal obliques (lead and trail). Following further analysis of the swing, the swing phase was broken up into early, middle and late swing giving the entire movement six phases with four of them occurring during the “swing phase.” The results showed that the semimembranosus, biceps femoris and gluteus maximus all were high during the pre-swing with maximum muscle test (MMT) values over 130% at 157 ± 68%, 154 ± 76% and 132 ± 53% respectively. Those muscles stayed active during the early-swing with the semimembranosus at 90 ± 62% MMT, the biceps femoris at 100 ± 71% MMT and the gluteus maximum at 125 ± 45% MMT. The vastus medialis obliques were most active during the middle and late-swing with values of 107 ± 47% MMT and 97 ± 32% MMT. The posterior deltid was active most throughout all four of the swing phases with values of 101 ± 91%, 88 ± 37%, 82 ± 45% and 76 ± 40%. The triceps was most active for the batters during the early and middle-swing with 92 ± 50% and 73 ± 35% respectively. The supraspinatus and serratus anterior did not reach over 40% of MMT at any point during the swing. The erector spinae lead stayed active during the pre, early, middle and late-swing phases with 94 ± 38%, 171 ± 93%, 136 ± 78% and 98 ± 78%. The trail erector spinae were also active most during the five subcategories of the swing phase with 127 ± 34%, 176 ± 89%, 131 ± 66% and 85 ± 55%. The abdominal obliques (lead and trail) were active during the entire swing but the wind-up. The lead abdominal obliques were at 109 ± 82%, 132 ± 92%, 108 ± 77%, 101 ± 53% and 101 ± 51% for the pre-swing, early-swing, middle-swing, late-swing and follow-through. The trail abdominal obliques were at 142 ± 70%, 168 ± 116%, 129 ± 63%, 132 ± 91% and
134 ± 71% for the pre-swing, early-swing, middle-swing, late-swing and follow-through. According to the results, Shaffer et al. concluded that the lower extremity is important during early pelvic stabilization and power generation while the muscles of the trunk were important for trunk stabilization and rotation for the smooth transfer of power to the swing. The lack of muscle activity in the arms suggests that instead of them being important for power generation, they are important for arm positioning.

There was a nine-year gap before the next baseball batting study came out with EMG. Nakata et al. (23) looked at the lower extremity during the movement of stopping the baseball swing. This is where the athlete starts to swing the bat but decides not to because of either a bad pitch discomfort with the beginning of their swing. The study aimed to first show the muscle activation of the rectus femoris, biceps femoris, tibialis anterior and medial gastrocnemius for both the front and back leg and then to find if there were any differences between skilled batters and novices. The skilled group for the study was defined as any subject that had college experience playing baseball while the novice group were either soccer players or dancers with no previous experience swinging a bat. During the stopping of the swing, the only differences found were in the peak amplitude of the back-leg rectus femoris and tibialis anterior. The back-leg rectus femoris was at 37 ± 13 MVC (maximum voluntary contraction) for the skilled group and 9 ± 1 % MVC. The back-leg tibialis anterior was seen at 58 ± 11% MVC for the baseball players and 32 ± 5% MVC for the novice group. The authors decided that the differences seen between the skilled and novices could mean that EMG can be evaluated to see differences in skill level and to help optimize batting performance.
Nakata et al. (22) used the same two groups to evaluate the differences between the actual baseball swing in 2013. Looking at the two groups the rectus femoris, biceps femoris, tibialis anterior and medial gastrocnemius of both legs was examined. During this study, the baseball swing was broken down into seven phases including the waiting, shifting body weight, stepping, landing, swing, impact and follow through. During the study, the timing of these phases were analyzed and differences were found in the shifting, stepping, landing and swing. The shifting phase was found to start 1418 ± 45 ms before contact for skilled batters and 1198 ± 73 ms before contact for the novices, while the stepping phase was found to start 905 ± 47 ms before contact for skilled batters and 629 ± 75 ms before contact for the novices. The big differences come in the landing phase and swing phase with the landing phase staring 417 ± 60 ms before contact for skilled batters and 275 ± 17 ms before contact and the swing phase with 243 ± 14 ms before contact for skilled batters and 311 ± 19 ms before contact for novices. The landing phase for skilled batters occurs before the swing starts while the novice batters start to swing before the landing phase occurs. This could potentially be a reason for the differences seen in skill for the batters. The onset latencies for the swing found differences in lead leg rectus femoris and biceps femoris and back leg biceps femoris. The lead leg rectus femoris was found to activate 1107 ± 117 ms before contact for the skilled batters and 806 ± 77 ms before contact for the novices. The lead leg biceps femoris was found to turn on at the 1411 ± 34 ms before contact for skilled batters and 856 ms before contact for the novices. The back-leg biceps femoris had an onset of 1213 ± 115 ms before contact for the skilled batters and 737 ± 88 ms before contact for the novice group. The peak latency for the back-leg tibialis anterior was found to be
significantly different with the skilled group at 75 ± 30 ms and the novice group at 184 ± 27 ms. The peak amplitudes for muscles is where the most differences were seen with significant differences between the back-leg rectus femoris, biceps femoris and medial gastrocnemius and lead leg biceps femoris, tibialis anterior and medial gastrocnemius. The skilled group was found to be at 115 ± 19% MVIC for the back-leg rectus femoris, 202 ± 12% MVIC for the biceps femoris and 233 ± 26% MVIC for the medial gastrocnemius. The novice group was found to be at 44 ± 4% MVIC for the back-leg rectus femoris, 132 ± 14% MVIC for the biceps femoris and 109 ± 18% MVIC for the medial gastrocnemius. The skilled group was found to be at 153 ± 29% MVIC for the lead leg biceps femoris, 79 ± 7% MVIC for the tibialis anterior and 159 ± 36% MVIC for the medial gastrocnemius. The novice group was found to be at 55 ± 10% MVIC for the lead leg biceps femoris, 47 ± 5% MVIC for the tibialis anterior and 73 ± 15% MVIC for the medial gastrocnemius. It was concluded that preparations are preformed earlier for skilled players while they are also recruiting their lower extremity muscles more effectively.

Studies of Kinematics for Baseball Hitting – Early Technology

Early baseball hitting analysis was completed using two-dimensional video analysis and many important basic principles of baseball hitting were established. In 1961, Race (25) found evidence of a kinetic chain in the baseball swing using 17 proficient professional hitters. It was found that the sharp increase in the bat velocity as it approached impact with the ball. The far greater velocity of the wrist and hands over the
hips and of the hips over the striding foot was deemed responsible for the increase seen of the bat. In 1964, Swimley (28) found that hitters known to pull the ball when hitting had greater pelvic angular velocity than hitters that tried to hit to all areas of the field. In 1967, Breen (1) analyzed six superb major league baseball hitters and found that each one of them exhibited five common traits: the center of gravity stays on a fairly constant plane, his head movements are adjusted pitch by pitch to maximize time the pitch is seen in flight, the lead forearm extends almost immediately after initiation of the swing to increase bat velocity, the stride length is generally the same for all pitches, and the upper body position after contact is in the same direction of the ball flight.

McIntyre and Pfautsch (19) investigated twenty former and current collegiate players in 1982. Hitters were divided into two different groups based on a rating on their ability to hit into opposite field given by their coach. Group one was deemed ineffective at hitting into the opposite field while group 2 was deemed effective. Significant differences were not seen between the groups but between actually hitting to same-field or opposite-field. It was found that opposite-field hitting had a significantly lower time from initiation of the swing to ball contact, and lower angular displacement and velocity for the bat, lead hand, and lead forearm. It was concluded from their findings that differences seen in the mechanics of hitting to same-field and opposite-field occur because of the differences in the angular displacement of the left wrist and left elbow, and because of differences in the temporal characteristics of the swing. Gelinas and Hoshizaki supported these findings in 1988 (11) using one effective opposite-field hitter from the Major League. Opposite-field hits required significantly lower angular displacement of the bat, pelvis, upper trunk.
Hirano (13) attempted to differentiate between skilled and unskilled batters in 1986. The definition of skill was defined by the evaluation of their college coach on their hip rotation against a pitched ball. Based on evaluation, five hitters were separated into the skilled group while the unskilled only had two. It was found that the skilled baseball hitters created a much higher bat velocity right before ball contact while their unskilled counterpart had a steadier velocity increase.

In 1994 Matuso et al. (18) used a visual target movement system to simulate real batting with five collegiate baseball hitters. Subjects were required to swing a bat as a light moved down a runway to simulate the ball and were given feedback based on if they were swinging too early, made contact or too late. The light moved at two different speeds and was randomized for each subject. It was found that the first movement of the swing occurred at the same point no matter what the swing velocity and that the differences in the target velocities didn’t appear until 300 ms after the ball release. It was also found that movement time of the bat fluctuated even when the pitch was the same speed.

In 2000, McLean and Reeder (20) examined eleven collegiate switch hitters to determine differences when swinging from each side of the plate. Eight of the hitters classified as right-hand dominant while three classified as left-hand dominant. There were no significant differences seen for the bat speed or maximum angular velocities when batting from the dominant and non-dominant side. The right-hand dominant hitters did exhibit higher maximum elbow angular velocity while the left-hand dominant hitters exhibited higher shoulder angular velocity when batting from the right side. No differences were seen between the groups when batting from the left side.
DeRenne et al. (4) investigated the effect of warming up with various weighted bats on swing velocity in 1992. Sixty male high school baseball players were used to compare thirteen different trials using various weighted implements. Warming up with implements within a +/- 10% range from the normalized 30 oz. bat resulted in the greatest bat velocity. When looking at the weighted donut most commonly used to warm-up the bat velocity was consistently the lowest bat velocity. As the weighted implement deviated farther from the 30 oz. bat velocity decreased. It was concluded that to achieve greatest bat velocity when batting, hitters should use a bat close to the same weight to warm-up. Following the steps of this study, Otsuji and Kinoshita (24) looked at the effects of using a weighted bat on swing velocity and the hitters perceived swing velocity and heaviness in 2002. It was found that hitters consistently had a slower bat velocity on the first swing following the weighted condition compared to the control condition. However, the second swing found a return of velocity to normal levels. When asked about their perceived bat velocity, all hitters said they felt they had actually swung the bat faster and that it felt lighter following the weighted condition. These finding suggest that the benefit from using a weighted bat to warm-up before batting is not biological but psychological.

In 2003, Southard and Groomer (27) examined how warming up with bats of varying moments of inertia would affect bat velocity and swing pattern for ten experienced baseball players. Six of the experienced players were currently playing on the collegiate team while the remaining four had played at least varsity in high school. There were three different conditions that were tested: condition one – standard bat (I = 0.27 kgm$^2$), condition 2 – standard bat plus 6.1 lead donut (I = 0.49 kgm$^2$), and condition
3 – plastic hollow bat (I = 0.08 kgm²). It was found that warming up with bats of increased moments of inertia (going from 0.27 kgm² to 0.49 kgm²) significantly changed the swing pattern and decreased bat velocity. The increase in the moment of inertia significantly changed the kinetic chain for the swing and resulted in a lower bat velocity.

Studies of Kinematics for Baseball Hitting – Modern Technology

In 1995, Welch et al. (32) conducted the first three-dimensional baseball hitting analysis. Six motion analysis cameras collecting at 200 frames per second collected the data for seven professional baseball hitters. A setup with 23 reflective markers placed on the hitter, bat and ball was used to quantify the swing. It was found that the hitter starts the swing with the majority of his weight shifting toward the back leg and generation of trunk coil. As the swing continues there is a shift seen of about 123% of body weight toward the front foot to promote segment acceleration. Supporting the kinetic chain findings of Race (25) (1961), it was found that the hip rotated at a maximum angular velocity of 714 degrees per second with the shoulder moving faster at 937 degrees per second and the arm moving the fastest at 1160 degrees per second. This chain allows the hitter to produce a maximum amount of linear bat velocity of 31 meters per second.

Dragoo (6) in 2004 looked at the differences between hitters at the collegiate, high school and youth levels. Using five cameras at 60 Hz and analyzing only the single best trial for each participant it was found that the collegiate group had higher bat speed and ball exit velocity than the other two groups at 20 m/s and 57 m/s respectively. The high school group exhibited the highest pelvis rotation velocity and upper trunk rotation
velocity at 470 degrees per second and 581 degrees per second respectively. It was also found that the youth hitters had the fastest reaction time with 315 ms, followed by the high school group at 288 ms and then the collegiate group at 278 ms. It is to be noted that this study is limited due to the frame rate being slow for a baseball swing.

Tago et al. (29-31) published three studies between 2005 and 2006 looking at biomechanical changes when hitting off a tee in nine different locations (outside, middle, and inside with low, middle, and high). Cameras in this study collected data from ten collegiate baseball hitters at 120 Hz. There were no differences in ball exit velocity between inside, middle and outside balls but low balls had a higher exit velocity than middle and high. During the time when the lead arm was parallel, the inside ball placement created more back hip and knee flexion, and lead ankle extension. During ball impact, inside ball placement created more lead knee and ankle extension and less back hip abduction. The inside ball placement also created a more open upper trunk and pelvis from toe-off to ball impact. The high ball placement created less back hip flexion from toe-off to ball impact, and less lead hip flexion from swing start to ball impact than low ball placement. During the lead arm parallel and ball impact, high ball placement also created less lead shoulder horizontal adduction, less lead elbow extension, and more back shoulder flexion. The upper trunk was also more open during ball impact for high placed balls than low placed balls. This study was limited due to the low frame rate and there were no exact kinematic data presented.

Escamilla et al. (7, 8) published two studies in 2009 looking at a group of right-handed adult players (collegiate or professional). One study looked at the adult hitters within-group for different bat grips and the other compared the kinematics between the
adult hitters and youth baseball hitters. In the bat grip study, the adult hitters were analyzed using their normal grip and a modified choke-up grip. When compared to the normal grip, the choke-up grip resulted in lower time for the stride and swing, a more open upper torso and foot contact, a more closed pelvis and less bat linear velocity at ball contact, less range of motion of the upper torso and pelvis, more elbow flexion at foot contact and greater elbow extension angular velocity of the lead arm. The fact that the upper torso and pelvis range of motion is smaller, and that the swing time duration is decreased, supports the idea that the choke-up grip results in a faster swing but the bat did not actually move faster. When compared to their youth counterparts, the adult hitters had greater knee flexion when the hands start to move, greater range of motion for the lead knee during the transition period, greater range of motion of the lead knee for bat acceleration, maintained a more open pelvis while the lead foot was off the ground and maintained a more open upper torso while the hands moved forward and a more closed upper torso at ball contact. Adult hitters also exhibited greater peak upper torso angular velocity, peak left elbow extension angular velocity, peak left knee extension angular velocity and bat linear velocity at ball contact. The numerous differences seen between groups suggest that there are mechanical differences in hitting.

In 2011, Inkster et al. (14) looked at the kinematics of the swing for hitters playing professional baseball. Subjects were divided into two groups based on the qualitative ratings of three coaches and batting averages. Data for the hitters was collected at 240 Hz and it was found that more skilled hitters have a higher maximum bat velocity during the swing at 36.8 m/s vs 33.8 m/s for the lesser skilled hitters. It was also found that the more skilled group had higher lead elbow maximum angular velocity and
maximum hip segment angular velocity. The back knee was also found to be more
extended for higher skilled hitters at ball contact. The evidence of higher velocities in the
hip, elbow and bat are suggestions that the hitters of higher skill use their kinetic chain
better than hitters of lesser skill.

Also in 2011, Fortenbaugh (10) looked at baseball hitting for forty-three minor
league baseball players. Players were pitched to in five different locations: high in, high
out, low in, low out and middle. It was found that a more rotated pelvis was critical to
success of hitting inside pitches while a less rotated pelvis was critical to hitting outside
pitches. The lead and trail arm were found to be critical in the closed chain to drive the
hand path during the swing. It was also found that the trail elbow extended more during
the high in pitches and flexed more for the low out pitches. While trying to hit the
changeup, batters were found to initiate the kinetic chain to early and in turn miss the
pitch. This study suggest that batters need to focus on their approach at the plate and be
more consistent. It is also noted that hitters need to focus on seeing the ball as early as
possible to identify the pitch type and location.

In 2016, Dowling and Flesig (5) analyzed 170 baseball hitters varying in
competition level. Subjects were split into four groups: youth (n =33), high school (n
=69), college (n =22), and professional (n =46). It was found that the youth and
professional hitters had the greatest kinematic differences. At the instant of ball contact
youth hitters had 27° of back shoulder abduction compared to 35° in professional hitters
and 89° of back elbow flexion compared to 78° for the professional hitters. The youth
hitters also had significantly less back elbow extension velocity at 1174°/s when
compared to the professional hitters at 1539°/s. It was also found that higher level hitters
had significantly higher bat angular and linear velocities when compared to the youth hitters. It was concluded that hitters should focus on their back arm by keeping the elbow up and arm extended as they progress through their career.
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