A Kinematic Comparison Of Shoulder And Elbow Dynamics Influenced By The Shoe-Surface Interface In Youth And Adolescent Baseball Pitchers

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A KINEMATIC COMPARISON OF SHOULD ER AND ELBOW DYNAMICS INFLUENCED BY THE SHOE-SURFACE INTERFACE IN YOUTH AND ADOLESCENT BASEBALL PITCHERS

A Dissertation
presented in partial fulfillment of requirements for the degree of
Doctor of Philosophy
in the Department of Health, Exercise Science, and Recreation Management
The University of Mississippi

By
Jacob Richard Gdovin
August 2017
ABSTRACT

From 1994-2006, 1.5 million baseball injuries were treated within emergency departments across the United States while the upper extremity was the second most commonly injured body part. Although it has been determined that pitch count, pitch type and pitching mechanics are the main contributors to upper extremity pain in baseball pitchers, footwear has not been considered a potential factor. Therefore, the purpose of this study was to determine how baseball-specific footwear [turf shoes (TS) and molded cleats (MC)] affects the shoulder and elbow dynamics of youth and adolescent pitchers during an overhead pitch on various surface inclinations [flat ground (FG) and pitching mound (PM)]. The aims of the study were to investigate the effect of wearing baseball footwear on (1) upper extremity kinematic variables, (2) lower extremity muscle activity, and (3) torso and pelvis kinematics while on various inclined surfaces. Eleven healthy male right-handed baseball pitchers (age: 13.18 ± 1.72 years; height: 179.01 ± 15.72 cm; mass: 61.00 ± 14.66 kg) who wore baseball footwear for 1 hour per week while actively playing completed the study. Participants threw ten fastballs in all counterbalanced conditions (MC x FG, MC x PM, TS x FG, TS x PM). A 3D motion capture system collected full-body kinematics and electromyography (EMG) data. Three pitches thrown without marker obstruction in each condition were analyzed and averaged for each participant. A 2x2 [2 Surfaces (FG, PM) x 2 Footwear (TS, MC)] repeated measures ANOVA was used to compare the variables of interest. Results showed no significant differences were seen for ball velocity. Significant differences were seen across surface conditions and footwear conditions (p<0.05). Pitching in TS elicited a greater
amount of shoulder external rotation while MC increased the amount of shoulder internal rotation. Pitching from a mound also placed more stress on the shoulder and elbow relative to flat ground. Stride leg ankle plantarflexion (PF) exhibited significant differences across surface and footwear. The TS showed a greater PF position relative to the MC. These results are consistent in the ankle stabilization muscles (G & TA) showing significantly greater muscle activity in the TS versus MC.
# LIST OF ABBREVIATIONS AND SYMBOLS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>COM</td>
<td>Center of Mass</td>
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<tr>
<td>DXA</td>
<td>Dual Energy X-Ray Absorptiometry</td>
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<td>ER</td>
<td>External Rotation</td>
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<td>EMG</td>
<td>Electromyography</td>
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<td>FG</td>
<td>Flat Ground</td>
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<td>G</td>
<td>Gastrocnemius</td>
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<tr>
<td>GRF</td>
<td>Ground Reaction Force</td>
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<td>H</td>
<td>Hamstrings</td>
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<td>IR</td>
<td>Internal Rotation</td>
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<tr>
<td>MC</td>
<td>Molded Cleats</td>
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<tr>
<td>MLB</td>
<td>Major League Baseball</td>
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<tr>
<td>MVIC</td>
<td>Maximal Voluntary Isometric Contraction</td>
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<td>PM</td>
<td>Pitching Mound</td>
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<tr>
<td>Q</td>
<td>Quadriceps</td>
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<tr>
<td>ROM</td>
<td>Range of Motion</td>
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<tr>
<td>SFC</td>
<td>Stride Foot Contact</td>
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<tr>
<td>TA</td>
<td>Tibialis Anterior</td>
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<td>TS</td>
<td>Turf Shoes</td>
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ACKNOWLEDGMENTS

Throughout my ten-year academic career, I have received guidance and support from many distinguished faculty and staff members at both The University of Mississippi (Oxford, MS) as well as Mercyhurst University (Erie, PA). My sincere appreciation goes out to my dissertation committee members: Dr. Chip Wade, Dr. Martha Bass, Dr. Alberto del Arco, and Dr. Mark Loftin for all of their expertise and assistance during this challenging process. I would also like to thank my advisor and mentor, Dr. John C. Garner (Troy University, Troy, AL), for believing in me and giving me the opportunity to expand my knowledge in the field of biomechanics and exercise science. The completion of this doctoral degree would not have been possible without these individuals. First and foremost, my sincere gratitude goes to Dr. Chip Wade who I consider to be a mentor, scholar, and friend. I am forever grateful for his assistance in every aspect of this project and showing me how to succeed in academia. I am extremely thankful for Dr. Martha Bass for serving on my committee and going above-and-beyond to help me finish this difficult journey. Her passion for research and desire to have students succeed allowed me to overcome many obstacles. I am also very appreciative for all of the insight provided by Dr. Alberto del Arco and Dr. Mark Loftin both in the classroom and laboratory. Most importantly, my deepest and heartfelt gratitude goes to my father (Mr. Rick Gdovin), mother (Dr. Gloria Gdovin), sister (Ms. Samantha Gdovin), and girlfriend (Ms. Avery Drennen). Having them by my side as well as their endless love and encouragement allowed me to reach this milestone.
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Within the past few decades, the popularity among youth and adolescents participating in all sports has increased to approximately 30-45 million (Brenner 2007) across the United States (U.S.) with baseball accounting for roughly 5.3 million as of 2013 (Costa 2015). Youth athletes (9-13 years old) are in the developmental stages of their baseball career and play a variety of positions on the field since they are physically and physiologically immature while adolescents (14-18 years old) on the other hand are more anatomically developed allowing their baseball skill set to adapt to one specific position (Davis, Limpisvasti et al. 2009). Although participation in athletics has increased, early specialization and year-round throwing among baseball players is becoming more prevalent placing undue stress on the upper-extremity. This trend is causing an increase in overuse injuries in young athletes due to high external forces acting on the arm coupled with inadequate muscle strength to stabilize the joints (Axe 2001, Garner, MacDonald et al. 2011, Astolfi 2013). Injuries within these age groups are typically defined and reported as “pain” which could be an early indicator of a more serious injury (Lyman and Fleisig 2005). Therefore, determining the biomechanical patterns related to the various phases of pitching mechanics and its interaction with the kinetic chain could lead to coaching and training modifications to prevent or rehabilitate athletic injuries.

From birth until the early teenage years, anatomical and physiological maturation occurs, including but not limited to, the humerus rotating from retrotorsion to antetorsion (Edelson 2000, Leonard and Hutchinson 2010, Astolfi 2013). The greatest amount of retrotorsion is seen between the ages of 11-12 which matches the time the epiphyses see the most growth (Damrow, Liu et al. 2015). This explains why throwing at high velocities with improper mechanics, as well as high pitch counts and certain pitch types producing more torque at the shoulder and elbow act as risk factors for potential injuries in youth pitchers (Calabrese 2013). With an increase in pitch
counts and appearances with minimal rest and an underdeveloped musculoskeletal system, approximately 26-35% of youth pitchers sustain an elbow or shoulder injury each season (Lyman, Fleisig et al. 2002, Lyman and Fleisig 2005). This means that repetitive overhead throwing may not only damage connective and muscular tissue but the epiphyses during the years of skeletal development. Humeral retroversion, from a pitching perspective, allows an athlete to increase their external rotation (ER) straining the glenohumeral joint tissues in the anterior shoulder complex while decreasing internal rotation (IR) (Leonard and Hutchinson 2010, Damrow, Liu et al. 2015). However, this developmental deficiency brought on by repeated overhead throwing may predispose young pitchers to a lifetime of elbow and shoulder complications such as dislocations, fractures, excessive stress on the connective tissue and musculature surrounding the articulation, and impingement problems including glenohumeral internal rotation deficit (GIRD). This dysfunctional change occurs frequently in adolescent athletes who have soft tissue complications such as muscle weakness and inflexibility within the dominant glenohumeral internal and external rotators. GIRD describes the decrease in total range of motion (ROM) [sum of ER and IR ROM] even though the ER ROM is increased in the dominant shoulder while IR ROM decreases (Guney, Harput et al. 2016).

Comparing pitching mechanics across various levels of experience showed that elbow flexion was the only variable related to position, rather than velocity, that was significantly different among populations while joint forces and torques significantly increased with each level (Fleisig, Barrentine et al. 1999). This data supports that early in an athletes playing career is the best opportunity to teach and correct any mechanical flaws since mechanics do not significantly change with age and playing level. While it is not uncommon for youth pitchers to throw over 200 pitches per week (Lyman, Andrews et al. 1998), previous research done in
collegiate athletes shows that the likelihood of injury does not increase with a greater number of pitches thrown since the joint forces and torques remain similar (Escamilla, Barrentine et al. 2007). Although muscular fatigue can be described as a decrease in force production, it is a very individualized variable. Fatigue may occur earlier or later throughout a game and may be determined on the amount of rest between innings, number and types of pitches thrown as well as musculoskeletal stress accumulated throughout the duration of an entire season (Escamilla, Barrentine et al. 2007). Therefore, the exact cause of why youth and adolescent pitchers sustain frequent elbow and shoulder injuries can only be speculated to this point.

One variable often overlooked by athletes and coaches that may affect performance and influence potential injuries is the shoe-surface interaction. Since energy is transferred from the most proximal segment during a baseball throw, the relationship between the outsole of an athletes shoe and the artificial playing surface is vital. Cleated footwear creates an interaction between the athlete’s foot and artificial playing surface. An interaction refers to the transfer of energy between objects while the shoe-surface interaction/interface is responsible for the surfaces’ ability to resist motion of a shoe (Driscoll, Kelley et al. 2015). Both vertical and horizontal resistive forces are used to calculate and determine the effectiveness of the shoe-surface interaction. Vertical forces determine a cleats ability to penetrate the surface which is affected by the surfaces’ hardness and stud shape (Driscoll, Kelley et al. 2015) while horizontal resistance is referred to as traction. According to the American Society for Testing and Materials Committee on Sports Equipment and Facilities, traction is the resistance to motion between a shoe outsole and a sport surface that does not always obey the laws of friction (2006). Therefore, changing the cleat configuration on the outsole of the shoe or the playing surface can alter the amount of traction.
There is no known research specifically analyzing how the shoe-surface interaction affects pitching mechanics or the lower extremity muscle activity. However, it has been determined with mechanical apparatuses that athletic footwear without cleats produce smaller torques at the ankle on artificial surfaces while heavier individuals experience 70% more torque when the entire foot is contacting the ground (Bonstingl, Morehouse et al. 1974). This partially explains how the lateral ligaments of the ankle are affected when the forefoot is inverted while the ankle is simultaneously supinated. In 1971, football cleats with more than seven studs (approximately thirteen to seventeen studs) were found to decrease the number of lower extremity joint injuries by half and produce fewer injuries on artificial turf (Torg and Quedenfeld 1971). Larger cleat heights were also found to be correlated with an increase in ankle torque (Torg and Quedenfeld 1971). However, since the variables regarding footwear have only been used to look at changes in the lower extremity, the need for understanding how the shoe–surface interface affects the upper extremity is important in the overhead baseball throw and its relation to biomechanical injuries.

**Purpose of the Study**

al. 1972, Torg and Quedenfeld 1973) as well as using mechanical apparatuses to analyze the cleat type on various surfaces (Torg, Quedenfeld et al. 1974, Andreasson, Lindenberger et al. 1986, Livesay, Reda et al. 2006, Kent, Crandall et al. 2012); however, no investigator has addressed baseball specific footwear as a potential cause for mechanical changes on surface inclinations in overhead throwing athletes.

With the rate of youth participation in baseball increasing, the need to determine the cause of injury and decrease the rate at which they occur is imperative. Therefore, the purpose of this study is to determine how baseball-specific footwear [turf shoes (TS) and molded cleats (MC)] affects the shoulder and elbow dynamics of youth and adolescent baseball pitchers during an overhead baseball throw on various surface inclinations [flat ground (FG) and pitching mound (PM)]. This study looks to analyze the kinematic variables of the elbow and shoulder, lower extremity muscle activity of the Quadriceps (Q), Hamstring (H), Tibialis Anterior (TA), and Gastrocnemius (G) as well as compare the movement (i.e. angular velocity) of the torso relative to the pelvis. Addressing these unknown questions will allow athletes, parents, coaches, and clinicians better understand how baseball specific footwear affects the mechanics of the throwing motion and muscle activity on various surface inclinations. The results may potentially lead to a decrease in injury rates by informing parents and young athletes to wear specific shoes to preserve longevity within the sport.

Hypotheses

_Throwing Kinematics and Kinetics Hypothesis - Specific Aim 1:

To investigate the shoe-surface interaction and how baseball specific footwear (MC and TS) on varying inclined surfaces (PM and FG) affect the kinematics of the pitching motion in youth and adolescent baseball pitchers.
**H\textsubscript{01}:** An individual’s kinematic and kinetic overhead throwing variables will not be modified when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).

**H\textsubscript{A1}:** An individual’s kinematic and kinetic overhead throwing variables will be modified when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).

**Dependent Variables:**

**Throwing Shoulder:**
- Maximum abduction (°)
- Maximum Horizontal Adduction (°)
- Maximum External Rotation (°)
- Maximum Internal Rotation (°)
- Internal Rotation Torque (Nm)
- External Rotation Torque (Nm)
- Maximum Internal Rotation Velocity (°/s)

**Throwing Elbow:**
- Maximum Elbow Flexion (°)
- Varus Torque (Nm)
- Flexion Torque (Nm)
- Extension Velocity (°/s)

**Lower Extremity:**
- Stride length
- Stride Length (% of height)
- Stride Leg Hip Flexion (°)
- Stride Leg Knee Flexion (°)
- Stride Leg Ankle Plantar Flexion (°)
- Trail Leg Hip Flexion (°)
- Trail Leg Knee Flexion (°)

**Time:**
- Time between maximum ER and maximum IR (s)
- Time between ball release and maximum IR (s)
- Time between maximum ER and ball release (s)
- Time between stride foot contact and maximum external rotation (s)
- Time between stride foot contact and ball release (s)
- Time between stride foot contact and maximum IR (s)

**Hypothesis Explanation:**
Proper shoe selection based on anatomy, gait characteristics, sport/position specificity, and playing surface could help redistribute forces in order to increase the quality of sports performance and decrease injury risks. Research has shown that number, length, and placement of cleat studs play a significant role in the risk for injuries in American football (hereafter referred to as football) cleats. More specifically, it was recommended that cleats meet the following specifications due to safety: (1) a synthetic molded sole, (2) a minimum of 14 studs per shoe, (3) a minimum stud diameter of 1/2 inch, and (4) a maximum stud length of 3/8 inch (Torg and Quedenfeld 1971, Torg, Pollack et al. 1972, Torg and Quedenfeld 1973, Torg, Quedenfeld et al. 1974). Similarly, studded cleats were found to be safer than bladed cleats when analyzing torsional injuries (Smeets, Jacobs et al. 2012) and throwing from a PM caused increased stress on both the shoulder and elbow compared to FG (Nissen, Solomito et al. 2013). Therefore, the null hypothesis that an individual’s upper extremity kinematic overhead throwing
variables will not be modified when exposed to various surface inclinations while wearing baseball specific footwear is expected to be rejected.

**Lower Extremity Muscle Activity Hypothesis - Specific Aim 2:**

To investigate the shoe-surface interface and how baseball specific footwear (MC & TS) on varying inclined surfaces (PM & FG) affects lower extremity muscle activity [Vastus Medialis (Q), Semitendinosus (H), Tibialis Anterior (TA), and Medial Gastrocnemius (MG)] in the stride and trail leg in youth and adolescent baseball pitchers.

- **H02:** An individual’s lower extremity muscle activity (Q, H, TA, MG) will not be modified in either the stride or trail leg when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).

- **HA2:** An individual’s lower extremity muscle activity (Q, H, TA, MG) will be modified in either the stride or trail leg when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).

**Dependent Variables:**

**Electromyography (EMG):**
- Mean muscle activity during a maximal voluntary contraction (MVIC) of stride leg
- Mean muscle activity of stride leg

**Hypothesis Explanation:**

The coordination of the upper and lower extremity and their associated musculature is needed to create a sequential pitching motion. While EMG activity has been examined extensively in the upper extremity (Jobe 1983, Gowan, Jobe et al. 1987, Townsend, Jobe et al. 1991, DiGiovine, Jobe et al. 1992), only two known studies (Yamanouchi 1998, Campbell, Stodden et al. 2010) have analyzed muscle activation in the lower extremity during a baseball pitch. The exact responsibilities of the lower extremity are unknown as to their contribution during the six phases
of the pitching motion but their importance is thought to be demonstrated within the first four phases (Campbell, Stodden et al. 2010). Yamanouchi (1998) concluded the adductor musculature acts as the primary source of energy during a baseball pitch; however, the musculature analyzed were classified into groups based on their joint action and the entire pitching motion was only divided into two phases. Therefore, study design limits the ability to identify which specific adductors were firing and where within the six phases of the pitching motion activation occurred. Campbell et al. (2010), on the other hand, utilized four phases of interest and measured the activity in the gastrocnemius, biceps femoris, gluteus maximus, rectus femoris, and vastus medialis. It was concluded that all muscles of interest increased from minimal to moderate activity (10%-31% MVIC) to moderately to highly active (42%-86% MVIC) bilaterally in the first and second phases, respectively (Campbell, Stodden et al. 2010). Therefore, the null hypothesis that an individual’s lower extremity muscle activity (Q, H, TA, MG) will not be modified in either the stride or trail leg when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS) is expected to be rejected. Although the Q and MG have been monitored, this will be the first study to determine how the H and TA influence pitching mechanics within any age group.

*Trunk and Pelvis Kinematic Hypothesis - Specific Aim 3:*

To investigate the shoe-surface interaction and how baseball specific footwear (MC & TS) on varying inclined surfaces (PM & FG) affect trunk and pelvis rotations in youth and adolescent baseball pitchers.

**H03:** An individual’s trunk and pelvis kinematic and kinetic variables will not be modified during an overhead baseball throw when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).
**Hₐ₃**: An individual’s trunk and pelvis kinematic and kinetic variables will be modified during an overhead baseball throw when exposed to varying inclined surfaces (PM and FG) while wearing sport specific footwear (MC and TS).

**Dependent Variables:**

**Pelvis:**
- Maximum pelvis angular velocity (°/s)
- Pelvis orientation at the time of maximum pelvis angular velocity (°)

**Trunk:**
- Maximum trunk angular velocity (°/s)
- Trunk Lateral Flexion (frontal plane)
- Trunk forward flexion (sagittal plane)
- Trunk rotation (transverse plane)
- Time until maximum trunk rotation (% of pitch cycle)

**Hypothesis Explanation:**

Throughout the entire pitching motion, the lower extremity, pelvis, and trunk function in sequence by transferring energy up the open kinetic chain reducing the stress placed upon the upper extremities. While proximal-to-distal sequencing assists in increasing ball velocity by transferring momentum to the distal ends of the upper extremity, movement in the most distal segment does not occur until the adjacent proximal segment reaches maximum angular velocity. The amount of angular velocity of the pelvis and trunk may be affected by the mechanical behavior of the underlying surface and the interaction with cleated footwear. Kent et al. (2015) concluded that when cleated footwear is engaged with artificial surfaces, there is little motion between the shoe and the surface. On artificial surfaces, an interaction referred to as a “hold” or
“slide” can occur indicating the cleated footwear is displaced relative to the surface without causing a divot or can hold with minimal displacement relative to the Earth, respectively (Kent, Forman et al. 2015). At the instant of stride foot contact, the timing of pelvis orientation and duration of the pitch are dependent upon pelvis orientation. As a pitcher approaches an “open” pelvis orientation, shoulder ER increases, maximum pelvis angular velocity occurs earlier, and the time until ball release decreases while both early and late rotators didn’t differ on the time to complete the arm acceleration phase (Wright, Richards et al. 2004). Maximum forces and torques placed on the shoulder and elbow have also been shown to decrease the more a pitcher approaches an “open” pelvis at the point of stride foot contact. Therefore, the null hypothesis that an individual’s torso and pelvis kinematic variables will not be modified during an overhead baseball throw when exposed to FG (artificial turf) and a manufactured PM while wearing sport specific footwear is expected to be rejected.
Operational Definitions

Acceleration:
The rate of change of velocity with respect to time, mathematically the second time derivative of displacement and the first time derivative of velocity. Acceleration is also a vector quantity that may take positive, negative, or zero values (Rodgers and Cavanagh 1984).

Adolescent Pitchers:
Pitchers that are more physiologically developed athletes compared to their youth counterparts, aged between 14-18 years old, and are approaching or have already reached skeletal maturity; they have generally progressed further in their pitching skill and play, primarily as pitchers on their club or high school team (Davis, Limpisvasti et al. 2009).

Angular Momentum:
Moment of inertia multiplied by the angular velocity (Southard 2009).

Angular Velocity:
The rate of movement in rotation calculated as the first time derivative of angular displacement (Rodgers and Cavanagh 1984).

Clinical Movement:
A movement description is called clinical if it relates to arbitrarily defined axes and/or coordinate systems. The clinical description has the advantage that movement can be quantified easily with sufficient accuracy in clinical and research settings. However, it has the disadvantage that it does not indicate actual joint motion (Nigg and Segesser 1992).

Core Stability:
The function of the lumbopelvic-hip complex to both prevent collapse of the vertebral column and return it to natural stability, allows for energy to be transferred from the lower extremity to the upper extremity (Oliver and Keeley 2010)
Divot (Footwear Interaction):
Cleated footwear can tear a portion of the underlying surface away from its original location (Kent, Forman et al. 2015).

Dual Energy X-Ray Absorptiometry (DXA):
Bone density scanning, also called dual energy x-ray absorptiometry (DXA) or bone densitometry uses a very small dose of ionizing radiation to produce pictures of the inside of the body to measure bone loss. It is commonly used to diagnose osteoporosis and to assess an individual’s risk for developing fractures. DXA is simple, quick and noninvasive. It’s also the most accurate method for diagnosing osteoporosis and is today’s established standard for measuring bone mineral density (Radiology and America 2016).

Electromyography (EMG):
A technique used to measure muscle activity. It can be done externally and internally. During the contraction of a muscle, an electrical signal is formed; motor unit action potential (m.u.a.p) (Winter 1995).

Friction:
The tangential force acting between two bodies in contact that opposes motion or impending motion. If the two bodies are at rest, then the frictional forces are called static friction. If there relative motion between the two bodies, then the forces acting between surfaces are called kinetic friction (Rodgers and Cavanagh 1984).
**Functional Movement:**

A movement description is called functional if it relates to actual joint axes and/or coordinate systems which are related to actual anatomical functions. The functional movement description of movement has the advantage of describing the actual movement with respect to rotation in actual joints. However, it often has the disadvantage that it can not be quantified easily (Nigg and Segesser 1992).

**Hold (Footwear Interaction):**

Cleated footwear can hold with minimal displacement relative to the Earth (Kent, Forman et al. 2015).

**Joint Force:**

Multiple forces exerted by a body segment on an adjacent segment can be substituted by a resultant force exerted through the joint center ("joint force") and a resultant couple ("joint torque"). (Feltner and Dapena 1986)

**Joint Torque:**

Multiple forces exerted by a body segment on an adjacent segment can be substituted by a resultant force exerted through the joint center ("joint force") and a resultant couple ("joint torque") (Feltner and Dapena 1986). The joint torque reflects the net muscular activity at the joint, except near the limits of the range of motion, where ligaments, bones, and other passive structures may also contribute to it (Andrews 1981).

**Kinematics:**

The description of motion (Rodgers and Cavanagh 1984)

**Kinetics:**

The study of forces that cause motion (Rodgers and Cavanagh 1984)
Moment Arm:
The perpendicular distance from the point of application of a force to the axis of rotation (Rodgers and Cavanagh 1984).

Non-Contact Injury:
Injuries that do not result from direct loading of the affected limb by another player or object (Kent, Forman et al. 2015).

Overuse Injury:
An injury resulting from accumulated microtrauma developed during repetitive use caused by the large forces and torques exerted at the shoulder and elbow joint during pitching (Fleisig, Andrews et al. 1995).

Pitching Mechanics:
A coordinated sequence of body movements and muscular forces that have an ultimate goal of high ball velocity and targeted accuracy (Calabrese 2013).

Proximal-to-Distal Sequencing:
Motion is generated from larger, centrally located segments and continues outward to smaller, distal segments as energy is increased. This interaction between results in a summation of speed allowing the distal (end) segment to reach maximal velocity (Bunn 1972, Southard 2009).

Slide (Footwear Interaction):
Cleated footwear can displace relative to the surface without tearing a portion away (Kent, Forman et al. 2015).

Stride Leg/Foot:
The contralateral leg and foot, relative to the dominant throwing arm, which is aimed in the direction of the target and is used as a pivot point during the follow through phase.
Stride Angle:
The angle between the stride leg and trail leg at maximum foot contact oftentimes measured when the pitcher reaches the foot flat position of the stride leg (Calabrese 2013).

Stride Length:
The horizontal distance from the trail leg calcaneus at peak knee height to the stride foot calcaneus at stride foot contact, is variable within and across pitchers (Crotin, Bhan et al. 2015). It is calculated as the distance from the stride ankle to the pitching rubber, expressed as a percentage of the subjects height (Fleisig, Barrentine et al. 1999).

Traction:
The resistance to motion between a shoe outsole and a sport surface that does not always obey the laws of friction (2006).

Trail Leg/Foot:
The ipsilateral leg and foot, relative to the dominant throwing arm, which is used to generate power and subsequently increase ball velocity while properly aligning the trunk and lower extremity to transfer energy to the upper extremity.

Youth Pitchers:
Pitchers aged 9-13 years old that represent skeletally and physiologically immature athletes who are at a generally developmental stage in baseball (Davis, Limpisvasti et al. 2009).
CHAPTER II

REVIEW OF LITERATURE
The purpose of this research is to determine how sport-specific footwear alters the kinematic variables of the shoulder and elbow in youth and adolescent baseball pitchers during an overhead baseball throw on various surface inclinations. This review of literature will provide an oversight as to what previous qualitative and quantitative research has found on cleat-surface interactions and how throwing a baseball affects the musculoskeletal system. This chapter will be comprised of six primary sections with the first titled kinesiology/biomechanics of an overhead baseball throw that will discuss the six phases of the throwing motion and the kinematic and kinetic changes that are seen in the upper and lower extremity. The second section will explain cleated footwear within various sports and how they influence the likelihood of injuries. The third section will specifically look at various playing surfaces and how it influences sport-specific movements and the rate of injuries while the fourth section will analyze the interaction between cleated footwear and various underlying playing surfaces. The fifth section will analyze the muscle activity of the upper and lower extremity while the final sixth section will compare pitching variables between age groups.

1. Kinesiology/Biomechanics of an Overhead Baseball Throw
   i. Phases of Pitching Motion

2. Cleated Footwear
   i. Types
   ii. Injury Risks

3. Playing Surfaces
   i. Types
   ii. Pitching Mounds
   iii. Injury Risks
4. Shoe-Surface Interface
   i. Footwear Characteristics and its Interaction with an Underlying Surface

5. Muscle Activity
   i. Upper Extremity
   ii. Lower Extremity

6. Comparison Parameters
   i. Age Groups
   ii. Pitch Type/Count

KINESIOLOGY/BIOMECHANICS OF AN OVERHEAD BASEBALL THROW

i. Pitching Mechanics:

Throwing a baseball is one of the most dynamic motions relative to all overhead activities. Pitching mechanics, in relation to an overhead throwing motion, places stress on the musculoskeletal system and is defined as a coordinated sequence of body movements and muscular forces attempting to produce a high ball velocity coupled with targeted accuracy (Calabrese 2013). Two primary starting positions are used among pitchers and no regulations exist regarding either stance. The “set” or “stretch” starting position is typically utilized with runners on base with the intention of increasing the delivery speed to home plate (Braatz and Gogia 1987). The lateral portion of the trail foot begins against the front portion of the pitching rubber while the stride foot is a half step ahead and evenly aligned with the trail foot (Braatz and Gogia 1987). The full windup starting position allows pitchers to face home plate with their shoulders aligned with their target and both feet on the pitching rubber.

The lower extremities, pelvis, and trunk work in sequence to transfer kinetic energy up the chain to produce the desired outcome. Understanding the outcome of the overhead throwing
motion for a baseball pitcher from an anatomical, kinesiological, and biomechanical perspective required it to be divided into six phases (Figure 1) including: the (1) wind-up, (2) stride (early cocking), (3) arm cocking, (4) arm acceleration, (5) arm deceleration, and (6) follow-through (Dillman, Fleisig et al. 1993, Werner, Fleisig et al. 1993, Fleisig, Escamilla et al. 1996).

Wind-Up:

The wind-up phase relies heavily on balance and is initiated at the instance when the pitcher moves from a static standing position. Lasting approximately 0.5-1.3 seconds, the windup aims to assist the timing and cadence for the extremities during the subsequent phases (Nicholas, Grossman et al. 1977, Braatz and Gogia 1987). The beginning of the overhead throwing motion is initiated as the pitcher steps backward with the stride foot/leg and the trail foot/leg pivots and rotates laterally in front of the pitching rubber (Dillman, Fleisig et al. 1993). Pivoting should occur by shifting body weight from the stride foot to the trail foot in order to begin the delivery sequence. Upon completion of the stride foot/leg moving backwards and simultaneously as the trail foot pivots, pitchers raise both hands concurrently ranging from their belt to over and/or behind their head with height dependent upon personal preference (Braatz and Gogia 1987). Neck flexion and the avoidance of scapular retraction are recommended in order to keep the center of gravity (COG) aligned within the base of support (BOS). A loss of balance occurs if the COG is positioned too far anteriorly or posteriorly while the torque placed upon the upper extremity joints increases predisposing the pitcher to injury (Calabrese 2013).

Subsequently, trunk rotation occurs up to ninety degrees and the stride leg is elevated off the playing surface. The stride legs hip and knee are flexed, lumbar spine moved from extension to flexion, pelvis rotates in the direction towards the pitching arm and hands are lowered to chest height (Braatz and Gogia 1987). Maximum knee height of the stride leg, also known as the
“balancing point” or “gathering point”, marks the end of the windup phase and the beginning of stride (early cocking) phase (Braatz and Gogia 1987, Fleisig, Escamilla et al. 1996, Calabrese 2013). If too high, stride leg maximum knee height pushes the shoulders back and retracts the scapula’s while a decreased value will cause the trunk and pelvis to open up causing the dominant arm to lag behind during the acceleration phase (Braatz and Gogia 1987).

**Stride:**

The stride phase begins at the “balancing point” or the first frame where the ball is removed from the glove and is responsible for aligning the trunk and lower extremity in a position to transfer energy to the upper extremity (Fleisig, Escamilla et al. 1996, Calabrese 2013). During this phase, the trail leg is flexed supporting body weight while the stride leg moves toward home plate and the catcher. Flexing the trail leg lowers the COG and accelerates to increase stride length. Nearly half of total ball velocity comes from the forces generated from trunk rotation and stride allowing for five specific lower body phases to accompany the traditional phases of the throwing motion: (1) Generation phase, (2) Brace-transfer phase, (3) Acceleration, (4) Deceleration, and (5) Follow-Through phase (Seroyer, Nho et al. 2010, Crotin, Bhan et al. 2015)

Mechanical energy, generated from ground reaction forces, is transferred up from the stride leg to the pitching hand through the pelvis, trunk, humerus, and forearm (Seroyer, Nho et al. 2010). The stride occurs during the early cocking phase which is described as the arm motion during a period of “single support” (Crotin, Bhan et al. 2015). During this time, only the trail foot is in contact with the ground while the stride leg is accelerating towards home plate and contacts the ground. The linear mechanical energy moves the body’s center of mass (COM) forward allowing the “single support” phase to be described as the “generation phase” (Crotin,
Advanced pitchers will land with stride foot toe contact to begin an internal rotation moment allowing ipsilateral transverse pelvic girdle rotation to occur transferring momentum from proximal to distal segments. Upon stride foot contact, maximal external rotation of the throwing shoulder is achieved from upward scapular rotation, posterior scapular movement, and retraction causing shoulder abduction (Seroyer, Nho et al. 2010). The stride leg will then stop the forward movement and transfer the energy to the pelvis and trunk causing rotation. The time period separating stride foot contact and maximum shoulder external rotation takes the body from a period of single leg support to double leg support creating the “brace-transfer phase” (Seroyer, Nho et al. 2010). Maximal external rotation to the time of ball release is known as the “acceleration phase” causing the internal rotators to transition from a period of an eccentric stretch to a concentric muscle action rapidly moving the arm towards the target (Seroyer, Nho et al. 2010).

Normative stride length values range form 75%-87% of the pitchers height while the pelvis rotates at a velocity between 400-700°/s and spinal rotation occurs about a steady trunk (Calabrese 2013). It has previously been suggested that a stride length greater than 90% of the pitchers height could be detrimental by increasing injury risk while decreasing performance (Schutzler 1980). However, stride lengths reaching 92% of a pitchers height had no negative effects on ball velocity or accuracy (Montgomery 2002). Longer stride lengths have previously demonstrated that foot contact at 80% of the time from peak knee height to ball release whereas a shorter stride saw a 73% change decreasing the time in single leg support (Crotin, Bhan et al. 2015). Flexibility in the stride leg hamstrings and trail leg hip flexors and rotators may restrict mobility and shorten stride lengths (Calabrese 2013). Musculature including the gluteus
maximus/minimus, piriformis, and obturator internus control the hip of the stride leg while the trail leg hip rotation is controlled by the tensor fascia latae, gluteus medius and hamstrings (Calabrese 2013). During the stride phase, young pitchers demonstrate inadequate trunk rotation prior to scapula positioning, stride foot contact direction, stride angle and knee flexion angle (Calabrese 2013).

Stride foot contact is classified as either “closed” or “open”. Right-handed pitchers typically demonstrate a “closed” contact towards third base while directed towards home plate and left-handers are in a “closed” position towards first base. Flexibility in the stride leg hip external rotators and trail leg internal rotators can negatively influence the stride length. An extremely closed stride foot position locks the pelvis and hip not allowing for appropriate energy transfer to occur between the upper and lower body causing the arm to throw ahead of the shoulder (Calabrese 2013). The throwing arm will then be forced to cross the body placing stress on the anterior shoulder capsule and medial elbow since an increase in arm velocity is needed to reach the desired ball velocity and target. An open foot position produces early pelvis rotation decreasing ball velocity since the throwing arm is “lagging” behind the body rotation adding a valgus load to the medial elbow (Calabrese 2013).

Stride angle, measured from the stride leg at foot flat and trail leg is a variable that explains hip flexibility to coaches and medical personnel (Calabrese 2013). Short stride angles place excessive strain on trunk musculature including the obliques and rectus abdominis allow rapid acceleration of the trunk (Calabrese 2013). With cleated footwear, forward movement of the lower extremities will stop upon stride foot contact allowing the trunk and upper extremity to rapidly rotate. Musculoskeletal structures, specifically the inferior glenohumeral ligament, act as static stabilizers working in conjunction with the rotator cuff (supraspinatus, infraspinatus, teres
minor, subscapularis) to properly position the humeral head within the glenoid fossa to reduce overload (Calabrese 2013). The scapula exhibits upward rotation and is in a retracted position allowing the rotator cuff musculature, along with the delotids, to abduct the throwing arm in preparation for the arm-cocking phase. Developing proper arm path, hand positioning, excessive wrist flexion, and placing the shoulder in external rotation too early are common faults among young pitchers (Calabrese 2013).

Arm-Cocking:

The arm-cocking phase begins at initial contact of the stride foot and ends when the throwing arm is in maximal external rotation, abducted to 90°-100°, horizontally adducted up to 20° while the elbow is flexed at 90°. Upon foot contact, lateral trunk rotation towards the target is followed by hip rotation. Internal oblique and erector spinae allows for trunk rotation allowing advanced pitchers to increase the amount of extension in the trunk (Calabrese 2013). Once the trunk is in a position facing the target, the arm is flexed at the elbow and the shoulder is maximally externally rotated.

Arm Acceleration:

Arm acceleration begins when the humerus begins to internally rotate within the glenoid fossa (Dillman, Fleisig et al. 1993). Elbow extension, prior to internal rotation, then increases the mass moment of inertia as mass is further from the axis of rotation allowing for increased internal rotation torque at the shoulder and subsequently a greater angular velocity (Dillman, Fleisig et al. 1993). This period of time from maximal external rotation until ball release lasts approximately 42-58ms making it one of the fastest movement among all sports (Dillman, Fleisig et al. 1993). At 9000°/sec transitioning from maximal external rotation to internal rotation and horizontal adduction, the elbow travels at 2251-2728°/sec causing impingement problems
Relative to professional pitchers, amateur pitchers display three times as much biceps brachii and rotator cuff muscle activation during the acceleration phase (Gowan, Jobe et al. 1987). On average, the throwing arm is abducted at 100° prior to ball release when it is then decreased to 95° (Dillman, Fleisig et al. 1993). 90°-110° of shoulder abduction is categorized as a strong position for both the arm and shoulder (Dillman, Fleisig et al. 1993). Therefore, anything less than 80° and greater than 120° in regards to shoulder abduction from foot contact to ball release is considered “abnormal” (Dillman, Fleisig et al. 1993). An altered lateral trunk flexion will either raise or lower the release point while the not changing the degree of abduction. Excessive amounts will lead to an “over the top” mechanism while a decreased lateral trunk flexion may force pitchers into a sidearm release placing added stress on the medial portion of the elbow, specifically the ulnar collateral ligament (Calabrese 2013). This phase ends once the ball is released.

Arm Deceleration:

From the time the ball is released until the throwing shoulder is maximally internally rotated, the arm goes through the deceleration phase (Dillman, Fleisig et al. 1993, Fleisig, Escamilla et al. 1996). Upon completion of this phase, the pitcher should be in a fielding position. The trail leg is suspended in the air while the trunk rotates over the stride leg towards the target. Hip internal rotation flexibility on the stride leg will determine how effectively a pitcher can assume a balanced fielding position while the teres minor, infraspinatus, and posterior deltoid prevent humeral head movement (Calabrese 2013). With that musculature acting to stabilize the humeral head, the serratus anterior and rhomboids act eccentrically to prevent scapular movement (Calabrese 2013). However, if the musculature is not eccentrically firing at a high enough rate, the large rotational forces developed as the throwing arm stretches
towards home plate may lead to shoulder injuries such as GIRD.

**Follow Through:**

Extension of the stride leg, hip flexion, shoulder adduction, horizontal adduction, elbow flexion, and forearm supination are utilized to take a pitcher from maximum internal rotation to the balanced fielding position (Dillman, Fleisig et al. 1993). Although this phase cannot directly improve or hinder the throwing motion, the time it takes to go from stride foot contact to ball release lasts 0.145 seconds with the ball traveling from 4-85 miles per hour (mph) (Dillman, Fleisig et al. 1993).

**CLEATED FOOTWEAR**

In 2009, approximately $17.1 billion dollars were spent on athletic shoes according to the National Sporting Goods Association while university students spent an average of $52 on each pair (Akpata, Thebe et al. 2015). In deciding which pairs to buy, quality, comfort, brand, price, athlete endorsement and style were considered, respectively (Akpata, Thebe et al. 2015). Therefore, understanding how a player’s foot in a cleated shoe interacts with the playing surface is often times over looked yet important for potential injury risk and sports performance. Cleated footwear, also referred to as “cleats” or “studs”, act as a tool for field-athletes to create a link between themselves and the playing surface.

**Injury Prevention:**

Although baseball specific footwear has yet to be studied, football and soccer cleats have been studied extensively. Approximately 21-61% of all lower extremity injuries that occur in both football and soccer are deemed “non-contact” and caused by “foot entrapment” (Torg, Quedenfeld et al. 1974, Lambson, Barnhill et al. 1996). It was originally reported that in order for a significant ankle or knee injury to occur due to footwear, cleats must firmly fixate the foot
to the ground to damage the musculoskeletal system (Torg and Quedenfeld 1971). Foot fixation is dependent upon two primary factors, the number and the size of the cleats (Torg and Quedenfeld 1971). When a cleat has fewer studs that are smaller in size, a larger force is generated through each cleat since there is a smaller surface area that is weight bearing (Torg and Quedenfeld 1971). On the other hand, if a cleat has longer studs, the depth of penetration will subsequently increase causing the foot to become fixed to the surface. When this occurs, a force initiated from the trunk and thigh is then transferred and absorbed by the knee and ankle. When a force of great magnitude is transmitted in a plane that is opposite of its normal joint motion, structural damage may occur (Torg and Quedenfeld 1971).

By changing the type of footwear utilized in a late 1960’s football league, a significant decrease in the incidence and severity of knee injuries was observed (Torg and Quedenfeld 1971). Having athletes change from a “conventional football shoe” with seven ¾ inch studs to a “soccer type shoe” with fourteen 3/8 inch studs, the total number, average injuries per game, and severe ankle and knee injuries decreased (Torg and Quedenfeld 1971). The soccer type shoe decreases the likelihood of foot fixation since it has twice as many studs that have a surface area of 2.8 square inches opposed to 0.8 square inches (Torg and Quedenfeld 1973). This indicates the surface area is 3.5 times greater on the soccer type shoe decreasing the force transmitted through each stud by a factor of 3.5 (Torg and Quedenfeld 1973). The conventional shoe led to an increase in injury since the cleats were long enough to penetrate the soil and link with the grass (Torg and Quedenfeld 1971, Bonstingl, Morehouse et al. 1974). Therefore, it was recommended that football players begin wearing cleats with the following specifications: (1) synthetic molded sole, (2) minimum of 14 studs per shoe, (3) minimum stud diameter of ½ inch, and (4) maximum stud length of 3/8 inch (Torg and Quedenfeld 1971).
Performance:

One vital extrinsic factor that may play a role in a pitcher's mechanics and the rate of injuries is the footwear. The ability of a cleat to firmly grip the underlying playing surface depends upon uncontrollable factors such as the size, number and distribution of the studs. From a performance perspective, the footwear interaction with the surface will determine how well an athlete can accelerate, slow-down/stop, and rapidly change direction (Kent, Forman et al. 2015).

Few studies have truly investigated the effects of various cleats and stud patterns/configurations on ground reaction forces (GRF) within athletics. While simulating game-like agility maneuvers, it was found that differences between cleats exist in total foot peak pressure and lateral, medial, and middle forefoot normalized maximum force (Queen, Charnock et al. 2008). However, results are solely dependent on the performance and skill level of the participants rather than the cleat patterns themselves since one cleat may break traction with the underlying surface while the other may not (Kent, Forman et al. 2015).

PLAYING SURFACES

Multiple types of playing surfaces exist and are used for either indoor or outdoor field based sports. Surfaces are categorized as either natural grass (i.e. Bermuda Grass, Kentucky Blue Grass) or artificial/synthetic surface (i.e. Astroturf, AstroPlay, or FieldTurf) (Livesay, Reda et al. 2006, Kent, Forman et al. 2015). A majority of the modern athletic fields utilize some type of infill including concrete, rubber pellets, sand, or other matter such as polyethylene fibers (Livesay, Reda et al. 2006, Kent, Forman et al. 2015). Artificial grass fibers are typically connected to the base layer with infill lying between them. Astroturf was the first synthetic playing surface developed and was made up of rough and asymmetrical nylon fibers where newer versions (i.e. Astroplay and FieldTurf) have been designed to mimic natural grass.
AstroTurf is made up of polyethylene fibers while Astroplay has a rubber infill and Field Turf has a 50%/50% combination of rubber and sand (Livesay, Reda et al. 2006).

In the late 1990’s, third generation artificial turf (3G turf) became popular among recreational and professional leagues, specifically within European soccer, while its similarities to natural grass are often questioned. The latest versions of turf use grass fibers that are longer (>40mm), skin-friendly, and an infill that is: (1) polyethylene fibers with a sand/rubber combination to allow for normal ball bouncing, (2) turf with no infill looked to prevent an increase in field temperatures, and (3) a semi synthetic turf uses natural grass that is reinforced with synthetic fibers (Smeets, Jacobs et al. 2012).

Within the baseball community, there are currently two major league baseball (MLB) ballparks, 32 National Collegiate Athletic Association (NCAA) ballparks and little league stadiums across the country that play baseball on FieldTurf. Depending on the age of the athletes, field dimensions will vary in regards to the length of the base paths, mound height (distance above home plate), as well as the distance from the pitching rubber to the apex of home plate.

**SHOE-SURFACE INTERFACE**

Cleated footwear is a common shoe worn among athletic populations playing on natural and artificial surfaces. The footwear acts as a bond between the athlete and the underlying surface allowing them to rapidly accelerate, slow down, and change directions and may potentially alter performance and the likelihood of injury. The surfaces’ ability to resist the motion of a shoe are divided into horizontal and vertical resistive classes (Driscoll, Kelley et al. 2015). Horizontal resistance to motion is classified as traction, which can be changed by
choosing alternative stud configurations and surface conditions, is determined by the outsole of the shoe and the surface (Driscoll, Kelley et al. 2015). Vertical resistive forces are determined solely on stud shape, the ability of a stud to penetrate a surface, and a surfaces’ hardness (Driscoll, Kelley et al. 2015). These resistive forces may lead to either contact or non-contact lower extremity injuries to the foot, ankle, and knee due to “foot entrapment”.

Mechanical tests such as penetrometers and motor-driven devices are oftentimes utilized to test a shoe configuration on various surfaces. Two types of mechanical testing exist in order to test the traction of a shoe configuration: (1) measuring translational traction by pulling a cleat across a surface and recording the resistance and (2) measuring the rotational traction by recording the torque required to rotate a shoe that is in contact with a surface (Driscoll, Kelley et al. 2015). These specific tests attempt to look at the shoe-surface interface at a micro level to determine how either rubber particles or soil are displaced when cleats move through a surface (Driscoll, Kelley et al. 2015). One of the first prototypes attempting to analyze the release coefficient and the safety characteristics of multiple shoe-surface interactions was referred to as “The Assay Device” (Torg, Quedenfeld et al. 1974). Quantifying the release coefficient as Force/Weight allows for the comparison between various shoe-surface combinations (Torg, Quedenfeld et al. 1974). It was concluded that any shoe-surface combination with a release coefficient 0.49 or greater are not safe while a score of 0.31 or less is deemed safe (Torg, Quedenfeld et al. 1974). The 0.31-0.49 area cannot be explained but researchers went on to hypothesize those that coefficients that fall closer 0.31 are safer than those closer to 0.49 (Torg, Quedenfeld et al. 1974). Molded sole “soccer-type” shoes with fifteen studs that are ½ inch in length and diameter were deemed to be safe on all surfaces.

Similarly, Kent et al. (2012) designed an apparatus to look at three different scenarios
that can generate forces three times greater than that of a 95kg elite athlete (Kent, Crandall et al. 2012). When these forces coupled with a resulting breakaway force (torque) are applied to cleated footwear, one of the situations can happen: (1) hold, (2) divot, or a (3) slide (Kent, Forman et al. 2015). Both a divot and slide are force-limiting situations indicating the characteristics of a cleat will determine the forces placed upon the foot while a hold is determined by the amount of force applied by an individual/machine (Kent, Forman et al. 2015). Although injuries can occur on both natural and artificial surfaces, artificial surfaces should not break away or cause a “divot” which eliminates a potential injury-alleviating characteristic. Therefore, the interaction between cleats and a surface will determine the release mechanics and potential for injury since a divot would typically decrease the loading on the foot. Various cleats on natural grass generated horizontal forces and torques ranging from 2.8kN-4.2kN in translational tests and 120Nm-174Nm in rotational tests indicating a positive relationship between horizontal forces and torques (Kent, Forman et al. 2015).

During common sport-specific tasks, musculoskeletal injuries occur with sudden stops and a change in direction, however, the greatest risk of injury is present when slowing a movement. The amount of torque and force generated from the shoe-surface interface are transferred up the kinetic chain and affects all joints. It was found that heavier athletes wearing cleated footwear are exposed to higher torques which increases by 70% when the entire foot is in contact with the underlying surface whereas non-cleated footwear produce smaller torques on both natural and artificial surfaces (Bonstingl, Morehouse et al. 1974). Andreasson et al. (1986) proposed that a balanced shoe that has distributed material from the heel to the toe might eliminate initial torque (Andreasson, Lindenberger et al. 1986). Friction developed from non-cleated footwear creates the torque transferred up the kinetic chain while a smaller amount is
created on natural grass rather than artificial turf; however, the differences in torque from various configurations are minimal on all surfaces when no studs are present (Bonstingl, Morehouse et al. 1974).

The total effective cleat surface area, or the number of studs in contact with the surface multiplied by the surface area on the bottom of each shoe, describes the amount of torque developed due to the characteristics of the surfaces and footwear (Bonstingl, Morehouse et al. 1974). Torque is developed based upon the type of shoe, playing surface, and the static or dynamic stance. Between a twelve-studded molded cleat and different surfaces, the largest average peak torque was 33.8Nm for a molded cleat-FieldTurf interaction while the lowest was 21Nm for a molded cleat-natural grass condition (Livesay, Reda et al. 2006). Turf shoe-Astroturf displayed the average largest peak torques at 33.2Nm and the turf shoe-natural grass exhibited an average torque of 22Nm (Livesay, Reda et al. 2006).

**MUSCLE ACTIVITY**

i. **Upper Extremity**

Along with kinematic and kinetic data, electromyography (EMG) has been used to analyze muscle activity of the overhead pitching motion. The upper extremity, trunk, and lower extremity all have to work in synchronization to produce maximum ball velocity with targeted accuracy. Muscle activity during the pitching motion is very precise in understanding the sequence and amplitudes of activation patterns and could assist with pre- and post-season conditioning, injury prevention, and rehabilitation. It is currently highly debated as to what a level of muscle activation is deemed “significant”. EMG activity ranging from 40-50% maximal voluntary contraction (MVC) was regarded as an optimal level for rehabilitation purposes while other studies suggested activations exceeding 50% MVC was difficult for participants
Therefore, criterion set forth by multiple researchers have defined muscle activation as minimal activity (0-20% MVC), moderate activity (20-35% MVC), moderately strong (35-50% MVC), and significantly high (>50% MVC) (Tucker 2005, Campbell, Stodden et al. 2010).

The initial wind-up phase only elicits up to 21% of muscle activation within the upper extremity musculature since there is a lack of movement (DiGiovine, Jobe et al. 1992). This level of activity within the elbow and shoulder makes it highly unlikely an injury will occur to a pitcher during this time. From the point of stride leg maximum knee height to foot contact (stride phase), the serratus anterior and upper trapezius align the glenoid fossa to articulate with the humeral head by upward rotating and protracting the scapula with 40% and 64% MVC, respectively (DiGiovine, Jobe et al. 1992). This motion simultaneously allowed for the deltotoids to exhibit 42% MVC and the supraspinatus 60% MVC to abduct the shoulder (DiGiovine, Jobe et al. 1992). The rotator cuff, as a unit, displayed a moderate activity level while the supraspinatus displayed high activity levels which then paralleled its surrounding musculature in subsequent phases (DiGiovine, Jobe et al. 1992).

The arm-cocking phase is characterized by maintaining the desired level of abduction while horizontal adduction decreased from 18° to 11° and ER increased from 46° to 170° (Feltner and Dapena 1986). The middle trapezius and levator scapula stabilize the scapula within this phase by retracting it with 51% and 72% MVC, respectively (DiGiovine, Jobe et al. 1992). Opposing scapular retraction, the serratus anterior exhibits 106% MVC activation while positioning the glenoid fossa for maximum congruency (DiGiovine, Jobe et al. 1992). If maximum congruency is not achieved, the athlete is at risk for injuries during the acceleration phase. Lasting 42-58ms, the shoulder shifting from maximal external rotation to internal rotation
and horizontal adduction moves at 9000°/second while the elbow nears 2700°/second in the scapular plane (Montgomery 2002). The posterior deltoid acts as the primary horizontal abductor while the teres minor and infraspinatus are highly and moderately activated during a baseball pitch, respectively (DiGiovine, Jobe et al. 1992). This may indicate why posterior cuff tendonitis can be isolated to the teres minor. In order to rapidly return the elbow to extension, the triceps fire at 89% MVC with the trapezius and levator scapulae generating more than 70% of their MVC (DiGiovine, Jobe et al. 1992). Although very similar muscle activity is observed between professional and amateur pitchers, one primary difference is professionals rely on the subscapularis and latissimus dorsi (185% and 133% MVC, respectively) to generate power whereas amateurs utilize the other rotator cuff muscle (Gowan, Jobe et al. 1987).

With the shoulder responsible for dissipating the energy not used to accelerate and release the ball, slowing the shoulder and elbow can occur at 500,000 m/s² (Pappas 1985). All musculature around the shoulder, elbow, and wrist fire concurrently with the upper, middle, and lower trapezius. All three portions of the deltoid exhibit high activity with the middle and posterior deltoids firing at a higher rate since they are positioned and act as an antagonist relative to the anterior head (DiGiovine, Jobe et al. 1992). Simultaneously, the latissimus dorsi, in conjunction with the subscapularis, prevents shoulder subluxation upon internal rotation and is able to provide a mechanical advantage once the humerus is below 90° (DiGiovine, Jobe et al. 1992). During the final follow-through phase, the deltoid, subscapularis, supraspinatus, infraspinatus and teres minor are highly active; however, no quantitative values were presented (Jobe 1983). However, conflicting results were found when all upper extremity musculature, except the serratus anterior, was below 36% MVC deeming the entire movement as a “noncritical motion” (DiGiovine, Jobe et al. 1992). Therefore, it is evident that all muscles in the
upper extremity responsible for throwing a baseball act in a coordinated sequence in order to maximize ball velocity and accuracy. After the completion of a game throwing 99 ± 29 pitches and 7 ± 2 innings, pitchers have exhibited a 15% decrease in external rotation, and a 15%, 13%, and 12% strength decrease in the rhomboids, middle trapezius, and lower trapezius, respectively (Mullaney 2005).

i. Lower Extremity

Although the lower extremities are vital to the baseball pitch sequence, muscle activity is rarely researched in comparison to the upper extremity. During a pitch sequence, the responsibilities of the lower extremities are still unknown and highly debated. It is suggested pitchers either “fall” forward towards home plate or use their trail leg to push off of the pitching mound to increase momentum. If an athlete uses the “push-off” method, hip and knee musculature would be highly active while the alternative would exhibit less muscular activity (Campbell, Stodden et al. 2010). Information collected on muscle activation patterns can then provide evidence regarding performance and injuries. An original study initially looked at the trail and stride legs abductors, adductors, quadriceps femoris, biceps femoris, tibialis anterior and gastrocnemius while only dividing the entire sequence into two distinct phases (Yamanouchi 1998). The adductors (84% ± 8% MVC) and quadriceps (48% ± 14% MVC) in the trail leg were significantly different than the control group and elicited moderate muscle activity during the first two seconds prior to stride foot contact (Yamanouchi 1998). The stride legs’ biceps femoris (71% ± 23% MVC) was significantly different in the first phase when the adductors, biceps femoris, and tibialis anterior varied in phase two (Yamanouchi 1998).

Clearly labeling each phase of the pitching sequence outlined by Campbell et al. (2010) allows for specific delineations between when the motion begins and ends monitoring muscle
activation. The four phases, based upon Fleisig et al. (1996), were defined as (1) the initiation of the pitch to maximum stride leg knee height, (2) maximum stride leg knee height to stride foot contact, (3) stride foot contact to ball release, and (4) ball release to 0.5 seconds after ball release (Campbell, Stodden et al. 2010). The arm cocking and acceleration phases were combined due to their short durations while the deceleration and follow-through phases led to the same conversion. The stride leg demonstrated moderate to high muscle activities for the gastrocnemius, vastus medialis, rectus femoris, gluteus maximus, and biceps femoris during phases two, three and four (23-170% MVC) while the trail leg saw moderate to high readings during phases two and three (38-172% MVC) (Campbell, Stodden et al. 2010). Fatigue, upon completion of 7 ± 2 innings, causes a 16%, 14.5%, 12.5%, and 12% decrease in strength for hip extensors, hip abductors, hip flexors, and hip adductors, respectively (Mullaney 2005). This is advantageous to the athlete in that the adductors fatigued the least while acting as the main source of energy for the upper extremity and stabilizing the trunk (Yamanouchi 1998).

The summation of speed principle describes the timing and momentum of larger proximal segments, such as the trunk, which begins movement when its adjoining proximal segment reaches its maximum angular velocities. The pelvis and torso have the largest contribution in regards to the body’s total angular momentum and provides 50% of the kinetic energy used in the overhead baseball throw (Putnam 1991). Core stability allows proximal stability for distal mobility and is defined as the function of the lumbopelvic-hip complex to both prevent collapse of the vertebral column and return it to natural stability (Oliver and Keeley 2010). Therefore, the lumbopelvic-hip complex that includes the gluteal muscles, transfers energy from the lower extremity to the upper extremity. Mean muscle activity for the gluteus maximus and medius can exceed 100% MVC from stride to arm-cocking phases and decrease to less than 100% in
subsequent phases (Oliver and Keeley 2010).

**COMPARISON PARAMETERS**

Regardless of the number of pitches one is able to throw, it is advantageous for a pitcher to throw with similar kinematics in order to disguise the pitch type to the opposing batter. Utilizing different throwing kinematics with off-speed pitches allows batters to identify the type of pitch when they have less than 0.5 seconds upon ball release until crossing home plate. However, the rate of injuries in youth baseball pitchers has been steadily increasing over the years with 32-35% of 9-19 year olds reporting shoulder pain (Lyman, Fleisig et al. 2002) with the frequency of ulnar collateral ligament (UCL) surgeries progressing from 119 from 1995-1998 to 619 from 2003-2006 (Dun, Loftice et al. 2008). Of those surgeries performed, 8% and 24% were high school athletes, respectively (Dun, Loftice et al. 2008). In order to minimize injuries, youth baseball organizations are restricting the number of pitches an athlete can throw.

Data supports that early in an athletes playing career is the best opportunity to teach and correct and mechanical flaws since mechanics do not significantly change with age and experience even when youth pitchers throw over 200 pitches per week (Lyman, Andrews et al. 1998). Fatigue occurs at different time points during a game making it an individualized variable controlled by rest between innings, number and types of pitches thrown as well as musculoskeletal stress accumulated throughout the duration of a season (Escamilla, Barrentine et al. 2007). On average, the number of pitches per inning for various age groups totaled 19 for little league, 18 for 13 year olds, 14 for high school, 16 for college, and 14 for professionals (Axe, Wickham et al. 2001). Although muscular fatigue can be described as a decrease in force production, it is a very individualized variable making it unknown why adolescent pitchers sustain frequent elbow and shoulder injuries.
Muscle soreness is deemed “normal and necessary” in order for a pitcher to develop, however, joint pain may indicate the beginning of an overuse injury (Lyman, Fleisig et al. 2002). Pitch type, pitch count, and pitching mechanics are the primary variables accounting for upper extremity pain. Therefore, it is recommended by USA Baseball that pitchers first learn how to throw a fastball at the age of 8 ± 2 years to avoid breaking pitches which should be avoided until 14 years old (curveball) and 16 years old (slider) (Lyman, Fleisig et al. 2002). Similarly, in order to avoid a high pitch count, USA Baseball recommends pitch limits rather than innings of 52 ± 15 pitches per game for 8-10 year olds, 68 ± 18 for 11-12 year olds, and 76 ± 16 pitches for 13-14 year olds (Lyman, Fleisig et al. 2002). For 9-14 year old pitchers, 81% (3075 of 3789) threw under 75 pitches per game since the rate of injury increases by 35% and 52% for the elbow and shoulder, respectively (Lyman, Fleisig et al. 2002).

It has previously been shown that young pitchers place more stress on the shoulder and elbow when throwing a fastball compared to a curveball (Dun, Loftice et al. 2008). Similarly, Nissen et al. discovered that the peak moment at each joint is directly correlated with ball velocity disproving the myth that a curveball, a slower breaking pitch, produces larger joint moments (Nissen, Solomito et al. 2013). However, this can vary between 10-14 year olds since large variability has been found in fastball pitching technique (Nissen, Westwell et al. 2007). In regards to the lower extremities, pitching kinematics between adolescents and collegiate pitchers are similar while momentum is smaller potentially due to a smaller body mass (Kageyama, Sugiyama et al. 2015).
CHAPTER III

MANUSCRIPTS
MANUSCRIPT I

A KINEMATIC INVESTIGATION OF THE SHOE-SURFACE INTERFACE AND THE PITCHING MOTION IN YOUTH AND ADOLESCENT BASEBALL PITCHERS
1. **Introduction:**

With pitchers holding the largest share by contract value in Major League Baseball (MLB) (Brown 2015), their importance on the baseball field cannot be understated. It is however the rate of injuries at this position that makes it extremely dangerous if proper mechanics are not taught or utilized, potentially outweighing the financial benefit. During the 2015 MLB season, 198 athletes were placed on the disabled list for an extended period of time accounting for $700 million in lost salaries (Brown 2015). Pitchers accounted for approximately 58.6%, or roughly $420 million of that total salary, with elbow and glenohumeral joint (hereafter referred to as the shoulder) injuries acting as the two leading causes for players landing on the disabled list at 21.7% and 17.1%, respectively (Brown 2015). Epidemiological studies have discovered similar injury trends are present in younger pitchers. Youth athletes, aged 9-13 years, are in the developmental stages of their baseball career and play a variety of positions since they are physically and physiologically immature while adolescents, aged 14-18 years, are more anatomically developed allowing their baseball skill set to adapt to one specific position (Davis, Limpisvasti et al. 2009). Injuries within these age groups are typically defined and reported as “pain” which could be an early indicator of a more serious injury (Lyman and Fleisig 2005).

Increases in age and weight have shown to be the primary risk factors inducing elbow pain with the number of pitches thrown throughout an entire season, resistance training, and pitching year-round exacerbating the issue (Lyman, Fleisig et al. 2001). Shoulder pain on the other hand has been found to be associated with increased pitches thrown throughout a season, throughout a game, and “fatigue” (Lyman, Fleisig et al. 2001). Upper extremity arm pain was reported in 15% of all pitching appearances in 9-14 year olds (Lyman, Fleisig et al.)
2002) while 32% and 26% reported shoulder and elbow pain after each game, respectively (Lyman, Fleisig et al. 2001). As such, baseball pitching has become a great concern among medical professionals, coaches and parents as to the safety of the overhead pitching motion in younger athletes.

As of 2013, the popularity among youth and adolescents participating in competitive baseball has increased to 5.3 million in the United States (Costa 2015). Although participation has increased, early specialization and year-round throwing among baseball players has become more prevalent placing undue stress on the upper-extremity. In attempt to minimize these injuries and stresses, USA Baseball has provided recommendations for pitch counts and pitch types for various age groups. Pitch limits of 52 ± 15 pitches per game for 8-10 year olds, 68 ± 18 for 11-12 year olds, and 76 ± 16 pitches for 13-14 year olds are suggested opposed to inning restrictions (Lyman, Fleisig et al. 2002). Similarly, pitchers are recommended to first learn how to throw a fastball at the age of 8 ± 2 years while breaking pitches should be avoided until 14 years old (curveball) and 16 years old (slider) (Lyman, Fleisig et al. 2002).

It has previously been shown that young pitchers place more stress on the shoulder and elbow when throwing a fastball compared to a curveball (Dun, Loftice et al. 2008) contradicting the results found by Lyman et al. (2002). However, peak moments at the shoulder and elbow are directly correlated with ball velocity negating the theory that a slower breaking pitch produces larger joint moments (Nissen, Solomito et al. 2013). This trend is causing an increase in overuse injuries in young athletes due to high external forces acting on the arm coupled with inadequate muscle strength to stabilize the joints (Axe 2001, Garner, MacDonald et al. 2011, Astolfi 2013). Although muscular fatigue can be described as a
decrease in force production, it is a very individualized variable. Fatigue may occur earlier or later throughout a game and may be determined on the amount of rest between innings, number and types of pitches thrown as well as musculoskeletal stress accumulated throughout the duration of an entire season (Escamilla, Barrentine et al. 2007). Therefore, the exact cause of why youth and adolescent pitchers sustain frequent elbow and shoulder injuries can only be speculated to this point.

One variable often overlooked by athletes and coaches that may affect performance and influence potential injuries is the shoe-surface interaction which is responsible for the surfaces’ ability to resist motion of a shoe (Driscoll, Kelley et al. 2015). Cleated footwear is the first point of contact between the athlete’s foot and artificial playing surface. Both vertical and horizontal resistive forces are used to calculate and determine the effectiveness of the shoe-surface interaction. Vertical forces determine a cleats’ ability to penetrate the surface which is affected by the surfaces’ hardness and stud shape (Driscoll, Kelley et al. 2015) while horizontal resistance is referred to as traction. Therefore, changing the cleat configuration on the outsole of the shoe or the playing surface can alter the amount of traction. While it has been shown that pitching from a mound, compared to flat ground, significantly increases the shoulder and elbow moments by 6% in adolescent pitchers (Nissen, Solomito et al. 2013), there is no known research specifically analyzing how the shoe-surface interaction affects pitching mechanics. Therefore, the specific aim of this study was to determine how baseball specific footwear [Molded Cleats (MC) and Turf Shoes (TS)] on varying inclined surfaces [Pitching Mound (PM) and Flat Ground (FG)] affect the kinematics of the pitching motion in youth and adolescent baseball pitchers throwing a fastball.
2. **Methodology:**

The purpose of the study was to investigate the shoe-surface interaction and how baseball specific footwear, MC and TS, on varying inclined surfaces, PM and FG, affect the kinematics of the pitching motion in youth and adolescent baseball pitchers throwing a fastball.

2.1 **Participants:**

Eleven healthy male right-handed baseball pitchers (Age: 13.18 ± 1.72 years; Height: 179.01 ± 15.72 cm; Mass: 61.00 ± 14.66 kg) completed the study. The term “healthy” was defined as those who were not currently injured or recovering from an injury at the time of testing and were at least twelve months removed from surgery (Dillman, Fleisig et al. 1993). If surgery took place, participants were excluded unless they were medically cleared and they felt they had returned to one-hundred percent of their pre-surgical skill level. All participants were between the ages of 10-15 years, had at least two years of pitching experience, and wore baseball specific footwear for a minimum of 1 hour per week while actively playing at a competitive level. All participants and their parents/guardians read and signed the informed assent and consent forms, respectively, while a physical activity readiness questionnaire (PAR-Q) was administered to screen for musculoskeletal, orthopedic, and cardiovascular anomalies. The study was approved by the University’s Institutional Review Board (IRB).

2.2 **Instrumentation:**

2.2.1 **3D Motion Capture System:**

Pitching motion data was recorded and analyzed via a Vicon Nexus (Oxford, UK) 3D motion capture system with 8 wall-mounted, infrared T-series cameras collecting at 240 Hz. Retroreflective markers were placed on anatomical landmarks in accordance with the full
body plug-in-gait model from the Helen Hayes marker system (Figure 1). Similarly, markers were placed on the portable underlying surfaces while two markers were placed on the baseball to determine pitch velocity. A custom-made configuration model was used within the Vicon Nexus software for both the surfaces and the ball.

2.2.2 Playing Surfaces:

A 6” x 14” flat strip of 34 mm monofilament synthetic turf with a Styrene-Butadiene Rubber (SBR) infill was placed in the center of the capture volume. Weights were placed at all four corners to prevent movement creating a stationary, FG throwing surface (Figure 2). When not in use, the FG surface was removed from the capture volume and replaced with a portable PM (Proper Pitch Mounds, Garner, NC) (Figure 3) meeting Little League field specifications (5’4”W x 9’L x 6”H).

2.2.3 Footwear:

The experimental procedures carried out by each participant were completed in baseball specific molded cleats [New Balance 4040v3 Low Youth Baseball Cleat (MC)] and turf shoes [New Balance 4040v3 Turf Shoe (TS)] (Figure 4). All footwear were owned and previously worn by participants throughout their respective season. Footwear characteristics are listed in table 1 with the most common shoe size being an eight and a half. No mechanical data was available on footwear differences.

2.3 Experimental Procedures:

All participants and their parents/guardians visited the Applied Biomechanics Laboratory for one, two-hour session. A description of the procedures is outlined below:

Prior to documenting participant characteristics and anthropometric measurements, initial paperwork including informed consent, assent and a physical activity readiness
questionnaire (PAR-Q) were completed to screen for any exclusionary criteria. Upper arm length was measured from the acromion process to the lateral epicondyle of the humerus and the forearm length was measured from the humeral epicondyle to the radial styloid. While wearing their personal spandex shorts, participants wore a provided compression shirt with customized sewn-in strips of VELCRO® (Manchester, NH, USA) placed on the trunk and upper extremity anatomical landmarks. Participants then received a dual energy x-ray absorptiometry (DXA; Hologic Delphi-W, Hologic, Waltham, MA) scan to measure body composition. Upon completion of the DXA scan, participants put on the appropriate footwear for the first of four counterbalanced conditions (MC x FG, MC x PM, TS x FG, TS x PM) designed to remove order effects. Thirty-nine retroreflective markers were then placed on anatomical landmarks following the full body plug-in-gait model from the Helen Hayes marker system to form computerized three-dimensional body segments. Each participant was then given an unlimited amount of time to perform their warm-up routine, including non-throwing drills, as if they would be pitching in a normal game situation (Werner, Fleisig et al. 1993, Fleisig, Andrews et al. 1995). The warm-up concluded with the participant throwing pitches in the laboratory setting with no constraint on the amount and speed.

Upon completion of the warm-up and placement of retroreflective markers, a static capture was taken. Participants were then instructed to throw only four-seam fastballs with the same technique and effort as if it were a game situation and were given a verbal signal of when to begin their pitching motion. Ten pitches, separated by thirty seconds of rest, were thrown from the stretch into a net ten feet away with a designated strike zone. Pitch result, in regards to strikes and balls, were not recorded meaning all ten pitches were collected regardless of outcome. Upon completion of ten pitches, a ten-minute rest between footwear
conditions acted as a washout period where participants sat down without wearing any footwear. Following the washout period, the same experimental protocol occurred for the three remaining counterbalanced conditions.

3. Data Analysis:

Of the six original phases of the overhead pitching motion (Dillman, Fleisig et al. 1993, Werner, Fleisig et al. 1993) (Figure 5), the arm-cocking [lead-foot contact to maximum glenohumeral ER], arm acceleration [maximum glenohumeral ER to ball release], and arm deceleration [ball release to maximum glenohumeral IR] were the phases of interest. Therefore, the pitching cycle used for data analysis was previously defined (Fleisig, Andrews et al. 1995) and began with stride-foot contact (0%) and ended with maximum glenohumeral IR (100%) of the throwing arm while the instant of maximum shoulder ER and ball release were used as two identifying time points (Figure 6). All data throughout the pitching cycle was identified using the Statistical Analysis System, version 9.3 (SAS Institute, Cary, NC). According to Nissen et al., stride-foot ground contact was defined as the instance either the heel or toe marker was closest to zero in the z-coordinate and when the velocity was less than -1.5m/s (Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013). Similarly, ball release was defined as when one of the two markers placed on the baseball were 2 cm or greater away from the marker on the throwing hand (Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013). The dependent variables of interest at the throwing shoulder included maximum abduction (°), maximum horizontal adduction (°), maximum external rotation (ER) (°), maximum internal rotation (IR) (°), IR torque (Nm), ER torque (Nm), and maximum IR velocity (°/s). Maximum elbow flexion (°), varus torque (Nm), flexion torque (Nm), and extension velocity (°/s) were the dependent variables of interest at the throwing elbow while
stride length (% of height), stride and trail leg knee flexion (°), stride and trail leg hip flexion (°), and stride leg ankle plantarflexion (°) were examined in the lower extremity. Time variables, relative to the aforementioned pitch cycle, looked at the differences between maximum ER and maximum IR (s), ball release and maximum IR (s), maximum ER and ball release (s), stride foot contact and maximum ER (s), stride foot contact and ball release (s), as well as stride foot contact and maximum IR (s).

An early study conducted by Pappas et al. reduced ten trials per participant and concluded pitchers are “remarkably consistent” with their delivery (Pappas 1985) while Feltner and Dapena concluded pitchers display “little variability among fastball pitches” allowing the authors to infer a single trial can be sufficient at representing normal mechanics (Feltner and Dapena 1986). The first three pitches thrown without marker obstruction in each shoe-surface condition were analyzed and averaged for each participant. Individual data sets were then averaged across all participants to compare means between each shoe-surface condition. In order to track the movement and timing of the anatomical landmarks, a right-handed reference frame defined the global coordinate system (Figure 7) with its axes defined as X₁, Y₁, and Z₁. X₁ is a vector directed from the pitching rubber to home plate, Z₁ is a downward vertical projection, and Y₁ is a cross product of X₁ and Z₁. Similar to previous studies (Fleisig, Escamilla et al. 1996, Fleisig, Barrentine et al. 1999, Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013), raw marker trajectories were smoothed using a fourth-order, zero-lag Butterworth filter with a cutoff of 13.6 Hz.

4. Statistical Analysis:

A 2x2 [2 Surfaces (FG, PM) x 2 Footwear (TS, MC)] repeated measure analysis of variance (ANOVA) was used to compare the upper and lower extremity kinematics. An
alpha level was set at p<0.05 while a minimum difference of 10% had to be present between conditions in order to classify it as clinically significant (Nissen, Solomito et al. 2013). Dependent variables were originally tested for surface x footwear interactions and if main effect significance was found, a Bonferroni post-hoc adjustment was used to compare simple main effects. If an interaction was seen in the ANOVA results, a univariate post hoc student t-test was conducted. Participant descriptive measures, body composition, ball velocities, and perceptual differences were analyzed using the SPSS 21 statistical software package (IBM SPSS® Statistics V21.0, Armonk, NY, USA) while remaining analyses were conducted using Stata, version 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

5. Results:

Table 2 displays participant characteristics and anthropometrics while body composition is broken down by segments in table 3. All eleven participants self-reported playing baseball for an average of 7.73 years and personal preference rankings (Table 4) indicated the MC x PM (54.5%) condition was most preferred relative to TS x FG (36.4%), TS x PM (9.1%), and MC x FG (0%). Mean pitch velocity (Table 5) was 28.92 ± 4.6 m/s (64.69 ± 10.3 mph), 28.67 ± 4.51 m/s (64.13 ± 10.09 mph), 28.22 ± 4.18 m/s (63.12 ± 9.36 mph), and 28.28 ± 4.51 m/s (63.25 ± 10.09 mph) for the MC x FG, MC x PM, TS x FG, and TS x PM conditions, respectively. No significant differences were found (p>0.05) for pitch velocity; however, there were significant ICC’s.

5.1 Kinematics:

Significant main effect differences were seen in peak shoulder ER (p=0.009) and IR
Maximum shoulder ER velocity (p=0.031) was greater in the TS both on the PM (1754 ± 156 °/s) and FG (1694 ± 161 °/s) while IR velocity (p=0.027) was larger in the MC on the PM (3143 ± 397 °/s) and FG (2996 ± 303 °/s) (Figure 9). In regards to the lower extremities, there was no significant difference in stride length (p=0.77) although the FG and MC independently displayed slightly greater values relative to their counterpart. No significant difference (p>0.05) was found for either hip or knee flexion in the stride and trail leg (Table 6). Stride leg ankle plantarflexion exhibited significant differences (p=0.03) along with significant footwear and surface interactions in all conditions except TS x FG & MC x PM (p>0.05) (Figure 10).

5.2 Kinetics:

Significant differences were shown among shoulder IR torque (p=0.002), ER torque (p=0.003) and elbow varus torque (p=0.002) (Table 7). The MC led to significantly larger IR moments about the shoulder on both the PM and FG producing 34.5 ± 13 Nm and 32.1 ± 7 Nm, respectively (Figure 11). Peak ER moments were significantly greater in TS on both the PM and FG generating 23.8 ± 7 Nm and 22.6 ± 8 Nm, respectively (Figure 11). Similarly, greater elbow varus torques were produced in the MC on the PM (35.1 ± 10 Nm) and FG (33.3 ± 6 Nm) relative to the TS.

5.3 Timing:

Based upon the phases of interest, the pitching cycle [stride foot contact (SFC) to maximum shoulder IR] was shorter while wearing TS on a PM (0.11 ± .004 s) relative to wearing MC on a PM (0.13 ± .004 s) although there was no significant difference (p=0.35) (Table 8). On a PM, the MC relative to the TS, produced shorter times for the remaining
events (SFC and ball release, SFC and maximum ER, maximum ER and ball release, maximum ER and maximum IR, ball release and maximum IR) while the MC on the FG produced longer times for all events except ball release and maximum IR although no significance was found (p>0.05) (Table 8).

6. Discussion:

The glenohumeral IR angle (°), moments and velocity as well as elbow varus moments were significantly greater when pitching in MC. This specific type of footwear brought about a 5.58% (2977 ± 397 °/s to 3143 ± 397 °/s) and 7.42% (2789 ± 303 °/s to 2996 ± 303 °/s) increase in IR velocity on a PM and FG, respectively. As a result of an increase in joint velocity, a 9.87% (31.4 ± 11 Nm to 34.5 ± 13 Nm) and 7.72% (29.8 ± 11 Nm to 32.1 ± 7 Nm) increase in IR torque on a PM and FG occurred, respectively. Similarly, throwing in MC elicited a 7.67% increase (32.6 ± 8 Nm to 35.1 ± 10 Nm) on a PM compared to an 11.37% increase (29.9 ± 7 Nm to 33.3 ± 6 Nm) on FG in elbow varus moments. Interestingly, the increase in elbow torque when throwing in the MC x FG condition demonstrated a clinically significant percent change (>10%) based on the definitions put forth by Nissen et al. (2013) suggesting throwing in MC on FG increases the injury risk at the elbow for youth and adolescent baseball pitchers.

As explained by Kent et al. (2015), artificial surfaces, similar to the ones used in the present study, do not tear away or become displaced. This allows the horizontal force experienced at the shoe-surface interface to peak at a magnitude equal to the maximum pushing/pulling force generated by the athlete. This in turn allows the MC to become engaged with the underlying surface limiting the motion between footwear and surface. In the current study, the MC grips the underlying surface providing foot stabilization and a
fixed surface for the pitcher to decelerate their arm against at a faster rate. On the other hand, ER angle (°), moments and velocity about the glenohumeral joint were significantly greater in TS.

While wearing TS compared to MC, maximum ER velocity increased by 3.84% on a PM (1689 ± 201 °/s to 1754 ± 156 °/s) and 6.01% on FG (1598 ± 158 °/s to 1694 ± 161 °/s). Similar results were seen for maximum ER torque in that TS elicited an 18.41% increase (20.1 ± 8 Nm to 23.8 ± 7 Nm) on a PM and a 17.71% increase (19.2 ± 6 Nm to 22.6 ± 8 Nm) on FG. Therefore, pitching in TS produced clinically significant results with torque about the elbow since the footwear caused a slipping mechanism forcing the footwear to become displaced without tearing the underlying surface. Unlike the MC which allowed the pitcher to decelerate their arm against a fixed surface, the TS doesn’t provide a similar resistant force. The absence of this force opposing forward motion increases the stress placed on the shoulder specifically with ER torque.

The lower extremities exhibited similar findings in stride length as well as hip and knee flexion in both the stride and trail leg. Across footwear conditions, there was a significant difference in stride leg ankle plantarflexion angle (°) indicating the stability each shoe provides differs. The TS elicited significantly greater values with the magnitude difference between TS and MC being 7° and 4° on the PM and FG, respectively. The length of the spikes on the bottom of the MC may explain these results in that the distance between the shoe and the floor is decreased. The timing of peak kinematic and kinetic variables at the dominant glenohumeral and elbow joint were not different across footwear and surface trials. These results supported our hypothesis because the length of the pitch sequence was not expected to change among conditions indicating pitching mechanics were consistent across.
the forty pitches thrown by each participant.

These results, in regards to timing, are contradicting to those found by Nissen et al. (2013) who found maximum shoulder ER and ball release, relative to stride foot contact, were approaching significance when pitching from a PM. Although it may explain the current study’s significant change in ankle plantarflexion in TS and not the time changes, Nissen et al. (2013) attributed their findings to the variation in surface inclination delaying stride foot contact on the PM because it takes longer to “fall down”. Likewise, Nissen et al. (2013) reported a 6% moment increase in both the shoulder and elbow when pitching from a PM. Although in different footwear, the current study did demonstrate similar findings in that the ER and IR moments at the glenohumeral joint can be greater in the PM relative to the FG; however, ER moments were not reported by Nissen et al (2013). It is important to note that this is the first study to control for and investigate how footwear affects pitching mechanics and may explain some differences between previous studies. This adds increased support to the current study in that footwear does play a role in how the shoe-surface interaction affects the shoulder and elbow.

Future studies should investigate footwear and their specific effect on the stabilizing distal segment utilizing various marker placements. This may help understand how the foot is rotating in each cleat during specific phases of the pitching cycle. Limitations of the study included a decreased throwing distance in a laboratory setting; however, since inverse dynamics about the upper and lower extremities were of interest, the researchers of this study are confident results were not effected. While the methodology was designed to control for and mimic game-like scenarios (i.e. warm-ups, rest between pitches and “innings”, throwing mechanics), the authors do acknowledge the fact that game situations may vary and
controlling for some intrinsic and extrinsic factors in a laboratory are not always possible. Similarly, while a larger sample size was preferred, there was irregularity in subject obtainability due to them being under the age of majority and being dependent upon a parent and/or guardian.

7. **Conclusion:**

In conclusion, it is evident the shoe-surface interaction does in fact affect torque and velocity in the dominant glenohumeral and elbow joints. TS produced greater ER moments and velocities while the MC produced larger IR moments and velocities pitching from various inclinations. Similarly, MC produced larger varus moments at the elbow compared to the TS. A previous study (Kent, Forman et al. 2015) has identified translational shoe-surface interactions with cleated footwear, however, based on the results from this study, there is evidence to suggest those outcomes (“hold” or “slide”) do affect shoulder and elbow dynamics and therefore injury risk in youth and adolescent baseball pitchers. Wearing a MC “holds” the underlying surface stabilizing the foot and allowing a pitcher to decelerate their throwing arm at a faster rate because they are doing so against a fixed surface. TS elicited a “slipping” mechanism producing greater external velocities and moments at the shoulder and elbow due to a lack of similar resistant forces.
MANUSCRIPT II

THE INFLUENCE OF THE SHOE-SURFACE INTERFACE ON LOWER EXTREMITY MUSCLE ACTIVATION IN YOUTH AND ADOLESCENT BASEBALL PITCHERS
1. *Introduction:*

The pitching motion in baseball requires the lower extremity, trunk, and upper extremity work in synchronization coupled with muscular forces to generate maximum ball velocity and controlled accuracy. The responsibilities of the lower extremity, however, are still relatively unknown. Pitchers either “fall” forward towards home plate in a controlled manner or use their trail leg to “push off” of the pitching rubber to increase momentum. The activity of the knee and hip musculature in the trail leg would indicate which method is occurring. A push-off would require the musculature to forcefully contract while a fall would reveal less activation. Knowing the activation patterns of lower extremity muscles while pitching a baseball may not only assist with pre- and post-season conditioning, but maximizing performance as well as injury prevention, diagnosis and rehabilitation.  

While electromyography (EMG) activity has been researched in the upper extremity (Jobe 1983, Gowan, Jobe et al. 1987, Townsend, Jobe et al. 1991, DiGiovine, Jobe et al. 1992) and trunk musculature (Watkins, Dennis et al. 1989), only two known studies (Yamanouchi 1998, Campbell, Stodden et al. 2010) have analyzed muscle activation in the lower extremity during a baseball pitch. Yamanouchi was the first to analyze the implications of six lower-extremity muscles [abductor, adductor, quadriceps, biceps femoris, tibialis anterior, and gastrocnemius] throughout the pitching cycle (Yamanouchi 1998). However, one limitation to the study design was that entire pitching motion was divided into two phases – phase one covered until two seconds prior to stride leg contact and phase two covered until two seconds after trail leg contact. Results of the first phase indicated the stride legs’ adductors (84% ± 8% MVIC) and quadriceps (48% ± 14% MVIC) and the trail legs’ biceps femoris (71% ± 23% MVIC) elicited significantly greater activation than the
control group (Yamanouchi 1998). Similarly, the stride legs’ adductors (84% ± 12% MVIC) and the trail legs’ adductors (83% ± 12% MVIC) and biceps femoris (60% ± 24% MVIC) were significantly different in the second phase (Yamanouchi 1998). This indicates that the adductor musculature, bilaterally, act as the primary source of energy in the lower extremity assisting in stabilizing the trunk and assisting with slowing the throwing arm after ball release (Yamanouchi 1998). However, rather than listing the exact musculature where activity was measured, Yamanouchi (1998) classified all muscles into groups based on their joint action.

The entire pitching motion has been previously separated into six phases including the wind-up, stride, arm-cocking, arm acceleration, arm deceleration, and follow-through (Dillman, Fleisig et al. 1993, Werner, Fleisig et al. 1993). Unlike Yamanouchi (Yamanouchi 1998) who combined the arm cocking, arm acceleration and follow-through phases, Campbell et al. (Campbell, Stodden et al. 2010) analyzed the vastus medialis, biceps femoris, rectus femoris, gluteus maximus and gastrocnemius while dividing the motion into four phases: (1) initiation of pitch to maximum knee height of stride leg [wind-up], (2) maximum knee height of stride leg to stride foot contact [stride], (3) stride foot contact to ball release [arm-cocking and arm acceleration], and (4) ball release to 0.5 seconds after ball release [arm deceleration and follow-through]. All muscles demonstrated minimal to moderate activity (10%-31% MVIC) and increased to moderately to highly active (42%-86% MVIC) bilaterally in the first and second phases, respectively. The rapid increase in muscle activity, also referred to as the “ramping” effect, occurs right before stride foot contact suggesting pitchers gradually increase force production causing them to “fall” towards home plate rather than “push off” (Campbell, Stodden et al. 2010).
One extrinsic variable often overlooked that may effect lower extremity muscle activation and the “ramping” effect is the shoe-surface interface. The surfaces ability to resist the motion of a shoe is categorized into horizontal and vertical resistive forces. Horizontal resistance is classified as traction and is determined by the outsole of the shoe and the surface; however, it can be altered by choosing substitute stud configurations and surface conditions (Driscoll, Kelley et al. 2015). Vertical resistive forces are determined solely on stud shape, the ability of a stud to penetrate a surface, and a surfaces’ hardness (Driscoll, Kelley et al. 2015). When vertical and horizontal resistive forces are coupled with a resulting breakaway force (torque), one of three situations can happen: (1) hold, (2) divot, or a (3) slide (Kent, Forman et al. 2015). Therefore, the interaction between cleats and an underlying surface and their corresponding release coefficient, specifically the stride leg/foot, may alter stride length resulting in a change in muscle activity in order to reach the desired ball velocity. There are currently no studies that analyze how baseball specific footwear effects lower extremity muscle activation throughout the pitching cycle. Therefore, the specific purpose of this study was to determine the influence baseball specific footwear [Molded Cleats (MC) and Turf Shoes (TS)] on varying inclined surfaces [Pitching Mound (PM) and Flat Ground (FG)] have on lower extremity muscle activity [Vastus Medialis (Q), Semitendinosus (H), Tibialis Anterior (TA), and Medial Gastrocnemius (G)] in the stride leg during an overhead baseball throw.

2. Methodology:

The purpose of this study was to determine the influence baseball specific footwear, MC and TS, on varying inclined surfaces, PM and FG, have on lower extremity muscle activity (Q, H, TA, and G) in the stride leg during an overhead baseball throw.
2.1 Participants:

Eleven healthy male baseball pitchers (Age: 13.18 ± 1.72 years; Height: 179.01 ± 15.72 cm; Mass: 61.00 ± 14.66 kg) completed the study. The term “healthy” was defined as those who were not currently injured or recovering from an injury at the time of testing and were at least twelve months removed from surgery (Dillman, Fleisig et al. 1993). If surgery took place, participants were excluded unless they were medically cleared and they felt they had returned to one-hundred percent of their pre-surgical skill level (Dillman, Fleisig et al. 1993). All participants were between the ages of 10-15 years, had at least two years of pitching experience, and wore baseball specific footwear for a minimum of 1 hour per week while actively playing at a competitive level. All participants and their parents/guardians read and signed the informed assent and consent forms, respectively, while a physical activity readiness questionnaire (PAR-Q) was administered to screen for musculoskeletal, orthopedic, and cardiovascular anomalies. The study was approved by the University’s Institutional Review Board (IRB).

2.2 Instrumentation:

2.2.1 Electromyography:

Surface EMG signals were recorded using an 8-channel Noraxon Telemetry DTS 900 system (Noraxon USA, INC, Scottsdale, AZ) via the Vicon (Oxford, UK) Nexus software. Eight silver/silver chloride monopolar disposable surface electrodes (EME Company, Baton Rouge, LA) were placed on the muscles of interest (2 per muscle) with the ground electrode being placed on the tibial plateau. Raw EMG data was collected at 960 Hz while an EMG pipeline was used for analysis. Pitching motion data was recorded and analyzed using a full
body plug-in-gait model from the Helen Hayes marker (Figure 1) system via a Vicon Nexus 3D motion capture system with 8 wall-mounted, infrared T-series cameras collecting kinematics at 240 Hz as well as EMG data.

2.2.2 Playing Surfaces:

A 6” x 14” flat strip of 34 mm monofilament synthetic turf with a Styrene-Butadiene Rubber (SBR) infill was placed in the center of the capture volume. Weights were placed at all four corners to prevent movement creating a stationary, FG throwing surface (Figure 2). When not in use, the FG surface was removed from the capture volume and replaced with a portable PM (Proper Pitch Mounds, Garner, NC) (Figure 3) meeting Little League field specifications (5’4”W x 9’L x 6”H).

2.2.3 Footwear:

The experimental procedures carried out by each participant were completed in baseball specific molded cleats [New Balance 4040v3 Low Youth Baseball Cleat (MC)] and turf shoes [New Balance 4040v3 Turf Shoe (TS)] (Figure 4). All footwear were owned and previously worn by participants throughout their respective season. Footwear characteristics are listed in table 1 with the most common shoe size being an eight and a half. No mechanical data was available on footwear differences.

2.3 Experimental Procedures:

All participants and their parents/guardians visited the Applied Biomechanics Laboratory for one, two-hour session. A description of the procedures is outlined below:

Prior to documenting participant characteristics and anthropometric measurements, initial paperwork including informed consent, assent and a physical activity readiness
questionnaire (PAR-Q) were completed to screen for any exclusionary criteria. Upper arm length was measured from acromion process to the lateral epicondyle of the humerus and the forearm length was measured from the humeral epicondyle to the radial styloid. While wearing their personal spandex shorts, participants wore a provided compression shirt and received a dual energy x-ray absorptiometry (DXA; Hologic Delphi-W, Hologic, Waltham, MA) scan to measure body composition. Upon completion of the DXA scan, participants put on the appropriate footwear for the first of four counterbalanced conditions (MC x FG, MC x PM, TS x FG, TS x PM) designed to remove order effects. Two surface electrodes were then placed on each of the Q, H, TA, and G bilaterally with the ground electrode being placed on the tibial plateau. Three maximal voluntary isometric contractions (MVIC) lasting 5 seconds were performed for each muscle where participants were instructed to “push as hard and as fast as possible” while receiving verbal encouragement. MVICs for the Q and H were performed while seated on a standard weight bench while the TA and G were completed while standing. An isometric knee extension and flexion at 90º (full extension: 180º) was performed for the Q and H, respectively. MVIC’s of plantar flexion and dorsiflexion at the right and left ankle joint were measured at an angle of 0º (neutral: 0º) for the G and TA, respectively.

Thirty-nine retroreflective markers were then placed on anatomical landmarks following the full body plug-in-gait model from the Helen Hayes marker system to form computerized three-dimensional body segments. Six markers were placed on the FG while ten markers were placed on the PM. Each participant was then given an unlimited amount of time to perform their warm-up routine, including non-throwing drills, as if they would be pitching in a normal game situation (Werner, Fleisig et al. 1993, Fleisig, Andrews et al.
The warm-up concluded with the participant throwing pitches in the laboratory setting with no constraint on the amount and speed.

Upon completion of the warm-up and placement of retroreflective markers, a static capture was taken. Participants were instructed to throw only four-seam fastballs with the same technique and effort as if it were a game situation and were given a verbal signal of when to begin their pitching motion. Ten pitches, separated by thirty seconds of rest, were thrown from the stretch into a net ten feet away with a designated strike zone. Pitch result, in regards to strikes and balls, were not recorded meaning all ten pitches were collected regardless of outcome. Upon completion of ten pitches, a ten-minute rest between footwear conditions acted as a washout period where participants sat down without wearing any footwear. Following the washout period, the same experimental protocol occurred for the three remaining counterbalanced conditions.

3. **Data Analysis:**

The first three pitches thrown without marker obstruction in each shoe-surface condition were used for analysis for each participant. Pitch velocity was calculated using two markers placed on the baseball. EMG values for each of the three trials were averaged equating to one mean EMG reading per muscle in all four shoe-surface conditions. Analog EMG data was measured and analyzed using the Vicon Nexus software. Raw data was collected at 960 Hz and filtered using a fourth-order, zero-lag Butterworth filter with a cutoff of 250 Hz. Events of the pitching motion were identified and labeled using the Statistical Analysis System, version 9.1 (SAS Institute, Cary, NC) beginning with stride-foot contact (0%) and ending with maximum glenohumeral IR (100%) of the throwing arm (Figure 6) while data was time normalized (Fleisig, Andrews et al. 1995). Stride-foot contact was
defined as the instance either the heel or toe marker was closest to zero in the z-coordinate and when the velocity was less than -1.5m/s while ball release was defined as the instance when one of the two markers placed on the baseball were 2 cm or greater away from the marker on the throwing hand (Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013). Raw muscle activity of the Q, H, TA, and G was rectified and smoothed to determine mean muscle activity during MVIC (mV) (Mean MVIC Q, Mean MVIC H, Mean MVIC TA, Mean MVIC G) and mean muscle activity (mV) (Mean Q, Mean H, Mean TA, Mean G) throughout all four phases. The middle three seconds of the five-second MVIC for each trial was used for analysis allowing the participants one second to reach MVIC (“ramping” up) while avoiding fatigue (“ramping” down) (Campbell, Stodden et al. 2010).

4. Statistical Analysis:

A 2x2 [2 Surfaces (FG, PM) x 2 Footwear (TS, MC)] repeated measure analysis of variance (repeated measures ANOVA) was used to analyze mean muscle activity. An alpha level was set at p<0.05 while mean EMG activation were classified based on the following criteria: minimal activity (0-20% MVIC), moderate activity (20-35% MVIC), moderately strong (35-50% MVIC), and significantly high (>50% MVIC) (Tucker 2005, Campbell, Stodden et al. 2010). If main effect significance was found, a Bonferroni post-hoc adjustment was used. If an interaction was seen in the ANOVA results, a univariate post hoc student t-test was conducted. Participant descriptive measures, body composition, and mean MVIC’s were analyzed using the SPSS 21 statistical software package (IBM SPSS® Statistics V21.0, Armonk, NY, USA) while mean muscle activity during the four phases of interest was conducted using Stata, version 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).
5. Results:

Table 2 displays participant characteristics and anthropometrics while body composition is broken down by segments in table 3. The results of mean MVIC’s for the Q, H, TA, and G in the stride leg are listed in table 9. The 2x2 repeated measures ANOVA showed no significant difference for the mean muscle activity in either the Q (Table 10, Figure 12) or H (Table 11, Figure 13) in all four phases while main effect significance (p<0.05) was observed for the TA (Table 12) and G (Table 13). There was a significant interaction (p<0.001) between footwear and surface at all four phases in the TA (Figure 14) and G (Figure 15).

6. Discussion:

The purpose of this study was to determine the influence baseball specific footwear has on lower extremity muscle activity (Q, H, TA, and G) in the stride leg during an overhead baseball pitch. Data demonstrated consistent trends throughout all four phases of interest showing the ankle stabilizing musculature was significantly active in comparison to the knee stabilizers. Significant interactions between footwear and surface existed for mean muscle activity for both the TA and G suggesting both footwear and surfaces influence both muscles during the pitch cycle. The mean muscle activity for the G was significantly greater throughout all four phases while wearing a TS on both the PM and FG. Similarly, the mean muscle activity for the TA was significantly greater in a TS on a PM, however, the MC elicited greater muscle activation on the FG except from ball release to maximum glenohumeral IR.

Campbell et al. (2010) has shown that the Q, H, and G are moderately active until
stride foot contact. From stride contact until 0.5 seconds after ball release, all three muscles are significantly active based on mean EMG percentage for the stride leg. Results from the current study correlate with significant ER glenohumeral angles, moments and velocities in TS. Both the TA and G provided enough foot and ankle stability to allow the glenohumeral ER velocity to increase by 6% and torque to increase 18% in TS. It is interesting to note that muscle activity continuously increases throughout the pitching cycle since the pitcher is in a period of single support with the stride leg suspended in the air. This may indicate the athlete continuously activates their dorsiflexors and plantarflexors to prepare for force absorption upon stride foot contact.

Future studies should investigate co-contraction indices in various types of cleated footwear to determine joint stability throughout the pitching cycle. Limitations of the study included a decreased throwing distance in a laboratory setting; however, since EMG was only of interest, the researchers of this study are confident results were not affected. Also, contracting a muscle into a pad may not be a true indication of a MVIC meaning activation exceeding 100% may just indicate which musculature is most active. While the methodology was designed to control for and mimic game-like scenarios (i.e. warm-ups, rest between pitches and “innings”, throwing mechanics), the authors do acknowledge the fact that game situations may vary and controlling for some intrinsic and extrinsic factors in a laboratory are not always possible.

7. Conclusion:

In conclusion, a greater mean muscle activity was seen in the G while wearing TS on both surfaces at stride foot contact, maximum ER, ball release, and maximum IR. Results for the TA also indicate a significantly larger mean muscle activity in the TS on the PM while
the MC elicited greater activation on the FG. At the point of glenohumeral ER, the TS produced greater activity in the ankle stabilizing musculature which coincides with the fact stride leg ankle plantarflexion was larger in the TS at the same time period. A gradual increase in muscle activation may support the fact that pitchers fall towards home plate rather than pushing off the pitching rubber.
MANUSCRIPT III

THE EFFECT OF THE SHOE-SURFACE INTERFACE ON THE PELVIS AND TRUNK IN RELATIONSHIP TO THE UPPER EXTREMITY IN YOUTH AND ADOLESCENT BASEBALL PITCHERS
Pitching a baseball is a highly dynamic movement where the lower extremity, pelvis, and trunk work in sequence to transfer energy up the open kinetic chain to produce a desired ball velocity, pitch accuracy, and alleviate stress on the upper extremity. Efficiency of this movement depends on an athlete’s ability to maximize the proximal-to-distal sequencing mechanism and properly time the movement of the trunk and pelvis. This concept is often described within the sport literature as the summation of speed principle stating motion is generated from larger, centrally located segments and continues outward to smaller, distal segments as energy is increased (Bunn 1972, Putnam 1993, Southard 2009). This linked interaction results in a summation of speed allowing the end of the distal segment to reach a maximal velocity greater than its adjacent segments by summing all the previous velocities within that sequence. While this mechanism assists in increasing ball velocity by transferring momentum from the legs, pelvis, and trunk to the distal ends of the upper extremity, movement in the most distal segment does not occur until the adjacent proximal segment reaches maximum angular velocity (Putnam 1993). Faulty mechanics or disadvantageous trunk and pelvis orientations may lead to a loss in the amount of angular momentum transferred to the throwing arm causing pitchers to compensate by increasing the amount of internal torque and therefore the injury risk within the upper extremity.

Most sports related injuries resulting in emergency department (ED) visits occur in youth athletes aged 5-14 years old costing between $500 million and $1.8 billion dollars in treatment annually (Aaron and Laporte 1997, Burt and Overpeck 2001, Conn, Annest et al. 2003, Ferguson 2013). The sport of baseball, compared to other team sports, has the fourth highest injury rate in those younger than 19 years old due to the fact 20% of all ED visits in
6-19 year olds were due to baseball related activities (Ferguson 2013) while 7% of the total 37% all team-sports from 1997-2001 led to ED visits by pediatric baseball players (Simon, Bublitz et al. 2006). Lyman et al. concluded upper extremity arm pain was reported in 15% of all pitching appearances in 9-14 year olds (Lyman, Fleisig et al. 2002) while 32% and 26% reported shoulder and elbow pain after each game, respectively (Lyman, Fleisig et al. 2001).

Pelvis orientation upon stride foot contact, with respect to the anterior superior iliac spine (ASIS), may affect the injury rate within the upper extremity. “Early rotators” are described as having an open pelvis orientation indicating they land with their pelvis facing towards home plate while “late rotators” demonstrate a closed pelvis orientation and land with their pelvis facing third or first base for a right handed and left handed pitcher, respectively (Wright, Richards et al. 2004). Releasing the ball with a closed pelvis is described as “throwing with your arm” and places added stress on the upper extremity since energy is transferred from the trunk to the throwing arm early in the pitch sequence causing it to dissipate rather than get transferred to the hand (Aguinaldo, Buttermore et al. 2007). This in turn increases the torque at the elbow and glenohumeral joint (hereafter referred to as shoulder) (Fleisig, Barrentine et al. 1996) increasing the risk for injury. Aguinaldo et al. (2007) supported this finding by concluding less shoulder IR torque is generated when a pitcher rotates their trunk later in the pitching cycle (Aguinaldo, Buttermore et al. 2007).

Following pelvic rotation, the trunk must rotate towards home plate as well. While a majority of trunk motion during the pitching sequence occurs in the transverse plane, it has shown to provide the highest segmental contribution to overhand movements in baseball (Aguinaldo, Buttermore et al. 2007), a tennis serve (Bahamonde 2000), and kicking (Putnam 1993). Pitchers have shown that different mechanics in regards to the position of the stride
leg and trunk rotation can be effective. However, “throwing with your arm” or throwing with an “open shoulder” at stride foot contact within the transverse plane indicates early trunk rotation and has shown to increases elbow varus loads (Davis, Limpisvasti et al. 2009) and internal rotation torques (Aguinaldo, Buttermore et al. 2007). This occurs because the shoulder is lagging behind the trunk placing added stress on the elbow. On the other hand, faulty mechanics within the coronal plane demonstrates contralateral trunk lean when the pitcher leans towards the nonthrowing side. While it has been shown excessive contralateral trunk lean induces faster ball velocities, it has also shown similar injury risks by increasing elbow varus moments when the shoulder is abducted 90°-100° (Oyama, Yu et al. 2013).

Various studies have looked at pelvic rotations (Wright, Richards et al. 2004), trunk rotations (Aguinaldo, Buttermore et al. 2007), and trunk angles (Matsuo, Fleisig et al. 2006, Oyama, Yu et al. 2013) during a baseball pitch and how that affects the upper extremity. However, one variable overlooked which effects the stride leg and subsequently pelvic and trunk rotations is the shoe-surface interface. Across the United States, there are currently two Major League Baseball (MLB), 32 National Collegiate Athletic Association (NCAA) and little league stadiums that utilize FieldTurf. The latest versions of turf use grass fibers that are longer than 40mm and have an infill that is comprised of polyethylene fibers with a sand/rubber combination to allow for normal ball bouncing (Smeets, Jacobs et al. 2012). Kent et al. (2015) concluded that when cleated footwear is engaged with artificial surfaces, there is little motion between the shoe and the surface. The magnitude of horizontal force generated on artificial surfaces is limited by the maximum force applied into the ground (Kent, Forman et al. 2015). This indicates cleated footwear can either “slide” or “hold” relative to the underlying surface meaning they are displaced relative to the surface without
causing a divot or can hold with minimal displacement relative to the Earth, respectively (Kent, Forman et al. 2015). Depending on the individual pitching mechanics, footwear, and playing surface, pelvis and trunk rotations may be altered affecting the upper extremity. Therefore, the purpose of the study was to investigate the shoe-surface interaction and how baseball specific footwear [Molded Cleats (MC) and Turf Shoes (TS)] on varying inclined surfaces [Pitching Mound (PM) and Flat Ground (FG)] affect the shoulder and elbow joints based on pelvis and trunk rotation.

2. **Methodology:**

The purpose of the study was to investigate the shoe-surface interaction and how baseball specific footwear, MC and TS, on varying inclined surfaces, PM and FG, affect the upper extremity based on pelvis and trunk rotation.

2.1 **Participants:**

Eleven healthy male baseball pitchers (Age: 13.18 ± 1.72 years; Height: 179.01 ± 15.72 cm; Mass: 61.00 ± 14.66 kg) completed the study. The term “healthy” was defined as those who were not currently injured or recovering from an injury at the time of testing and were at least twelve months removed from surgery (Dillman, Fleisig et al. 1993). If surgery took place, participants were excluded unless they were medically cleared and they felt they had returned to one-hundred percent of their pre-surgical skill level (Dillman, Fleisig et al. 1993). All participants were between the ages of 10-15 years, had at least two years of pitching experience, and wore baseball specific footwear for a minimum of 1 hour per week while actively playing at a competitive level. All participants and their parents/guardians read and signed the informed assent and consent forms, respectively, while a physical activity readiness questionnaire (PAR-Q) was administered to screen for musculoskeletal, orthopedic,
and cardiovascular anomalies. The study was approved by the University’s Institutional Review Board (IRB).

2.2 Instrumentation:

2.2.1 3D Motion Capture System:

Pitching motion data was recorded and analyzed via a Vicon Nexus (Oxford, UK) 3D motion capture system with 8 wall-mounted, infrared T-series cameras collecting at 240 Hz. Retroreflective markers were placed on anatomical landmarks in accordance with the full body plug-in-gait model from the Helen Hayes marker system (Figure 1). Similarly, markers were placed on the portable underlying surfaces while two markers were placed on the baseball to determine pitch velocity. A custom-made configuration model was used within the Vicon Nexus software for both the surfaces and the ball.

2.2.2 Footwear:

The experimental procedures carried out by each participant were completed in baseball specific molded cleats [New Balance 4040v3 Low Youth Baseball Cleat (MC)] and turf shoes [New Balance 4040v3 Turf Shoe (TS)] (Figure 4). All footwear were owned and previously worn by participants throughout their respective season. Footwear characteristics are listed in table 1 with the most common shoe size being an eight and a half. No mechanical data was available on footwear differences.

2.3 Experimental Procedures:

All participants and their parents/guardians visited the Applied Biomechanics Laboratory for one, two-hour session. A description of the procedures is outlined below:

Prior to documenting participant characteristics and anthropometric measurements,
initial paperwork including informed consent, assent and a physical activity readiness questionnaire (PAR-Q) were completed to screen for any exclusionary criteria. Upper arm length was measured from acromion process to the lateral epicondyle of the humerus and the forearm length was measured from the humeral epicondyle to the radial styloid. While wearing their personal spandex shorts, participants wore a provided compression shirt with customized sewn-in VELCRO® (Manchester, NH, USA) strips placed on the trunk and upper extremity anatomical landmarks and received a dual energy x-ray absorptiometry (DXA; Hologic Delphi-W, Hologic, Waltham, MA) scan to measure body composition. Upon completion of the DXA scan, participants put on the appropriate footwear for their first of four (MC x FG, MC x PM, TS x FG, TS x PM) counterbalanced conditions designed to remove order effects. Thirty-nine retroreflective markers were then placed on anatomical landmarks following the full body plug-in-gait model from the Helen Hayes marker system to form computerized three-dimensional body segments. Each participant was then given an unlimited amount of time to perform their warm-up routine, including non-throwing drills, as if they would be pitching in a normal game situation (Werner, Fleisig et al. 1993, Fleisig, Andrews et al. 1995). The warm-up concluded with the participant throwing pitches in the laboratory setting with no constraint on the amount and speed.

Upon completion of the warm-up and placement of retroreflective markers, a static capture was taken. Participants were then instructed to throw only four-seam fastballs with the same technique and effort as if it were a game situation and were given a verbal signal of when to begin their pitching motion. Ten pitches, separated by thirty seconds of rest, were thrown from the stretch into a net ten feet away with a designated strike zone. Pitch result, in regards to strikes and balls, were not recorded meaning all ten pitches were collected.
regardless of outcome. Upon completion of ten pitches, a ten-minute rest between footwear conditions acted as a washout period where participants sat down without wearing any footwear. Following the washout period, the same experimental protocol occurred for the three remaining counterbalanced conditions.

3. *Data Analysis:*

The pitching cycle used for data analysis was previously defined (Fleisig, Andrews et al. 1995) and began with stride-foot contact (0%) and ended with maximum glenohumeral IR (100%) of the throwing arm while the instant of maximum shoulder ER and ball release were used as two identifying time points (Figure 6). All data throughout the pitching cycle was identified using the Statistical Analysis System, version 9.3 (SAS Institute, Cary, NC) from the instance of stride-foot contact (0%) to maximum glenohumeral IR (100%). Stride-foot contact was defined as the instance either the heel or toe marker was closest to zero in the z-coordinate and when the velocity was less than -1.5m/s (Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013). Similarly, ball release was defined as the instance when one of the two markers placed on the baseball were 2 cm or greater away from the marker on the throwing hand (Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013).

An early study conducted by Pappas et al. reduced ten trials per participant and concluded pitchers are “remarkably consistent” with their delivery (Pappas 1985) while Feltner and Dapena concluded pitchers display “little variability among fastball pitches” allowing the authors to infer a single trial can be sufficient at representing normal mechanics (Feltner and Dapena 1986, Werner, Fleisig et al. 1993, Aguinaldo, Buttermore et al. 2007). Therefore, similar to previous studies (Dillman, Fleisig et al. 1993, Fleisig, Andrews et al. 1995, Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013), the first three pitches...
thrown without marker obstruction in each shoe-surface condition were analyzed and averaged for each participant. Individual data sets were then averaged across all participants to compare means between each shoe-surface condition. The dependent variables of interest of the pelvis included maximum pelvis angular velocity (°/s) and pelvis orientation at the instant of maximum pelvis angular velocity (°) while maximum trunk angular velocity (°/s), trunk lateral flexion (°), forward flexion (°) and rotation (°) and time until maximum trunk rotation (% of pitch cycle) were analyzed for the trunk.

In order to track the movement and timing of the anatomical landmarks, a right-handed reference frame defined the global coordinate system (Figure 7) with the origin at the midpoint of the back end of the pitching mound for all experimental conditions with its axes defined as $X_1$, $Y_1$, and $Z_1$. $X_1$ is a vector directed from the pitching rubber to home plate, $Z_1$ is a downward vertical projection, and $Y_1$ is a cross product of $X_1$ and $Z_1$. Similar to previous studies (Fleisig, Escamilla et al. 1996, Fleisig, Barrentine et al. 1999, Nissen, Westwell et al. 2007, Nissen, Solomito et al. 2013), raw marker trajectories were smoothed using a fourth-order, zero-lag Butterworth filter with a cutoff of 13.6 Hz. Pelvis orientation, at stride foot contact, was defined by a previous study (Wright, Richards et al. 2004). A pelvis orientation between 0°-30° and greater than 30° was defined as a closed and open position, respectively (Wright, Richards et al. 2004). For either a right handed or left handed pitcher, 90° indicated the pelvis was facing home plate.

4. **Statistical Analysis:**

A 2x2 [2 Surfaces (FG, PM) x 2 Footwear (TS, MC)] repeated measure analysis of variance (ANOVA) was used to analyze the variables of interest with an alpha level set at $p<0.05$. If main effect significance was found, a Bonferroni post-hoc adjustment was used. If
an interaction was seen in the ANOVA results, a univariate post hoc student t-test was conducted. Participant descriptive measures, body composition, ball velocities, and perceptual differences were analyzed using the SPSS 21 statistical software package (IBM SPSS® Statistics V21.0, Armonk, NY, USA) while remaining analyses were conducted using Stata, version 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

5. Results:

Table 2 displays participant characteristics and anthropometrics while body composition is broken down by segments in table 3. Participants self-reported playing baseball for an average of 7.73 years while personal preference rankings (Table 4) indicated the MC x PM (54.5%) was most desirable compared to TS x FG (36.4%), TS x PM (9.1%), and MC x FG (0%). Mean pitch velocity (Table 5) was 28.92 ± 4.6 m/s (64.69 ± 10.3 mph), 28.67 ± 4.51 m/s (64.13 ± 10.09 mph), 28.22 ± 4.18 m/s (63.12 ± 9.36 mph), and 28.28 ± 4.51 m/s (63.25 ± 10.09 mph) for the MC x FG, MC x PM, TS x FG, and TS x PM conditions, respectively. No significant differences were found (p>0.05), however, there were significant ICC’s. There was no main effect significance (p>0.05) for pelvis (maximum angular velocity and pelvis orientation at maximum pelvis angular velocity) and trunk (maximum angular velocity, lateral flexion, forward flexion, rotation, and time until maximum trunk rotation) dependent variables (Table 14).

6. Discussion:

Results indicate there are no differences between pitching in MC and TS on varying inclined surfaces across pelvis and trunk rotations. A previous study conducted by Solomito
et al. (2015) concluded that pitchers approach maximum trunk lean (coronal plane) around maximum glenohumeral ER and reach maximum trunk lean at the point the maximum elbow varus moment occurs. It was found that ninety-nine, twenty year-old pitchers displayed a maximum trunk lean of 19 ± 10° while the current study saw 24.2 ± 5°, 23.8 ± 4°, 24.6 ± 2°, and 25.8 ± 4°, in the TS x PM, TS x FG, MC x PM, and MC x FG conditions, respectively. It is reported that for every 10° increase over the median trunk lean at maximum glenohumeral ER, elbow varus moments increase by 3.7 Nm while the IR moment increases by 2.5 Nm (Solomito, Garibay et al. 2015). Interestingly, findings in the current study showed pitching in a MC significantly increased glenohumeral IR moments by 9.87% (31.4 ± 11 Nm to 34.5 ± 13 Nm) and 7.72% (29.8 ± 11 Nm to 32.1 ± 7 Nm) on a PM and FG, respectively. Similarly, a significant 7.67% increase (32.6 ± 8 Nm to 35.1 ± 10 Nm) and an 11.37% increase (29.9 ± 7 Nm to 33.3 ± 6 Nm) occurred in elbow varus moments on a PM and FG, respectively. However, no significant differences were seen within pelvis and trunk kinematics.

It was hypothesized that wearing a MC “holds” the underlying surface stabilizing the foot creating a larger angular momentum of the trunk about the mediolateral axis while the TS would produce the opposite effect. However, no differences were seen in maximum trunk angular velocity nor the time it took to reach that value in the pitching cycle. The TS caused the trunk to reach a larger maximum angular velocity on the PM compared to the FG (901 ± 102 °/s to 924 ± 101 °/s) allowing the pitcher to reach that point of peak trunk rotation earlier in the pitch cycle (55.6 ± 8 % to 53.2 ± 7 %). The MC generated faster trunk angular velocities on FG relative to the PM while the time difference was almost identical.

Regardless of footwear worn and the surface inclination, it appears that all
participants pitched with what is referred to as a “closed” pelvis and are categorized as “late rotators” at the time of maximum angular velocity based on classifications put forth by Wight et al. (2002). Although dependent variables were extracted as peaks rather than time normalized to the pitch cycle, Wight et al. (2002) found that late rotators wait until stride foot contact to begin pelvis rotation. At this point in the pitching cycle, pelvis orientation values between the two studies were comparable. Wight et al. (2002) exhibited a 10.5 ± 3.4º pelvic rotation while the current study exhibited 13.1 ± 3º, 12.3 ± 2º, 11.6 ± 3º, and 12.4 ± 3º, for TS x PM, TS x FG, MC x PM, and MC x FG, respectively.

Future studies should investigate footwear utilized by pitchers associated with higher performance levels (i.e. high school, college, professional) on similar and different surfaces. This could possibly lead to finding specific cleated footwear that allows for optimal pelvis and trunk rotation protecting youth pitchers from shoulder and elbow injuries. Limitations of the study included a decreased throwing distance in a laboratory setting; however, since inverse dynamics about the pelvis, trunk and upper extremity were of interest, the researchers of this study are confident results were not effected. While the methodology was designed to control for and mimic game-like scenarios (i.e. warm-ups, rest between pitches and “innings”, throwing mechanics), the authors do acknowledge the fact that game situations may vary and controlling for some intrinsic and extrinsic factors in a laboratory are not always possible. Similarly, while a larger sample size was preferred, there was irregularity in subject obtainability due to them being under the age of majority and being dependent upon a parent and/or guardian.

7. Conclusion:

Footwear, and its interaction with the underlying playing surface, does not appear to
have an effect on the amount of pelvis rotation nor trunk lean in all three cardinal planes. Youth and adolescent pitchers demonstrated to be “late rotators” (orientation < 30°) at the time of maximum pelvis angular velocity while contralateral trunk lean was insignificant, although the mean was greater than previous studies.
REFERENCES


APPENDICES
Table 1: Footwear Characteristics

<table>
<thead>
<tr>
<th>Footwear Characteristics</th>
<th>Molded Cleat (MC)</th>
<th>Turf Shoe (TS)</th>
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<tbody>
<tr>
<td>Mass (kg)</td>
<td>0.258</td>
<td>0.292</td>
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<td>Total # of Studs</td>
<td>18</td>
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<td>Forefoot Stud Height (cm)</td>
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<td>Hindfoot Stud Height (cm)</td>
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Table 2: Participant Characteristics and Anthropometrics

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<td>Height (cm)</td>
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<td>Mass (kg)</td>
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<td>14.66</td>
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<td>Right Upper Arm Length (cm)</td>
<td>32.2</td>
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<td>Left Upper Arm Length (cm)</td>
<td>32.19</td>
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<td>Right Forearm Length (cm)</td>
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<td>Left Forearm Length (cm)</td>
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<td>Playing Experience (years)</td>
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<tr>
<td>Shoe Size (US)</td>
<td>10.77</td>
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Table 3: Participant Body Composition

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<td>Total Body Fat (%)</td>
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<td><strong>Left (Non-Throwing) Arm</strong></td>
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<tr>
<td>Total Mass (kg)</td>
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<td>Total Mass (kg)</td>
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<td>Lean Mass (kg)</td>
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<td><strong>Left (Stride) Leg</strong></td>
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<td>Lean Mass (kg)</td>
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<td>20.37</td>
<td>8.99</td>
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### Table 4: Preferences on Footwear-Surface Conditions

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<thead>
<tr>
<th>Footwear-Surface Condition</th>
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<tr>
<td>MC x FG</td>
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<td>18.2</td>
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<td>MC x PM</td>
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<tr>
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<td>9.1</td>
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### Table 5: Ball Velocities for Footwear-Surface Conditions

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<tr>
<th>Variable</th>
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<th>Confidence Intervals</th>
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<td>Lower Bound</td>
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<td>Pitch Velocity (m/s)</td>
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<tr>
<td>MC x FG</td>
<td>28.92</td>
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<td>MC x PM</td>
<td>28.67</td>
<td>4.51</td>
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<td>TS x FG</td>
<td>28.22</td>
<td>4.18</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TS x PM</td>
<td>28.28</td>
<td>4.51</td>
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<tr>
<td>Pitch Velocity (mph)</td>
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<tr>
<td>MC x FG</td>
<td>64.69</td>
<td>10.3</td>
<td>0.984</td>
<td>&lt;0.001</td>
<td>0.959</td>
</tr>
<tr>
<td>MC x PM</td>
<td>64.13</td>
<td>10.09</td>
<td></td>
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<td>TS x FG</td>
<td>63.12</td>
<td>9.36</td>
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<tr>
<td>TS x PM</td>
<td>63.25</td>
<td>10.09</td>
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### Table 6: Kinematic Differences in Lower Extremity

<table>
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<tr>
<th>Kinematic Differences in Lower Extremity</th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
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<tbody>
<tr>
<td>Stride Length (m)</td>
<td>1.06 ± 0.1</td>
<td>1.08 ± 0.2</td>
<td>1.07 ± 0.2</td>
<td>1.08 ± 0.1</td>
<td>0.77</td>
</tr>
<tr>
<td>Stride Leg Hip Flexion (°)</td>
<td>61 ± 7</td>
<td>59 ± 4</td>
<td>62 ± 8</td>
<td>63 ± 8</td>
<td>0.44</td>
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<tr>
<td>Stride Leg Knee Flexion (°)</td>
<td>43 ± 8</td>
<td>47 ± 7</td>
<td>41 ± 6</td>
<td>47 ± 4</td>
<td>0.32</td>
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<tr>
<td>Stride Leg Ankle Plantarflexion (°)</td>
<td>-27 ± 4</td>
<td>-19 ± 3</td>
<td>-20 ± 3</td>
<td>-15 ± 3</td>
<td>0.03*</td>
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<tr>
<td>Trail Leg Hip Flexion (°)</td>
<td>12 ± 2</td>
<td>13 ± 2</td>
<td>14 ± 3</td>
<td>11 ± 2</td>
<td>0.58</td>
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<tr>
<td>Trail Leg Knee Flexion (°)</td>
<td>52 ± 11</td>
<td>47 ± 10</td>
<td>53 ± 12</td>
<td>44 ± 11</td>
<td>0.62</td>
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</tbody>
</table>

* Significance (p<0.05) among footwear x surface

Post-hoc comparisons: significant differences (p<0.001) between: 

- TS x PM & TS x FG,
- TS x PM & MC x PM,
- TS x PM & MC x FG,
- TS x FG & MC x PM,
- TS x FG & MC x FG,
- MC x PM & MC x FG
Table 7: Kinematic Differences in Throwing Arm

<table>
<thead>
<tr>
<th>Kinematic Differences in Throwing Arm</th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
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<tr>
<td><strong>Right Shoulder</strong></td>
<td></td>
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<tr>
<td>Maximum Abduction (°)</td>
<td>81.1 ± 8</td>
<td>81.5 ± 4</td>
<td>79.3 ± 2</td>
<td>80.2 ± 3</td>
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<td>Maximum Horizontal Adduction (°)</td>
<td>3.1 ± 1</td>
<td>3.8 ± 1</td>
<td>4.1 ± 1</td>
<td>3.6 ± 1</td>
<td>0.34</td>
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<tr>
<td>Maximum ER (°)</td>
<td>116.7 ± 13</td>
<td>108.4 ± 11</td>
<td>110.2 ± 7</td>
<td>101.4 ± 8</td>
<td>0.009*abcdef</td>
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<tr>
<td>Maximum IR (°)</td>
<td>132.2 ± 7</td>
<td>125.1 ± 7</td>
<td>141.2 ± 8</td>
<td>138.4 ± 7</td>
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<td>Maximum IR Torque (Nm)</td>
<td>31.4 ± 11</td>
<td>29.8 ± 11</td>
<td>34.5 ± 13</td>
<td>32.1 ± 7</td>
<td>0.002*abcde</td>
</tr>
<tr>
<td>Maximum ER Torque (Nm)</td>
<td>23.8 ± 7</td>
<td>22.6 ± 8</td>
<td>20.1 ± 8</td>
<td>19.2 ± 6</td>
<td>0.003*abdef</td>
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<tr>
<td>Maximum ER Velocity (°/s)</td>
<td>1754 ± 156</td>
<td>1694 ± 161</td>
<td>1689 ± 201</td>
<td>1598 ± 158</td>
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<td>Maximum IR Velocity (°/s)</td>
<td>2977 ± 397</td>
<td>2789 ± 303</td>
<td>3143 ± 397</td>
<td>2996 ± 303</td>
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<td><strong>Right Elbow</strong></td>
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<tr>
<td>Maximum Flexion (°)</td>
<td>56.7 ± 12</td>
<td>58.4 ± 9</td>
<td>61.1 ± 11</td>
<td>58.7 ± 3</td>
<td>0.61</td>
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<td>Maximum Varus Torque (Nm)</td>
<td>32.6 ± 8</td>
<td>29.9 ± 7</td>
<td>35.1 ± 10</td>
<td>33.3 ± 6</td>
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<tr>
<td>Maximum Flexion Torque (Nm)</td>
<td>18.4 ± 6</td>
<td>19.9 ± 8</td>
<td>22.3 ± 8</td>
<td>23.4 ± 8</td>
<td>0.77</td>
</tr>
<tr>
<td>Maximum Extension Velocity (°/s)</td>
<td>1854 ± 211</td>
<td>1987 ± 178</td>
<td>2112 ± 156</td>
<td>2132 ± 187</td>
<td>0.67</td>
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* Significance (p<0.05) among footwear x surface

Post-hoc comparisons: significant differences (p<0.001) between aTS x PM & TS x FG, bTS x PM & MC x PM, cTS x PM & MC x FG, dTS x FG & MC x PM, eTS x FG & MC x FG, fMC x PM & MC x FG
Table 8: Time between the Phases of Interest

<table>
<thead>
<tr>
<th>Timing Variables</th>
<th>MC x FG</th>
<th>MC x PM</th>
<th>TS x FG</th>
<th>TS x PM</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC to Max IR (s)</td>
<td>0.11 ± 0.006</td>
<td>0.13 ± 0.004</td>
<td>0.13 ± 0.003</td>
<td>0.11 ± 0.004</td>
<td>0.35</td>
</tr>
<tr>
<td>SFC to Ball Release (s)</td>
<td>0.15 ± 0.004</td>
<td>0.14 ± 0.002</td>
<td>0.14 ± 0.003</td>
<td>0.16 ± 0.006</td>
<td>0.66</td>
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<tr>
<td>SFC to Max ER (s)</td>
<td>0.14 ± 0.003</td>
<td>0.11 ± 0.003</td>
<td>0.12 ± 0.004</td>
<td>0.14 ± 0.005</td>
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<td>Max ER to Ball Release (s)</td>
<td>0.031 ± 0.001</td>
<td>0.027 ± 0.001</td>
<td>0.029 ± 0.002</td>
<td>0.036 ± 0.001</td>
<td>0.48</td>
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<td>Ball Release to Max IR (s)</td>
<td>0.063 ± 0.003</td>
<td>0.058 ± 0.003</td>
<td>0.061 ± 0.002</td>
<td>0.062 ± 0.003</td>
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<td>Max ER to Max IR (s)</td>
<td>0.073 ± 0.004</td>
<td>0.076 ± 0.003</td>
<td>0.082 ± 0.002</td>
<td>0.085 ± 0.003</td>
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Table 9: Mean MVIC for the Q, H, TA, and G in the Stride Leg

<table>
<thead>
<tr>
<th>Electromyography: Mean MVIC</th>
<th>Left (Stride) Leg</th>
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<tr>
<td>Mean MVIC Q (V)</td>
<td>0.5779 0.2628 11</td>
</tr>
<tr>
<td>Mean MVIC H (V)</td>
<td>0.5496 0.2348 11</td>
</tr>
<tr>
<td>Mean MVIC TA (V)</td>
<td>0.7729 0.1472 7</td>
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<tr>
<td>Mean MVIC G (V)</td>
<td>0.2199 0.0473 11</td>
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Table 10: Mean Muscle Activity of the Quadriceps (Q) in the Stride Leg

<table>
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<tr>
<th></th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
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<tbody>
<tr>
<td>Stride Foot Contact</td>
<td>0.294729 ± 0.123786</td>
<td>0.277392 ± 0.130374</td>
<td>0.300508 ± 0.141239</td>
<td>0.317845 ± 0.149387</td>
<td>0.61</td>
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<tr>
<td>Maximum ER</td>
<td>0.312066 ± 0.146671</td>
<td>0.294729 ± 0.097261</td>
<td>0.317845 ± 0.149387</td>
<td>0.335182 ± 0.157536</td>
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<tr>
<td>Ball Release</td>
<td>0.358298 ± 0.168400</td>
<td>0.335182 ± 0.157536</td>
<td>0.329403 ± 0.085645</td>
<td>0.398751 ± 0.187413</td>
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<tr>
<td>Maximum IR</td>
<td>0.468099 ± 0.210645</td>
<td>0.416088 ± 0.195561</td>
<td>0.427646 ± 0.200994</td>
<td>0.444983 ± 0.209142</td>
<td>0.28</td>
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Table 11: Mean Muscle Activity of the Hamstring (H) in the Stride Leg

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<thead>
<tr>
<th></th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
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<tr>
<td>Stride Foot Contact</td>
<td>0.280296 ± 0.131739</td>
<td>0.263808 ± 0.123990</td>
<td>0.285792 ± 0.102885</td>
<td>0.30228 ± 0.142072</td>
<td>0.51</td>
</tr>
<tr>
<td>Maximum ER</td>
<td>0.296784 ± 0.139488</td>
<td>0.294729 ± 0.131739</td>
<td>0.30228 ± 0.096730</td>
<td>0.318768 ± 0.149821</td>
<td>0.69</td>
</tr>
<tr>
<td>Ball Release</td>
<td>0.340752 ± 0.160153</td>
<td>0.318768 ± 0.089255</td>
<td>0.313272 ± 0.147238</td>
<td>0.379224 ± 0.178235</td>
<td>0.44</td>
</tr>
<tr>
<td>Maximum IR</td>
<td>0.445176 ± 0.195877</td>
<td>0.395712 ± 0.185985</td>
<td>0.406704 ± 0.191151</td>
<td>0.423192 ± 0.131190</td>
<td>0.32</td>
</tr>
</tbody>
</table>
### Table 12: Mean Muscle Activity of the Tibialis Anterior (TA) in the Stride Leg

<table>
<thead>
<tr>
<th></th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride Foot Contact</td>
<td>0.394179 ± 0.126137</td>
<td>0.370992 ± 0.174366</td>
<td>0.353679 ± 0.166229</td>
<td>0.374084 ± 0.175819</td>
<td>0.002*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maximum ER</td>
<td>0.417366 ± 0.196162</td>
<td>0.294729 ± 0.126137</td>
<td>0.374084 ± 0.175819</td>
<td>0.394488 ± 0.185409</td>
<td>0.008*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ball Release</td>
<td>0.479198 ± 0.225223</td>
<td>0.448282 ± 0.210693</td>
<td>0.387687 ± 0.182213</td>
<td>0.469305 ± 0.150178</td>
<td>0.007*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maximum IR</td>
<td>0.626049 ± 0.212857</td>
<td>0.556488 ± 0.261549</td>
<td>0.503312 ± 0.161060</td>
<td>0.523717 ± 0.246147</td>
<td>0.001*&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

* Significant Difference (p<0.05) among footwear x surface

**Post-hoc** comparisons: significant differences (p<0.001) between<sup>a</sup>TS x PM & TS x FG,<sup>b</sup>TS x PM & MC x PM,<sup>c</sup>TS x PM & MC x FG,<sup>d</sup>TS x FG & MC x PM,<sup>e</sup>TS x FG & MC x FG,<sup>f</sup>MC x PM & MC x FG

---

### Table 13: Mean Muscle Activity of the Gastrocnemius (G) in the Stride Leg

<table>
<thead>
<tr>
<th></th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride Foot Contact</td>
<td>0.137943 ± 0.064833</td>
<td>0.129829 ± 0.042844</td>
<td>0.114348 ± 0.053743</td>
<td>0.113688 ± 0.053434</td>
<td>0.002*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maximum ER</td>
<td>0.146058 ± 0.048199</td>
<td>0.294729 ± 0.064833</td>
<td>0.120945 ± 0.056844</td>
<td>0.394488 ± 0.056348</td>
<td>0.003*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ball Release</td>
<td>0.167696 ± 0.078817</td>
<td>0.156877 ± 0.073732</td>
<td>0.125343 ± 0.015041</td>
<td>0.142627 ± 0.067035</td>
<td>0.007*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Maximum IR</td>
<td>0.219086 ± 0.052581</td>
<td>0.194743 ± 0.091529</td>
<td>0.162726 ± 0.076481</td>
<td>0.159164 ± 0.035016</td>
<td>0.004*&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;&lt;sup&gt;d&lt;/sup&gt;&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

* Significant Difference (p<0.05) among footwear x surface

**Post-hoc** comparisons: significant differences (p<0.001) between<sup>a</sup>TS x PM & TS x FG,<sup>b</sup>TS x PM & MC x PM,<sup>c</sup>TS x PM & MC x FG,<sup>d</sup>TS x FG & MC x PM,<sup>e</sup>TS x FG & MC x FG,<sup>f</sup>MC x PM & MC x FG
Table 14: Pelvis and Trunk Kinematics

<table>
<thead>
<tr>
<th>Pelvis and Trunk Kinematics</th>
<th>TS x PM</th>
<th>TS x FG</th>
<th>MC x PM</th>
<th>MC x FG</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Angular Velocity (°/s)</td>
<td>607 ± 97</td>
<td>776 ± 84</td>
<td>778 ± 87</td>
<td>684 ± 77</td>
<td>0.52</td>
</tr>
<tr>
<td>Pelvis orientation @ time of Maximum pelvis angular velocity (°)</td>
<td>13.1 ± 3</td>
<td>12.3 ± 2</td>
<td>11.6 ± 3</td>
<td>12.4 ± 3</td>
<td>0.49</td>
</tr>
<tr>
<td>Trunk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Angular Velocity (°/s)</td>
<td>924 ± 101</td>
<td>884 ± 99</td>
<td>901 ± 102</td>
<td>898 ± 94</td>
<td>0.69</td>
</tr>
<tr>
<td>Lateral Flexion (frontal plane)</td>
<td>24.2 ± 5</td>
<td>23.8 ± 4</td>
<td>24.6 ± 2</td>
<td>25.8 ± 4</td>
<td>0.69</td>
</tr>
<tr>
<td>Forward flexion (sagittal plane)</td>
<td>15.8 ± 2</td>
<td>16.2 ± 3</td>
<td>17.2 ± 3</td>
<td>17.8 ± 5</td>
<td>0.56</td>
</tr>
<tr>
<td>Rotation (transverse plane)</td>
<td>9.2 ± 3</td>
<td>9.5 ± 1</td>
<td>10.2 ± 4</td>
<td>10.1 ± 3</td>
<td>0.61</td>
</tr>
<tr>
<td>Time until maximum trunk rotation (% of pitch cycle)</td>
<td>53.2 ± 7</td>
<td>54.1 ± 8</td>
<td>55.6 ± 8</td>
<td>54.3 ± 9</td>
<td>0.88</td>
</tr>
</tbody>
</table>
APPENDIX B: FIGURES
Figure 1. Full Body Plug-in-Gait Marker Placement from the Helen Hayes marker system

Figure 2. 6” x 14” flat ground (FG) of 34 mm monofilament synthetic turf with a Styrene-Butadiene Rubber (SBR) infill
Figure 3. Pitching Mound (PM), 5’4”W x 9’L x 6”H, (Proper Pitch Mounds, Garner, NC)

Figure 4. Athletic Footwear Worn by Participants: Top Row: New Balance 4040v3 Low Youth Baseball Cleat (MC); Bottom Row: New Balance 4040v3 Turf Shoe (TS)
Figure 5. The Six Phases of an Overhead Baseball Pitch, (Fleisig, Escamilla et al. 1996).

Figure 6. The pitching cycle used for data analysis began with stride-foot contact (0%) and ended with maximum glenohumeral IR (100%) of the throwing arm (Fleisig, Andrews et al. 1995).
**Figure 7.** Global coordinate system (R₁): Axes defined as X₁ (vector directed from the pitching rubber to home plate), Y₁ (cross product of X₁ and Z₁), and Z₁ (downward vertical projection).

**Figure 8.** Kinematic Internal and External Rotation Differences in the Right Shoulder in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]

‡ Indicates significant interaction; * Indicates significant difference in IR for MC and surface interaction; * Indicates significant difference in ER for TS and surface interaction
**Figure 9.** Internal and External Velocity Differences in the Right Shoulder in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

‡ Indicates significant interaction; * Indicates significant difference in IR for MC and surface interaction; ‡ Indicates significant difference in ER for TS and surface interaction
Figure 10. Bilateral Lower Extremity Kinematic Differences in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

Lower Extremity Kinematic Differences

‡ Indicates significant interaction; * Indicates significant difference in PF for TS and surface interaction
Figure 11. Internal and External Torque Differences in the Right Shoulder in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

‡ Indicates significant interaction; * Indicates significant difference in IR for MC and surface interaction; * Indicates significant difference in ER for TS and surface interaction.
Figure 12. Mean Muscle Activity in the Stride Leg’s Quadricep (Q) in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

![Mean Muscle Activity in the Stride Leg Quadricep (Q)](image)

Figure 13. Mean Muscle Activity in the Stride Leg’s Hamstring (H) in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

![Mean Muscle Activity in the Stride Leg Hamstring (H)](image)
Figure 14. Mean Muscle Activity in the Stride Leg’s Tibialis Anterior (TA) in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

† Indicates significant interaction; * Indicates significant difference in TA for TS and PM interaction; ‡ Indicates significant difference in TA for MC and FG interaction
**Figure 15.** Mean Muscle Activity in the Stride Leg’s Gastrocnemius (G) in Baseball Footwear [Turf Shoes (TS) and Molded Cleats (MC) on Inclined Surfaces [Flat Ground (FG) and Pitching Mound (PM)]]

‡ Indicates significant interaction; * Indicates significant difference in G for TS and surface interaction
APPENDIX C: CONSENT FORM
Consent for Your Child to Participate in Research

Study Title: A Kinematic and Kinetic Comparison of the Shoe-Surface Interface and its Effect on Shoulder and Elbow Dynamics in Youth and Adolescent Baseball Players.

Investigator
Jacob R. Gdovin, PhD(c)
HESRM
242 Turner Center
University of Mississippi
University, MS 38677
(520) 904-7033
jrgdovin@go.olemiss.edu

Faculty Sponsor
Martha Bass, Ph.D.
HESRM
232 Turner Center
University of Mississippi
University, MS 38677
(662) 915-5563
mabass1@olemiss.edu

The purpose of this study:
The purpose of this study is to determine how the shoe (molded cleats and turf shoes) interacts with the underlying surface (flat and sloped artificial turf) and effects the shoulder and elbow dynamics of youth and adolescent baseball players during an overhead throw.

What your child will do for this study:
1. This will be the one and only visit where you and your child need to come to the Applied Biomechanics Laboratory (ABL) located in the Turner Center at The University of Mississippi, which will last approximately 90 minutes.

2. Upon agreement to participate and with your help, your child will be asked to complete a Physical Activity Readiness Questionnaire (PAR-Q). If your child is able to participate in physical activity based on the PAR-Q questionnaire, the study will begin. Following this, your child’s height, weight, leg/arm length, and leg/arm width will be measured. They will then be verbally told of what will be asked of them to do for the duration of the study.

3. If your child has not already done so, they will be asked to change into their compression shorts and compression socks and shirt which will be provided by the researchers at the time of testing. Strips of artificial field turf will be securely placed on the laboratory floor to allow proper traction between the cleat (your team issued turf shoe and molded cleat) and ground floor.

4. Next, your child will lie on a table for approximately 10 minutes and receive a dual energy x-ray absorptiometry (DXA) scan to measure body composition and bone density.

5. A warm-up will then be completed as if your child would be pitching in an actual baseball game with no constraint on the time or number and speed of warm-up throws.

6. In order to track body motion, retro-reflective markers will be placed on anatomical landmarks on your child's upper and lower body. Markers will be applied to their skin,
feet/shoes and clothing via double-sided adhesive tape and velcro (used only on clothing). Similarly, adhesive electrodes will be placed on four muscles on the lower extremity to capture muscle activity. Immediately following, they will stand up straight with their arms outstretched and palms facing forward so the motion capture system can capture a static trial.

7. Your child will then throw 40 fastballs in total with 10 pitches being thrown in each possible footwear-surface condition (molded cleat x flat ground, molded cleat x sloped ground, turf shoe x flat ground, turf shoe x sloped ground).

8. Your child will be asked to give maximal effort for every trial without receiving critiques or coaching from the researchers. A 30-second rest between throws will be allotted as well as a 10 minute break between shoe-surface conditions where they will sit down without shoes on to act as a washout period.

Videotaping / Audiotaping:
Your child will be videotaped while they perform all forty pitches so we can confirm joint angles and analyze technique.

Time required for this study:
This study will consist of one testing session lasting approximately 90 minutes.

Possible risks from participation:
Although highly unlikely, throwing a baseball 40 times in one session may result in a muscle or joint injury. Your child may experience some muscle soreness 24 to 48 hours after testing, but this should go away within a few days. Their training status will influence the likelihood an injury occurs and how quickly any muscle or joint soreness goes away. Therefore, if your child consistently throws a baseball, soreness may be reduced. To minimize these risks, your child will throw a baseball with their “normal” mechanics meaning it is the easiest and most comfortable method for them. If at any time during the study they experience unexpected pain, discomfort, soreness, headache, dizziness, unusual fatigue or difficulty breathing, they should immediately tell a member of the research team.

Your child will also will receive a dual energy x-ray absorptiometry (DXA) scan for the researchers to compare how fat-mass and fat-free mass affect throwing mechanics since there is a correlation between an increase in age, height, and weight and reported elbow pain. A DXA scan does expose your child to a small amount of radiation, however, according to the American College of Radiology and Radiological Society of North America, an individual receives 0.001mSv of radiation from a DXA scan compared to the amount of radiation exposure with an intraoral dental x-ray which exposes an individual to 0.005mSv.

Benefits from your participation:
Neither you nor your child should expect benefits from participating in this study. However, you and your child may gain insight into the potential benefits of utilizing specific athletic footwear
on flat-ground and inclined artificial turf and how that may alter their throwing motion. Similarly, a dual energy x-ray absorptiometry (DXA) readout can allow your child, as well as yourself, to view their body composition related to fat mass and fat-free mass.

**Confidentiality:**
Any information about your child 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 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. Identity on the research records will be indicated by a case number rather than by name. Data may be used for educational conferences or published in scientific journals; however, specific names will not be used.

**Confidentiality and Use of Video/Audio Tapes:**
Video will be utilized to compare movements and joint angles from real-time data to computer generated images. Only investigators on the research team will have access to the video(s) and recordings will be kept on the laboratories password-protected computer. These will then be used for future studies to compare movements across various sports and genders.

**Right to Withdraw:**
Your child is not required to participate in this study. If they decide to participate, but later change their mind, they can withdraw at any time. There are no penalties or consequences of any kind if they decide that they want to withdraw. Their participation in this study may be terminated at any time by the investigators if they believe that it is in their best interest to do so or if they fail to follow the study procedures.

**Compensation for Illness OR Injury:**
I understand that my child and I are not waiving any legal rights or releasing the institution or their agents from liability from negligence. I understand that in the event of physical injury resulting from the research procedures, The University of Mississippi does not have funds budgeted for compensation for 1) lost wages, 2) medical treatment, or 3) reimbursement for such injuries. The University will help, however, obtain medical attention which I or my child may require while involved in the study by securing transportation to the nearest medical facility.

**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 or your child have any questions or concerns regarding their 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 your questions have been answered, then decide if you want your child to be 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 allow my child to participate.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study’s risks as well as my child’s right to refuse to participate and to withdraw, and that I am the parent/legal guardian of the child listed below.

Signature of Parent/Legal Guardian: ___________________________ Date: ____________

Printed Name of Parent/Legal Guardian: ____________________________

Printed Name of Child: ___________________________________________

Signature of Investigator: ___________________________ Date: ____________

NOTE TO PARTICIPANTS: DO NOT SIGN THIS FORM IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED
APPENDIX D: ASSENT FORMS
Oral Assent Script with Record of Child’s (Aged 7-13) Response

I would like to ask you to help me with a project that I am doing at The University of Mississippi. If you agree, you would throw 40 fastballs while wearing two different types of shoes on two different surfaces. It will take about 90 minutes.

1. This will be the only time you have to come to the lab and it will last about 90 minutes.

2. If you agree to participate, you will sign paperwork and have your height, weight, leg/arm length, and leg/arm width measured.

3. You will bring and wear your compression shorts (“sliders”) as well as a tight-fitting shirt and socks which are provided by the researchers. This clothing will be worn throughout the entire study.

4. Artificial field turf will be placed on the floor so you can safely walk and throw a ball.

5. Next, you will be asked to lie on a table for 10 minutes while a machine measures your body weight and the strength of your bones.

6. You will then complete a warm-up as if you are pitching in an actual baseball game with no constraint on the time or number and speed of warm-up throws.

7. In order for cameras to track your motions, small markers will be placed on your upper and lower body. Markers will be placed on your skin, feet/shoes and clothing via tape and velcro (used only on clothing). Similarly, sticky pads will be placed on four muscles on your leg to capture muscle movement.

8. You will then throw 10 fastballs in four conditions equaling 40 total pitches with a 30-second rest in-between pitches.

9. You will be asked to give maximal effort for every pitch without receiving coaching from the researchers or your parents. A 10 minute break between shoe conditions will occur after your throw 10 pitches.

What questions do you have about what you will do for me?

Will you do this study?  Response: ☐ YES ☐ NO

Print Name:_______________________________________________ Date:________

Sign Name:_______________________________________________ Date:________
Assent Form for Children (Aged 14-15)

Dear Participant,

I would like to invite you to help me with a research project that I am doing at The University of Mississippi.

The purpose of this project is to help me learn more about how two different types of cleats on two different sloped surfaces affect the elbow and shoulder when throwing a baseball. No one will see your results except my research team and I, and your name will not be used in any reports.

If you take part in my research, you will throw a total of 40 fastballs. It will take you about 90 minutes to finish.

You are free to quit this research at any time and I won’t be upset with you. If you have any questions or concerns, please ask me now or call me at (520)-904-7033. Thank you for your help.

Protocol:

1. This will be the only time you have to come to the lab and it will last about 90 minutes.

2. If you agree to participate, you will sign paperwork and have your height, weight, leg/arm length, and leg/arm width measured.

3. You will bring and wear your compression shorts (“sliders”) as well as a tight-fitting shirt and socks which are provided by the researchers. This clothing will be worn throughout the entire study.

4. Artificial field turf will be placed on the floor so you can safely walk and throw a ball.

5. Next, you will be asked to lie on a table for 10 minutes while a machine measures your body weight and the strength of your bones.

6. You will then complete a warm-up as if you are pitching in an actual baseball game with no constraint on the time or number and speed of warm-up throws.

7. In order for cameras to track your motions, small markers will be placed on your upper and lower body. Markers will be placed on your skin, feet/shoes and clothing via tape and velcro (used only on clothing). Similarly, sticky pads will be placed on four muscles on your leg to capture muscle movement.
8. You will then throw 10 fastballs in four conditions equaling 40 total pitches with a 30-second rest in-between pitches.

9. You will be asked to give maximal effort for every pitch without receiving coaching from the researchers or your parents. A 10 minute break between shoe conditions will occur after your throw 10 pitches.

Sincerely,

Jacob Gdovin

I agree to help with this research project.  ☐ YES  ☐ NO

Print Name: _____________________________________________ Date: __________

Sign Name: _____________________________________________ Date: __________

Signature of Investigator: ________________________________ Date: __________
VITA
JACOB R. GDavin, MS, Ph(d(c)
Department of Health, Exercise Science and Recreation Management
The University of Mississippi
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EDUCATION

The University of Mississippi, Oxford, MS
Doctor of Philosophy in Health and Kinesiology, Concentration: Exercise Science and Biomechanics
Dissertation Title: “A Kinematic Comparison of Shoulder and Elbow Dynamics Influenced by the Shoe-Surface Interface in Youth and Adolescent Baseball Pitchers”

Anticipated: 8/2017

Mercyhurst University, Erie, PA
Master of Science in Exercise Science 8/2014

Mercyhurst University, Erie, PA
Master of Science in Organizational Leadership, Concentration: Human Resources
Thesis Title: “Leadership and Management in Orthopedics: An Investigation of Alternative Strategies”

5/2013

Mercyhurst University, Erie, PA
Bachelor of Science in Sports Medicine, Concentration: Pre-Medical
Research Project: “The effectiveness of utilizing the pack-and-fill protocol in order to maintain the cervical neutral position on a football player with a potential catastrophic cervical neck injury”

5/2011

PROFESSIONAL EXPERIENCE

The University of Mississippi, Oxford, MS 8/2014-Present
Graduate Assistant/Instructor

• Primary instructor for undergraduate lecture, laboratory, and exercise leisure courses
  - Biomechanics, Kinesiology, Exercise Leadership (Strength and Conditioning), Personal and Community Health, First Aid/CPR, Volleyball, Introduction to Exercise Science

• Graduate student supervisor of the Applied Biomechanics Laboratory
  - Manage/coordinate the laboratory calendar
  - Manage and troubleshoot all equipment/supplies
  - Assist in the development, implementation, collection, and analysis of research designs

• Assist full-time faculty members with research projects and grading

• Advise exercise science undergraduate students

Movement Analysis Laboratory Graduate Assistant

• Collect and reduce data to create quantitative graphs for physical therapists and physicians to analyze
• Analysis of the gait cycle of patients with motor and physical disabilities - Specializing in pediatric care
• Assist Physical Therapist in conducting hands-on physical examinations of patients
• Prepare, set-up, and calibrate laboratory and equipment for patient examinations/testing
• Equipment responsibility and familiarity: calibrating motion capture systems, cameras, and marker sets
Secondary Instructor

• Implementing, assessment, planning, organizing, and rehearsal of pre-hospital care of catastrophic medical emergencies in athletics
  • Delivery of on-site training sessions for medical staffs including physicians, ATC’s, PT’s, EMT’s
  • Sites included: Dallas Cowboys, Houston Texans, New York Giants, Northeast Regional High School Athletic Departments
• Techniques: spine boarding, pack-and-fill protocol, intubation, equipment removal
• Assisted medical staffs in the creation, planning, rehearsal, and revision of their team-based emergency action plan for the management of critical on-field injuries
  • Suggestions re: emergency action plan improvement/changes based on organizational demands/needs to improve efficiency and quality of care
• Oversaw interns assigned to the SMC Inc. team and delegated responsibilities accordingly
• Supported the SMC Inc. Team Leader in: lab activities, lab set-up and take-down, completing inventory logs, and providing additional educational support

RESEARCH FUNDING

University of Mississippi Graduate Student Council Research Grant (2015-2016)
Kinetic and Kinematic Comparison of Cleat Type during Performance Movements
Role: Primary Investigator
Funding Request: $1,000
Status: Funded

REFEREED ARTICLES


Jacobson, B; Cendoma, M; Gdovin, J; Cooney, K; Bruening, D. The effectiveness of utilizing the pack-and-fill protocol in order to maintain the cervical neutral position on a football player with a potential catastrophic cervical neck injury. *Journal of Athletic Training*. 49(1):42-48, 2014.

MANUSCRIPTS UNDER REVIEW

Gdovin, JR; Williams, CC; Wilson, SJ; Cazas-Moreno, VL; Eason, JD; Hoke, EL; Allen, CR; Chander, H; Wade, C; Garner, JC. Influences of athletic footwear on ground reaction forces during a side step cutting maneuver on artificial turf. *Journal of Sports Sciences*.

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*.

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*. 
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.

Williams, CC; Gdovin, JR; Wilson, SJ; Cazas-Moreno, VC; Eason, JD; Hoke, EL; Allen, CR; Wade, C; Garner, JC. The effects of various weighted implements on baseball swing kinematics in collegiate baseball players. Journal of Strength and Conditioning Research.

Allen, CR; Fu, YC; Cazas-Moreno, VL; Valliant, MW; Gdovin, JR; Williams, CC; Garner, JC. The effects of jaw clenching and a jaw alignment mouthpiece on force production. Journal of Strength and Conditioning Research.

MANUSCRIPTS IN PREPARATION

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.”

ABSTRACTS


RESEARCH COLLABORATIONS
Troy University, Department of Kinesiology and Health Promotion
Mississippi State University, Department of Kinesiology

TEACHING EXPERIENCE
Undergraduate:

**ES 447: Biomechanics Laboratory**
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 402: Exercise Leadership (Strength and Conditioning)
This course provides an overview of the educational concepts, performance techniques, program design, and leadership skills needed to teach individuals exercise programs within the field of strength and conditioning.

ES 346: Kinesiology
This is a clinically oriented human anatomy course 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: Red Cross Responding to Emergencies (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 117: Volleyball
An interactive activities course that is designed to teach the essential fundamentals and techniques of volleyball. Students are introduced to the history, rules/regulations, scoring, and basic strategy of the game.

ES 100: Introduction to Exercise Science
An introduction to the faculty and courses in exercise science, with an emphasis on career planning and student development. This course provides an overview of the field of exercise science, its development, professional activities, and sub-disciplines.

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.

TECHNIQUES/SKILLS
Biomechanical Analysis:
Equipment:
- Cortex version 3.6 Motion Capture system (Motion Analysis Corporation, Santa Rosa CA, USA)
• Visual 3D, version 4 software (C-Motion, Inc., Rockville MD, USA)
• 8 Vicon M2 cameras with a Vicon 612 Datastation (Vicon, Oxford, UK)
• 16 channel Trigno Wireless EMG System (Delsys, Boston MA, USA)
• 3 force plates (Advanced Mechanical Technology, Inc., Watertown MA, USA)
• 2 Canon GL-2 video cameras (Canon, Lake Success NY, USA)
• Retroreflective markers (3M, St. Paul MN, USA)
• Power Plate Whole Body Vibration Platform (Performance Health Systems, Northbrook IL, USA)
• Neurocom® Equitest

**Aerobic Testing:**
**Equipment:**
• ParvoMedics True 100
• VO2max: cycling and treadmill
• VO2: cycling and treadmill

**Anaerobic Testing:**
**Equipment:**
• Biodex System 4
• Biodex Balance Platform
**Testing:**
• Wingate and Thorstensson protocol

**Body Composition:**
• Dual-Energy X-Ray Absorptiometry (DXA)
• Bod Pod
• Skin folds

**Miscellaneous:**
• Measuring onset of blood lactate (OBLA)
• Spirometry: manual vs. automated
• Blood Pressure: resting vs. exercise

**RESEARCH INTERESTS**
• Analyzing athletic footwear and the shoe-surface interface
• Pitching and throwing mechanics
• Various surfaces and their effects on sport-specific movements
• Effects of athletic and ergonomic footwear on balance
• Biomechanics of gait
• Improve athletic performance: biomechanical assessments and strength and conditioning exercises

**LEADERSHIP**
The Applied Biomechanics Laboratory, Oxford, MS 8/2015-Present
Graduate Student Supervisor
• Development and implementation of research designs
• Assist with data collection and analysis
• Coordinate the laboratory calendar for data collection among undergraduate/graduate students
Management of equipment/supplies

**Mercyhurst Residence Life Department, Erie, PA**

*Hall Director*
- Supervise 150 freshman male college students in a dormitory setting
- Direct a staff of six undergraduate resident assistants
- Trained in conflict resolution, crisis intervention, and communication
- Hold weekly office hours and sanction meetings that enforce student code of conduct

**Resident Assistant**
- Supervised 48 co-ed college students in an apartment-style setting
- Trained in conflict resolution, crisis intervention, and active listening
- Coordinated monthly educational, social, and community building activities

**CERTIFICATIONS/CLEARANCES**

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<tr>
<td>First Aid/CPR/AED Instructor, American Red Cross</td>
<td>January 2018</td>
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<tr>
<td>Adult/Pediatric First Aid, American Red Cross</td>
<td>May 2017</td>
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<tr>
<td>Adult/Pediatric CPR, American Red Cross</td>
<td>May 2017</td>
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<td>Adult/Pediatric AED, American Red Cross</td>
<td>May 2017</td>
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**CLEARANCES**

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<td>ACT 33 – Pennsylvania Child Abuse History Clearance</td>
<td>March 2013</td>
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<tr>
<td>ACT 34 – Pennsylvania State Police Criminal Record Check</td>
<td>March 2013</td>
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<tr>
<td>ACT 73 – FBI Criminal Background Check</td>
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**DEPARTMENTAL SERVICES**

Departmental:
- 2015-2016: The University of Mississippi, Exercise Science (Motor Control) Search Committee

Student Advising:

*Sally McDonnell Barkdale Undergraduate Honors College Research Thesis:*
- 2015-2016 - Jessica Hiskey, student advisor
- 2015-2016 - Zachary Bridges, student advisor
- 2016-2017 - Alexandra Adderholt, student advisor

**PROFESSIONAL MEMBERSHIPS**

<table>
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<tr>
<td>American Society of Biomechanics</td>
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<tr>
<td>American College of Sports Medicine – Southeast Chapter</td>
<td>January 2015-Present</td>
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<tr>
<td>National Strength and Conditioning Association</td>
<td>January 2015-Present</td>
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**CONFERENCES/CONTINUING EDUCATION**

<table>
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<th>Conference</th>
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<tr>
<td>SEACSM Annual Meeting: February 2017, Greenville, SC</td>
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<td>ASB Annual Meeting: August 2016, Raleigh, NC</td>
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<tr>
<td>SEACSM Annual Meeting: February 2016, Greenville, SC</td>
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<tr>
<td>NSCA National Conference: July 2015, Orlando, FL</td>
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<tr>
<td>SEACSM Annual Meeting: February 2015, Jacksonville, FL</td>
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EATA Annual Convention: January 2012, Boston, MA

HONORS/AWARDS

Journal of Athletic Training (JAT) Kenneth L. Knight Award for Outstanding Manuscript
• Award given annually to the most prestigious and scholarly article
• Awarded for the year of 2014
The Sister Eustace Taylor Award - Exercise Science
• Awarded to the top graduate student in their respective program
• Criteria for selection include GPA and overall contribution to their respective school
Boy Scouts of America: 4 Palms
Boy Scouts of America: Eagle Scout Award

COMMUNITY OUTREACH

Mary Cathey Head Start Center
• Mission: Provide children and families with a range of individualized services in the areas of education, medical, dental and mental health. Head start programs are designed to build on the strengths of families and communities.
  • Lecturer: child and infant choking and CPR

Oxford Park Commission – Youth Football Recreational Coach
• Under 10 league and Under 6 league

RELEVANT COURSEWORK

The University of Mississippi

Biomechanics:
ES 620 Selective Topics in Exercise Science – 3D Kinematics/Kinetics Modeling (Spring 2015-2016)
ES 620 Selective Topics in Exercise Science – Stress (Spring 2015-2016)
ES 632 Advanced Structural Kinesiology (Spring 2015-2016)
ES 609 Motor Control and Learning (Fall 2015-2016)
ES 612 Instrumentation and Analysis in Biomechanics (Fall 2015-2016)
ES 548 Biomechanics of Injury (Spring 2014-2015)
ES 512 Foundations of Biomechanics (Fall 2014-2015)

Exercise Physiology:
ES 618 Advanced Muscle Physiology (Fall 2015-2016)
ES 620 Selective Topics in Exercise Science - Strength and Conditioning (Spring 2014-2015)
ES 611 Exercise Physiology I (Fall 2014-2015)

Statistical Coursework:
EDRS 733 Special Topics in Educational Research – Hierarchical Linear/Multilevel Modeling (Spring 2015)
PSY 704 Quantitative Methods in Psychology II (Spring 2014-2015)
HP 626 Statistical Analysis I (Fall 2014-2015)
REFERENCES
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(662) 202-7977
hchander@colled.msstate.edu