THE INFLUENCE OF A PREPARATORY ARM SWING ON LOWER EXTREMITY KINEMATICS DURING A HORIZONTAL JUMP

by

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ABSTRACT

Horizontal jumping is a ballistic motion that includes horizonal propulsion, during which many athletes experience movement deficits like knee valgus and foot pronation that are known to be indicators of muscular weakness, deficits or predisposition to injury, making it a valuable motion to study. This project endeavored to investigate how a novel arm swing preparation motion may influence knee valgus and foot eversion during the horizontal jump. The novel arm swing had the participants perform the usual arm swing several times before jumping. The results indicated no significant difference in either knee or foot motion between jump conditions. A significant difference was noted between right and left knee valgus when collapsed across all jumps. While this project failed to reach significance between jumps it did suggest that researchers should investigate both limbs to assure that critical information is not missed.

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CHAPTER 1

INTRODUCTION

Jumping tasks such as countermovement vertical jumps and countermovement horizontal jumps are widely studied due to their simulation of sport specific movements and sufficiency in providing a range of biomechanical data that can be used to explain performance outcomes and potential injury risk (Dufek et al 1991). Further, data from several studies suggest that horizontal movements more closely resemble sport-specific behaviors during which mechanisms such as side-stepping and cutting occur at high velocities, emphasizing the importance of observing injury risk in horizontal movements (Hewett et al 2005). It has been shown that high impact forces occurring during horizontal or lateral movements increase the biomechanical loading on the knee and hip joints, which can lead to increased injury risk (Nedergaard et al 2020). Injury to the lower extremity, specifically the knee, is common in sports such as basketball, volleyball, lacrosse and track & field events due to the inability of the knee joint to withstand high impact forces during jumping and adapt to perturbations during the flight phase in preparation for landing (Fagenbaum 2003, Louw, & Grimmer, 2003).

The literature has observed lower extremity biomechanics during sporting events, identifying changes in knee flexion, increased knee angulation and foot collapse as a result of the strenuous requirements of the given tasks (Markholf et al 1995; Dai et al 2019). Specifically, loading on the knee contributes to increased anterior tibial shear forces which have been shown to increase prevalence of ligamentous knee injuries (Markholf et al 1995, Hewett et al 2005), which are also commonly found in athletes who participate in the above-mentioned sports (Sinsurin et al., 2013). It is important to note, that this thesis is a branch of a larger ongoing project which focuses on addressing the overarching implications of a novel arm swing on movement patterns during jumping tasks. This project is an investigation regarding the influence of said novel preparatory arm swing on knee and foot behavior. Specifically, how a repetitive preparatory arm swing prior to movement might alter knee and foot angulation during propulsion.

Preparatory actions, occurring prior to initiation of the intended movement of the body, have been shown to enhance task performance (Payne et al., 1968). During sport specific movements, techniques such as a countermovement or arm swing during the preparation phase of a ballistic movement, can alter force production, energy distribution, and performance outcomes (Luhtanen and Komi, 1978; Harman et al., 1990; Feltner et al., 1999). Specifically, while the literature continues to examine knee behavior and lower extremity biomechanics (Markholf et al 1995; Dai et al 2019), the need for understanding how other segments of the body contribute to these outcomes has become more prevalent. One ongoing hypothesis has focused on the role of the motion of the upper extremities on the preparation of the body for jumping tasks (Payne et al., 1968; Luhtanen and Komi, 1978; Harman et al., 1990; Feltner et al., 1999; Ashby & Heegaard, 2002; McKenzie et al., 2014).

As a preparatory movement often associated with a countermovement, the arm swing, defined as simultaneous swinging of the arms (Ashby et al., 2006) has been shown to enhance factors such as ground reaction force (Payne et al., 1968), velocity (Luhtanen and Komi, 1978; Harman et al., 1990; Feltner et al., 1999;), height of center of mass (COM) (Payne et al., 1968; Luhtanen and Komi, 1978; Harman et al., 1990), torque generation (Feltner et al, 1999) and contraction rate of lower extremity musculature (Harman et al., 1990; Feltner et al., 1999). Overall, implementation of an arm swing has been shown to increase the height of a vertical jumping task, however, additional research is required to expand our understand of the contribution of the arm swing to jumping mechanics. As the arm swing during the preparatory motion prepares the body to produce increased forces it is reasonable to conclude that a longer arm swing motion would yield larger forces. Therefore, research is needed to determine if these larger forces cause changes in form. Particularly, does the body adopt postures that may indicate susceptibility to injury such as increased knee valgus or an everted foot position.

Dynamic jumping tasks are often used in sport science data collection procedures. More specifically, biomechanical outcomes of vertical and horizontal jumping tasks are often used to predict or examine the rehabilitation from lower extremity injury (Ford et al. 2009; Padua et al. 2009; Schultz et al. 2010; Paterno et al. 2010). Dynamic knee valgus, the inward angulation of the knees during a propulsive or landing movement, has been used to predict knee joint injuries such as anterior cruciate ligament tears or patellar tendon ruptures (Hewett et al. 2005; Schultz et al 2010). Further, excessive foot pronation, a possible contributor to dynamic knee valgus, has been shown to exacerbate the angulation of the knee in both the frontal and sagittal planes (Coplan et al 1989; Beckett et al 1992; Loudon et al 1996). Due to the anatomical influence of the knee on jumping mechanisms and the high prevalence of knee injuries during jumping tasks, close attention to knee and foot kinematics, during a horizontal jumping task with a novel preparatory arm swing jump is warranted.

In summary, the arm swing has been used in vertical and horizontal jumping tasks to advance biomechanical outcomes. Despite the plethora of literature that exists regarding the role of the arm swing, the influence of a repetitive preparatory arm swing on lower extremity mechanics during the execution of the horizontal jump has yet to be considered. While the implications of a novel arm swing on lower extremity kinematics is a broad topic, this project will focus only on knee and foot angulation during periods within the propulsive phase of the horizontal jump. Thus, the purpose of this study will be to investigate the influence of a novel repetitive preparatory arm swing on knee valgus and foot angulation during a countermovement horizontal jumping task.

Research Questions and Hypotheses:

1. RQ1: Does a repetitive preparatory arm swing influence knee valgus during the countermovement horizontal jump?

   H1: The novel preparatory arm swing will significantly increase frontal plane knee valgus angle during the propulsive phase of the countermovement horizontal jump.

   H2: The novel preparatory arm swing will not elicit a significant difference between left and right knee valgus during the countermovement horizontal jump.

2. RQ2: Does a repetitive preparatory arm swing influence foot inversion/eversion during the countermovement horizontal jump?

   H1: The novel preparatory arm swing will significantly increase frontal plane foot angle during the propulsive phase of the countermovement horizontal jump.

   H2: The novel preparatory arm swing will not elicit a significant difference between left and right foot eversion during the countermovement horizontal jump.

LIMITATIONS

This study is not free from limitations. First, the sample size the researchers had to work with was extremely limited due to students not being on campus because of COVID-19 protocols. This impacted the number of participants willing to participate in the current research study.

Another limitation of the study is that the movement in which the participants were asked to perform was a novel and not well understood movement. There is a possibility that the movement was too difficult or complex for some participants to understand. The complexity of the movement was evident by the variation in interpretation of the task and execution between participants. Future research should acknowledge this and implement increased learning protocols to ensure that participants are accustomed to and used to the requirement of the task prior to the data collection. Additionally, the population used in this study was a normal student population in which not all were collegiate level or advanced level athletes, who could familiarize themselves with an enhanced arm swinging motion such as the one they were instructed to use in this study. Identifying a population in which all participants were college level or professional athletes might provide a stronger acclimation for performing the intended activity.

DELIMITATIONS

Additionally, this study is not free from delimitations. As expected, when performing an analysis on lower extremity activity of the musculature and joint movements, electromyography may be expected to provide a muscular explanation for the changes occurring during the task.

For the sake of this project, electromyography was not included. This was due to a plethora of reasons, with the largest and most prominent being that this study was conducted during the COVID-19 pandemic under strict protocols. The researchers decided that for the safety of all involved, it would be safest to refrain from including electromyography as a component of the current study, with intended plan to include it in future research.

CHAPTER II

REVIEW OF LITERATURE

OVERVIEW

To date, the literature has provided a large collection of data regarding lower extremity injuries and the mechanical behavior of the lower extremity during tasks such as horizontal jumping and lateral movements throughout sport activity. Similarly, there is an abundance of literature that addresses the increased mechanical deficits that exist in female athletes during horizontal and lateral movements such as inward angulation of the knees, also discussed as valgus, as well as inward angulation of the foot-ankle complex which for the sake of this study will be discussed as inversion of the foot.

It is well known the impact of preparatory movement on overall execution of the motion as well as preparation of the body to perform the intended movement. What is not currently understood is how emphasized or excessive preparatory movements may influence the lower extremity movement outcomes that are often perturbed without the presence of some sort of preparatory movement at all. It is important to identify how these movements may influence overall performance outcomes as well as potential injury risk due to the spontaneity of how athletes recruit parts of their bodies during their sporting activities to facilitate the movements and performance that they need to complete. This literature review will provide background on lower extremity movement kinematics during horizontal jumping tasks and how upper extremity preparatory movements might influence those outcomes. The organization of this review will begin with the frequency in which jumping tasks are used to assess kinematic data, and how jump outcomes have been used to evaluate performance outcomes, injury risk in female populations. The second section of this literature review will discuss the influence of preparatory movements, specifically arm swing, on horizontal jumping tasks and how modifications to the preparatory component of the movement might alter kinematic outcomes. Lastly, this review will discuss the rationale behind why the intended movement was used for the purpose of this study and how the anticipated outcomes may contribute to current biomechanical reports which discuss how preparatory movements may influence lower extremity behavior.

PART I: Lower extremity kinematics during ballistic movements

The relationship between sport activity and ligamentous lower extremity injury has long been established. More specifically, there is a highlighted association between sports involving jumping and lateral movements and ligamentous knee injuries such as anterior cruciate ligament tears and patellar tendon ruptures. The literature extensively studies the mechanisms by which these injuries most commonly occur, and how they can even be predicted with certain movement patterns.

There are trends in the literature that explore how knee mechanics during landing from a jumping task help show predictive components of knee injuries such as valgus knee and pronation of the foot-ankle complex. There is less literature that discusses how these trends may appear in the propulsive phase of the movement. DeLang et al 2021, recently published a report which discusses inter- and intra-limb knee valgus differences during the propulsive phase of a novel lateral vertical jump. The lack of direct literature has led this researcher to consider current literature which discusses knee valgus during the landing phase of a jump, and applying these findings to the present project, while appreciating the different muscle actions that occur during landing and propulsion phases of a jump.

According to previous literature, angulation of the knee in both the frontal and sagittal planes can be predictive of knee injury or indicators of weakness of the hip or knee musculature (Powers, 2010; Loudon, 2016). Knee valgus is the inward angulation of the knee or outward angulation of the bone segments distal to the knee, causing a collapsing or caving in the leg at the knee (Hewett et al., 2005). Knee valgus, or inward angulation of the knee has long been associated with knee injuries such as patellofemoral pain syndrome, iliotibial band syndrome and anterior cruciate ligament tears (Hewett et al., 2005; Dufek et al., 1991). This disadvantageous knee position, relative to the hip and ankle is often caused by hip extensor and abductor weakness that results in hip adduction and internal rotation. This combination moves the knee medially relative to the foot (Hoglund et al., 2014). Inward movement of the knee induces both tibial abduction and foot pronation and can often lead to further injuries along the kinetic chain.

Hip and knee contribution to knee valgus

The hip joint allows movements of the femur relative to the pelvis, as well as movements of the pelvis relative to the femur, thus, the hip serves as an important multifunctioning joint during most multi-segment movement (Neumann, 2009). There is a well-established relationship between hip strength and knee behavior during dynamic movement. Specifically, the relationship between decreased hip extensor strength and knee valgus has been well documented (Hoglund et al., 2014). During dynamic movements such as running or jumping, hip adduction and internal rotation is needed to prevent femoral instability and keep the knee joint positioned over the foot as the movement occurs (Loudon et al., 2016). Weakness or underactivity in the hip musculature has been shown to contribute to this instability, making it an obvious contributor to knee valgus. Specifically, weakness in the hip extensors, which include the gluteus maximus, adductor magnus and hamstrings, contribute to decreased overall hip strength and increased dynamic knee valgus. When the hamstrings are weakened, the hips are unable to recruit those muscles to extend the hip, thus requiring the body to recruit support from surrounding musculature. Therefore, weakness in the hip extensors is a primary contributor to dynamic knee valgus. Additionally, the gluteus maximus is the primary external rotator muscle of the hip. Increasing stability of the proximal attachment site of the gluteus maximus might contribute to overall hip stability. This stability would then allow the extensors and external rotators to extend the hip out of a flexed position without presenting knee valgus.

Foot and ankle contribution to knee valgus

Knee valgus can be a product of foot pronation and lack of ankle dorsiflexion (Wyndow et al., 2016). Increases in foot pronation during locomotion or standing are commonly found within lower medial longitudinal arches. Medial longitudinal arch height has been used to determine foot type and mildly explain ankle instability (Fraser et al., 2016). Further, it has been understood as a risk factor for obtaining injuries at the knee, specifically ACL tears (Loudon et al., 1996). Pes planus, or flat foot denoted by a lack of medial longitudinal arch height causes pronation or inward rolling of the foot during locomotion or steady standing (Hertel et al., 2002; Hertel et al., 2005). Excessive foot pronation can cause internal rotation of the tibia, thus internally rotating the hip and causing knee valgus (Nigg et al 1993). The behavior of the knee is often explained by muscular and anatomical contribution of the trunk, hip and ankle, thus, notable changes in muscle activation and recruitment strategy of the trunk, hip and ankle may influence the angulation of the knee during dynamic movements.

Foot inversion as an indicator of lower extremity weakness

Inversion/eversion of the foot differs from pronation/supination in that inversion/eversion of the foot is classified as frontal plane movement of the ankle at the hindfoot in which it rotates either inward toward the medial aspect of the body or outwards towards the lateral aspect of the body. Everted frontal plane movement of the foot is known as a component of foot pronation as it is combined with abduction of the foot and talocrural dorsiflexion. While both values are telling, the purpose of this project sought to assess how frontal plane kinematics of the foot would be influenced by the movements being performed. Previous literature highlights how external rotation of the foot (eversion) contributes to altered knee joint loading, specifically on the tibiofemoral joint, increasing risk of ligamentous injury and chronic injuries like knee osteoarthritis (Levinger et al 2013, Mei et al 2019).

PART II: Contribution of the arm swing to dynamic jumping tasks

Vertical Jump Outcomes

Vertical jumping is one of the most commonly used movements in sporting activity and therefore has received tremendous attention in the literature. (Payne et al., 1968; Luhtanen and Komi, 1978; Harman et al., 1990; Feltner et al., 1999). When a vertical jump is performed with an arm swing, researchers have primarily reported that arm swing augments the vertical jump by enhancing vertical GRF at takeoff (Payne et al., 1968; Harman et al., 1990). Payne et al (1968) suggested that during an arm swing, the upward acceleration of the arms before the end of the takeoff phase increased the magnitude of the ground reaction force at takeoff.

Arm swing has also been shown to increase vertical jump height performance by increased height of the participants center of mass and vertical velocity at takeoff (Feltner et al., 1999). According to Payne et al, the downward force exerted through the body from the upward acceleration of the arms causes an increase in vertical ground reaction impulse, thus increasing the vertical velocity of the center of mass. These findings were supported by Harman et al (1990), who reported that an arm swing both with and without a countermovement would contribute 10% to the takeoff velocity of a vertical jump. Similarly, Luhtanen and Komi reported a segmental contribution of 10% to takeoff velocity during a vertical jump. Lees et al (2004) found that vertical jump performance was enhanced by increased height and velocity of the center of mass at takeoff, due to a buildup of stored energy at the shoulders. They proposed that stored energy from the shoulder flexion movement during the arm swing would be used later in the jump during the propulsive phase by the hip, knee and ankle joints. These findings identify the positive role of the arm swing on lower extremity performance during jumping tasks.

Arm Swing and Countermovement

Arm swing, when used with a countermovement vertical jump, can increase the utilization of the stretch shortening cycle on lower extremity musculature. Harman et al (1990) found that arm swing slows down the contraction rate of the quadriceps and gluteal muscle group, preparing them to exert a greater force. They believed that as the arms are brought in closer to the body, it creates an upward pull on the rest of the body, causing the lower extremity muscles to develop more force and move the body faster. Feltner et al (1999) also reported an increased magnitude of knee extensor torque during the arm swing jump when compared to the no arm swing jump, at the start of the takeoff phase. According to Hill's Muscle Model (1938), muscle tension is augmented with slower concentric contraction rate. Therefore, increased tension of the hip extensors during the eccentric portion of the movement would increase their force generating capabilities during the concentric or propulsive phase of the jump.

Horizontal Jump Outcomes

Although a majority of the literature reports findings on vertical and squat jump outcomes, a few researchers have observed the influence of arm swing on horizontal jump performance (Davies et al., 1988; Wu et al., 2003; Stefanyshyn, & Nigg, 1998, Ashby et al 2002, Lees et al 2004). It is previously been shown that the horizontal jump compares to vertical jump in both performance preparation, muscle recruitment and plane of movement (Stefanyshyn, & Nigg, 1998; Maulder et al., 2005). Previously observed differences between the horizontal jump and the vertical jump include displacement of the body, propulsion strategy and maintenance of energy throughout the movement (Meylan et al., 2009).

Ashby et al (2002) studied the role of arm swing on horizontal jump performance. The authors found that, similar to vertical jump outcomes, take off velocity and jump distance were influenced by an arm swing during the horizontal jump. Further, differences in lower body joint angles were observed, with enhanced ability of the hip and trunk extensor muscles to produce force during the propulsive phase of the horizontal jump. Literature suggests that enhancing the effect of the arm swing by adding additional arm swings to the preparatory phase, might release a chain reaction down the posterior kinetic chain, due to its linkage in musculature and muscular recruitment strategy (Kaur et al 2014; Kaur et al 2020). Despite the findings that support the positive influence of an arm swing and countermovement on vertical jump performance, the known benefits of a preparatory arm swing on horizontal jump kinetic and kinematic outcomes are unknown. Therefore, observing how an enhanced preparatory arm swing further augments the outcomes of the movement should be examined.

Summary

The purpose of this literature review was to establish what is currently known about arm swing and preparatory movement contribution to horizontal jump biomechanical outcomes that have been shown to predict lower extremity injury. The research questions of this thesis will be as follows; 1) does preparatory arm swing influence knee valgus during the propulsive phase of the horizontal jump, and 2) Does preparatory arm swing influence foot eversion during the propulsive phase of the horizontal jump? By submerging into the depth of vertical jump literature, it has been established that preparatory arm swing contributes to overall increased jump performance by increasing jump height, takeoff velocity, acceleration, and height of center of mass (Payne et al., 1968; Luhtanen and Komi, 1978; Harman et al., 1990; Feltner et al., 1999). Further, we now know that arm swing also contributes to increased force being exerted into the ground during the propulsive phase (Cavagna et al., 1968; Feltner et al., 1999; Luhtanen and Komi, 1978; Harman et al., 1990; Akl, A.R., 2013). While these findings are reported for vertical jumping tasks, the literature also suggests that vertical jumping and horizontal jumping are similar in the way the human body prepares for the movement (Davies et al., 1988; Wu et al., 2003; Stefanyshyn, & Nigg, 1998, Ashby et al 2002, Lees et al 2004). This, along with what is known about countermovement and the ability of skeletal muscle to better prepare for initiation of a movement following the activation of the muscle, contribute to the idea that an enhanced preparatory movement such as a novel preparatory arm swing, might intensify the propulsive components of the jump, thus, potentially influencing lower extremity kinematic outcomes. Further, it has been established how identifiers such as knee valgus and eversion/inversion of the foot-ankle complex can be indicative of lower extremity musculature weakness or potential injury risk. Thus, assessing how a preparatory arm swing influences lower extremity kinematics like knee valgus and foot eversion during a ballistic jumping task is warranted.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this research study was to investigate an upper body preparatory motion on lower extremity kinematics during a jumping task. Specifically, the methodologies outlined within this chapter were utilized to address the following research questions; (1) Does preparatory arm swing influence knee valgus during the propulsive phase of the horizontal jump? and 2) Does preparatory arm swing influence foot eversion during the propulsive phase of the horizontal jump? The chapter is presented in three sections, which will discuss the research design, protocol framework and statistical procedures.

Research Study Design

The data collection will occur in the Auburn University Sport Biomechanics Laboratory. Participants will be asked to come into the lab over a total of two visits, each lasting 90 minutes with at least 24 hours between visits. This research study will have a within-subject experimental design. Visit one, the familiarization day, will consist of signing the informed consent documents, completing a health screening questionnaire to identify if the participant meets the inclusion criteria to participate in the study, and reviewing the protocol. In addition, height, weight, anthropometric and foot arch height measurements will be taken. Familiarization will require each participant to practice each jumping condition three times.

Data collection will occur during visit two, during which the participant will perform a total of six horizontal jump. Jumps performed incorrectly or that cause retroreflective markers to fall off of the participant prior to takeoff will be omitted and participants will be asked to repeat that trial. Three jumps will be performed as a traditional countermovement horizontal jump with a traditional arm swing component included. Participants will not be asked to restrict their arms in any manner, rather, they will be instructed to naturally use their arms to perform the task. The additional three jumps will be performed with a preparatory arm movement consisting of swinging their arms several times before performing the horizontal jump. Jump conditions will be randomized to eliminate a learning effect on the results. The Auburn University Institutional Review Board approved all testing procedures prior to beginning this study.

Population, Sample Size and Sampling Technique

Nineteen women (n=19) between the ages of 19-35 (mean age = 20.04 years) were recruited to participate in this study. A health screening questionnaire was given to each participant to assess whether they met the inclusion criteria for the study. Inclusion criteria for all participants included an average healthy active lifestyle, currently exercising a minimum of 30 minutes at least 3 times a week, free of any injury that would have prevented them from exercising for longer than 1 week and having had no history of surgery on the lower extremities within the last 6 months. A convenience sampling technique was used to recruit research participants for this research study.

Instrumentation

All instruments used during the data collection of this research study were operated within the Sport Biomechanics Laboratory at Auburn University. Kinematic data was collected and recorded using a 10-camera motion capture system at a sampling frequency of 200 Hz (Vicon®, Los Angeles, CA, USA) (Figure 1). The kinematic variables of interest for this study included knee angulation, height of center of mass, and foot angle.

Two AMTI force plates (Advanced Mechanical Technology Inc., Watertown, MA) operating at a sampling frequency of 1000 Hz were used to collect horizontal ground reaction forces from the participant during the jump trials. To uphold as much consistency as possible with recording style and data collection procedures, the same researcher operated the Vicon Nexus software during all data collections.

Figure 1. Laboratory setup for experimental procedure

Twenty-nine retroreflective markers (20mm) were affixed bilaterally to the following anatomical locations: anterior superior iliac spine, posterior superior iliac spine, sacrum, 7th cervical vertebrae, 10th thoracic vertebrae, xiphoid process, sternum, acromion process, anterior deltoid, lateral deltoid, posterior deltoid, triceps, medial elbow, lateral elbow, medial forearm, lateral forearm, medial wrist, lateral wrist, anterior thigh, lateral thigh, greater trochanter, medial femoral epicondyle, lateral femoral epicondyle, anterior, posterior and lateral shank, medial malleolus, lateral malleolus, and posterior calcaneus.

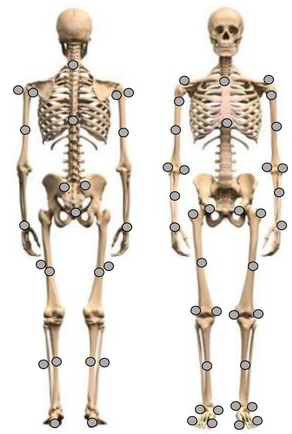

Figure 2. Modified VICON Plug-in Gait Model with full-body marker placements

Bilateral landmarks were determined according to a modified Vicon Plug-In Gait Model (Figure 2). A standard electronic weight scale and wall ruler were used to take participants weight and height, respectively. Due to spacing restriction within the laboratory, a safety harness was attached around the torso of each participant to restrict their flight distance but will not influence takeoff in any manner.

Research Framework

Procedures

Day 1: Familiarization Session

On the familiarization day, participants were asked to read and complete an Institutional Review Board approved informed consent and health screening questionnaire. The completion of informed consent and health screening questionnaire assured the participant's voluntary involvement and removed any participants that did not meet the inclusion criteria.

Participants were instructed to complete a warmup consisting of both static and dynamic stretches that they would normally do prior to an exercise. If participants were unsure, researchers would recommend body weight squats, static stretching, lunges and jogging. The duration of the warm-up period was recorded for investigator records. Researchers then provided each participant with the same verbal instructions to complete the movement tasks, as alterations may influence differences in movement patterns (Brinkerhoff et al 2019). The instructions for completing the traditional and preparatory arm swing jump condition were stated specifically, "to emphasize multiple preparatory arm swings prior to initiating a normal swing and horizontal jump". Following the given instruction of the researcher, participants familiarized themselves with completing the jumping tasks correctly by practicing the two jumping conditions (typical arm swing and novel arm swing) 3 times. There was a 90 second rest period between each jump to reduce the influence of fatigue. After completion of the jump trials, the participant was dismissed. Total familiarization time and IRB document review took no longer than 90 minutes.

Day 2: Data Collection Session

Before the data collection session, participants were asked to refrain from any strenuous exercise or physical activity for a minimum of 24 hours. Participants were asked to come to the lab wearing athletic attire consisting of a recommended dark colored compression shorts and top, that allowed for proper execution of the dynamic tasks as well as providing access for marker placement. Participants were also be asked to, if possible, refrain from wearing any reflective gear such as bright shoes or designs on clothing and to wear the tennis shoes that are used during weekly physical activity. Upon arrival to the lab, participants were asked to change into their athletic attire. They were informed of the randomized order of jumping conditions selected for their session. Previously sanitized retroreflective markers were placed on the bilateral landmarks of the participant previously discussed (Figure 3).

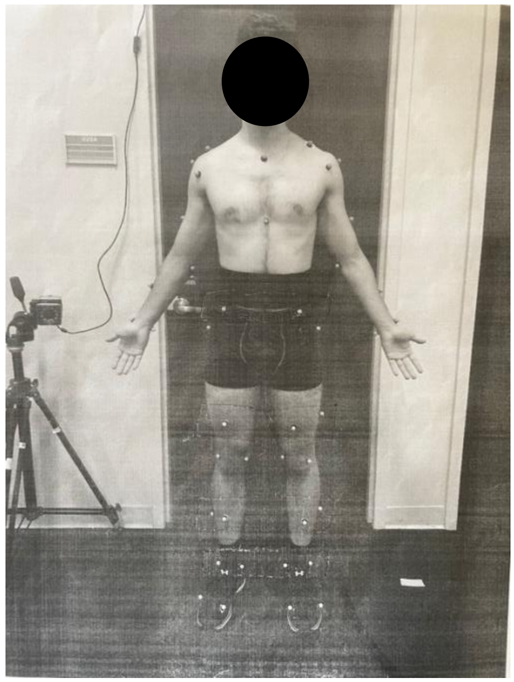

Figure 3. Participant data collection model with marker placements and harness attachment

Participants were allotted an unlimited time to warm up after all sensors were affixed in the proper locations. Participants then performed 6 maximal effort horizontal jumps under 2 conditions, typical and with a novel preparatory arm swing. During the novel preparatory arm swing condition, participants emphasized a bilateral preparatory arm swinging motion, prior to initiation of the horizontal jump. Specifically, the novel preparatory arm swing had the participant complete several arm swinging motions prior to the arm swing associated with the movement. For both jumping conditions, participants were asked to place their feet shoulder width or a comfortable distance apart, with each foot resting on each force platform. There was a 90 second rest period between each jump to reduce the influence of fatigue. The participant was asked to remain within the designated jumping area in the lab, marked off by white athletic tape on the ground. During the jumping trial, if markers fell off of the participants body at any point prior to takeoff, the trial was omitted, markers were replaced on the locations where they fell off, a new static trail was collected, and the jump trial was repeated. Additional rest period was allocated for repeated jumps if necessary. After completion of the jump trials, retroreflective markers were removed from the participant, they were thanked for their participation and dismissed from the lab. The total time to complete the data collection session less than 90 minutes.

Measurements

The measures that will be taken during this research study relate directly to the understanding of the behavior of the knee and foot when influenced by a preparatory upper extremity movement during a dynamic jumping task. This section will identify the variables being observed and the justification for the method in which the variables were calculated.

For the preparatory arm swing condition, a jump was considered successful if the participant completes three or more preparatory arm swings prior to initiating their countermovement. The propulsive phase was as determined by the time point in which the pelvis was at its lowest point. The left and right anterior superior iliac spine (ASIS) and left and right posterior superior iliac spine (PSIS) were used in Vicon (Vicon Nexus®, Los Angeles, CA, USA) to construct a volume and the calculated center of the volume was used as the estimated center of the pelvis. Each trial was evaluated to determine whether it met the criterion to be determined a successful or full trial to ensure missing events were not present.

Knee valgus was measured in the frontal plane at the point determined by the lowest point of center of mass. Reference points used for analysis were the anterior superior iliac spine

(ASIS), a vertical line bisecting the medial and lateral femoral condyles and a vertical line bisecting the medial and lateral malleoli at the talocrural joint (Ramirez et al 2018). Foot angle in the frontal plane (inversion/eversion) was measured at the point in which the horizontal ground reaction force is highest. Knee angle, foot angle and preparatory arm swing jump condition relationship was evaluated through a repeated measures ANOVA.

Statistical Analysis

Kinematic data was first labeled and processed using Vicon Nexus 2.10 (Vicon Nexus, Los Angeles, CA). Data for all participants was further processed and filtered using Visual 3D V6 Professional (C-Motion, Germantown, MD). Kinematic data observed in this study were analyzed using MatLab (The Mathworks Inc.^{TM}). Filtered data were extracted into Matlab (The Mathworks Inc.^{TM}) and imported for all participants across three trials. Mean and median were calculated and concatenated into a large spreadsheet that includes the variables of interest. A repeated measures ANOVA was run on condition type (horizontal jump with preparatory arm swing, HJA; and horizontal jump without preparatory arm swing, HJNA) and side of the body (left and right side). Significance will be set apriori at 0.05 level for all analyses.

CHAPTER IV

RESULTS

Fig. 4 shows the mean knee angles in the frontal plane, for the left and right legs (top) as determined by the time point in which the estimated center of mass is at its lowest point. The bottom graphs present the left and right foot angle at peak horizontal ground reaction force (bottom) for all subjects for both conditions.

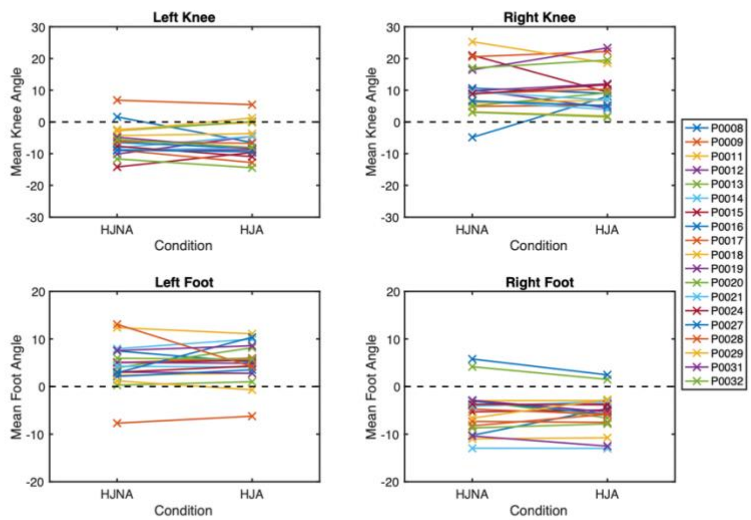

Figure 4. Mean angles for knee (top) and foot (bottom) by left side of the b (left column) and right (right column) by condition HJNA and HJA for all subject, color coded.

The dashed line across the graph at 0 represents fully neutral (angle at 0 degrees). Although there are some participants that show a reduction in knee valgus between the two conditions, there does not seem to be an overall group pattern for the different conditions for either the foot or the knee. All participants had a range of knee angle values between positive and negative 30, with the vast majority of the participants ranging between positive and negative 20. As shown in the bottom left (Fig. 4) and bottom right (Fig. 4) images, all participants mean foot angle values exist between positive and negative 15 degrees for both the left and right foot.

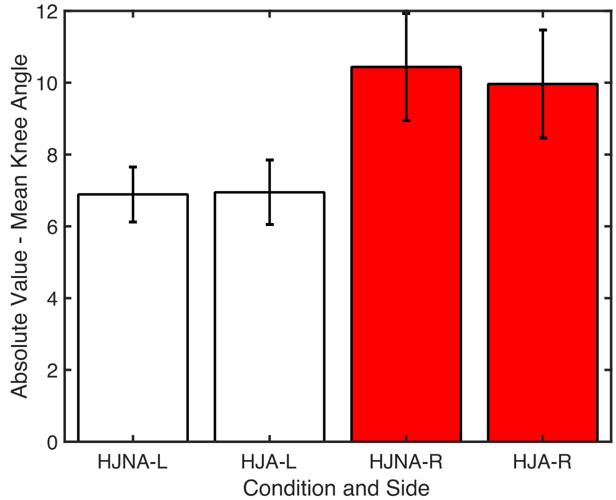

Figure 5. Abs value of mean angles for knee by condition (HJNA vs HJA) and side of the body (left, white; right, red)

Figure 5 presents the absolute value for mean knee angle by condition: horizontal jump without the preparatory arm swing (HJNA) and horizontal jump with preparatory arm swing (HJA); and side: Left leg (white bars) and right leg (red bars) for the knee. Error bars represent standard error (standard deviation/square root of number of participants). As shown in the image, there is a clear side difference but no difference between condition.

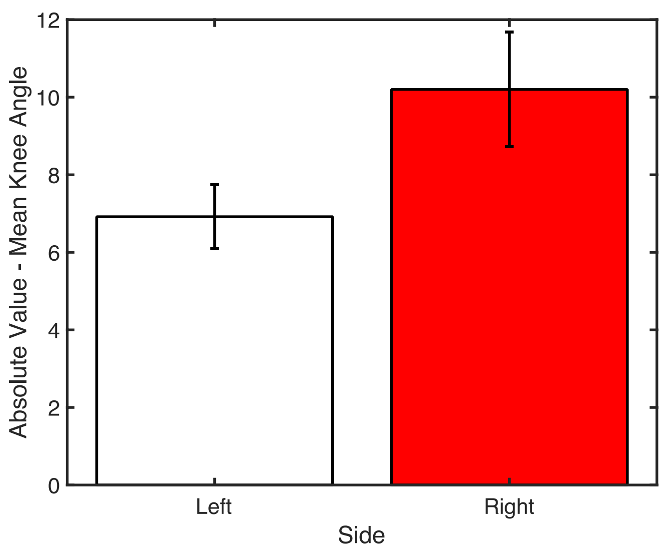

Figure 6. Absolute value of mean angles for knee by side of the body (left, white; right, red)

Figure 6 presents the absolute value of mean knee angles for the left (white bar) and right (red bar) sides with arrow bars representing standard error. Repeated measures analysis of variance (ANOVA) was used to examine differences between conditions and side of the body for the absolute mean knee angle. The tests revealed there was a significant main effect of side (Left vs. Right) (F (1,18) = 4.57, p=0.047). However, there was no significant main effect of condition (HJNA vs. HJA) (F (1,18) = 0.07, p=0.78), or a no significant Side x Condition interaction (F (1,18) =0.75, p=0.40).

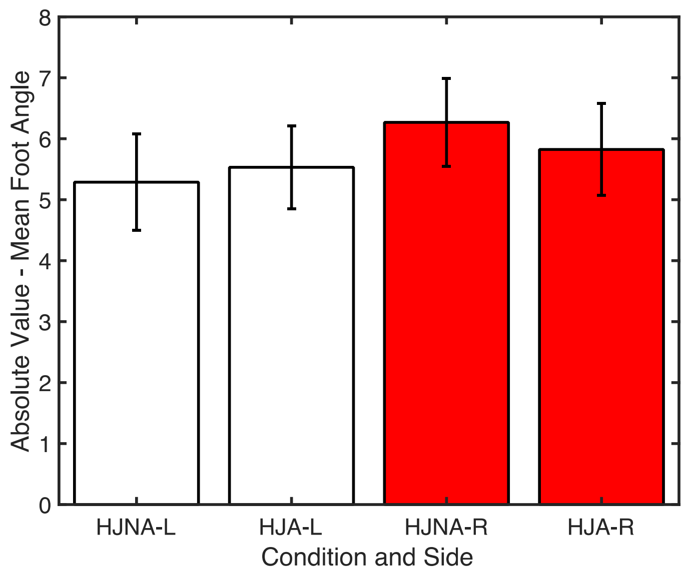

Figure 7. Abs value of mean angles for foot by condition (HJNA vs HJA) and side of the body (left, white; right, red)

Figure 7 depicts the absolute mean foot angle by condition HJNA versus HJA and side left (white bars) and right (red bars) for the foot. Arrow bars represent standard error (standard deviation/sqrt of # of participants). Figure 8 presents the absolute value of mean frontal plane foot angles for the left (white bar) and right (red bar) sides with arrow bars representing standard error. Repeated measures analysis of variance (ANOVA) was used to examine differences between conditions and side of the body for the absolute mean foot angle.

There was no significant main effect of condition (*F* (1,18) =0.04, *p*=0.84), side (*F* (1,18) =2.25, *p*=0.15), or condition by side interaction (*F* (1,18) =0.79, *p*=0.39).

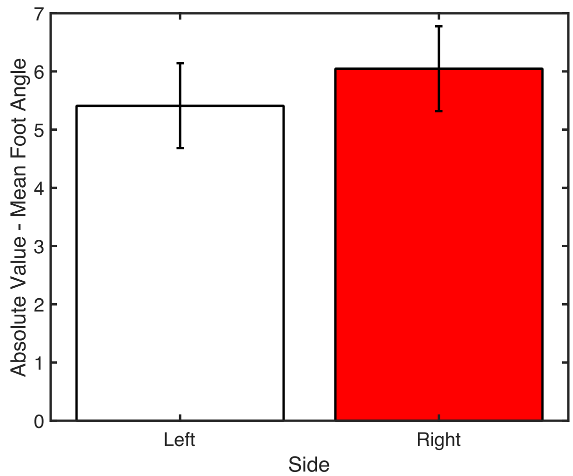

Figure 8. Abs value of mean angles for foot side of the body (left, white; right, red)

CHAPTER V

DISCUSSION

This study examined how a preparatory arm swing or normal arm swing during a horizontal jumping task could influence knee and foot angulation during the propulsive phase of the jump. The first research question of the present study sought to identify if the preparatory arm swing influenced knee valgus during the propulsive phase of the countermovement horizontal jump. The first hypothesis was rejected, as there was not a significantly greater increase in knee valgus for one condition compared to the other. The second hypothesis of this research question suggested that there would not be a difference in valgus for side of the body, and that hypothesis was also rejected, as there was a clear side difference in valgus without respect to the condition in which the jump was performed. The second research question of the present study sought to identify if the preparatory arm swing influenced foot eversion during the propulsive phase of the countermovement horizontal jump. The first hypothesis was rejected, as there was not a significantly greater increase in foot eversion for one condition compared to the other. The second hypothesis of this research question suggested that there would not be a difference in foot eversion for side of the body, and that hypothesis was accepted, as there was no difference in foot eversion without respect to the condition in which the jump was performed.

The purpose of this chapter was to consider the implications of the results of the present study in relation to current literature that exists on lower extremity kinematics during a horizontal jumping task, and potential future implications. The structure of this chapter will present findings in light of the two research questions in addition to implications for overall findings, summarize the outcomes and provide a generalized basis for future research.

The first research question of the present study sought to identify if there was an influence of a novel preparatory arm swing on knee valgus during the countermovement horizontal jump. The results of this study showed that there was a significant effect of side of the body when collapsed across both jumping conditions. However, the results of this study did not show any significant effect of jump condition or a condition by side interaction.

It is important to note that the results show that there was no difference between arm swing conditions, thus we do not believe that the emphasized arm swing puts the body at greater risk. Participants demonstrated significantly greater knee valgus angles on the right side of the body versus the left side. Limb dominance was not addressed in the data collection aspect of this study, thus for analysis purposes, interpretations are speculative. Based on a speculative reasoning, it is entirely possible that a majority of participants were right limb dominant. The left side stayed relatively the same between jump types (Figure 5). The right side had greater overall knee valgus across both jumps. Clear differences in the presence of knee valgus on one side of the body (in this case, the right side) could put a person at greater risk for knee injury during ballistic movements. Since the diff between right and left knee valgus angles is so small, we don't believe it puts the right knee specifically at greater risk, however, does potentially increase risk of injury one side of the body compared to the other. Additionally, the lack of significant findings at the foot encourages us to expand our research to assess the contribution of the hip to the increase in knee valgus. Further insight on how inter-limb valgus differences influence performance outcomes and injury risk are required to identify if these observed limb differences are attributed to limb dominance, or if the requirement of the task puts greater demand on one side of the body, requiring increased work and load to come from that one side. Furthermore, the results of this project demonstrated the importance of considering the limbs on each side of the separately. In projects where only a single limb is considered, important right to left differences may be missed.

The second research question of the present study sought to identify if there was an influence of a novel preparatory arm swing on foot angulation (inversion/eversion) during the countermovement horizontal jump. The results of this study showed that there was no significant difference in foot angulation between jump type, nor was there an effect of side of the body when collapsed across both jumping conditions, nor a side by condition interaction. In light of the significantly larger right knee valgus value compared to the left knee, the lack of a finding in foot posture was unanticipated. The lack of a significant finding between jump conditions or between sides suggests that the participants utilized the same frontal plane strategy for force production during propulsion.

It is difficult to compare these results to previous literature as the foot posture commonly considered is pronation/supination. Pronation/supination are compound movements, with motion occurring all three planes. The lack of specificity of these combined motions may occlude deleterious motion in a single plane and obscure motion that may contribute to lower extremity injuries. In the present study, frontal plane kinematics were isolated, allowing us to, more readily indicate which training protocols would be needed if differences were observed.

When the knee and ankle results are considered together, the lack of significant findings at the foot indicates that the larger knee valgus findings on the right leg are the result of hip motion. This finding suggests that the right hip musculature behaved differently than the left hip musculature. Hip kinematic data were not collected for this study, thus future research should consider hip and pelvis angulation changes during this novel movement. Findings from this investigation may provide further support for the kinetic chain theory and identify how distal and proximal joints to the knee joint contribute to knee valgus during ballistic movements.

Summary

The findings of the present project suggest that the novel arm swing investigated did not significantly influence frontal plane motion of the knee nor the foot. It was hypothesized that as preparatory arm swing motion increases ground reaction forces, adding cycles of arm swing to the preparatory movement would enhance the ground reaction forces further. It was anticipated that the enhanced ground reaction forces would increase the demand on the lower extremity and cause compensatory kinematic changes. Taken in totality, the significant finding of right knee valgus, but not right foot eversion implies that the right knee valgus is due a lack of stability at the hip. Future research should consider motion in all three planes separately to identify which plane is the greater contributor to the knee valgus during horizontal jumping.

Future Research

Future research should consider assessing both limbs, at hip, knee and ankle joints to fully depict where kinematic differences are occurring. This may provide insight on dominance contribution to inter-limb performance as well as inter-limb contribution to increased injury risk. Further, as this movement included a novel preparatory arm swing motion, future research should consider adapting a population to this movement for a longer period of time, to acclimate participants to the unfamiliarity of the task.

Appendix A. Informed Consent

SCHOOL OF
KINESIOLOGY

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

****DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP HAS BEEN APPLIED TO THIS DOCUMENT****

INFORMED CONSENT

For a Research Study entitled:
"The Influence of a Preparatory Arm Swing on Horizontal and Vertical Jumping Tasks"

COVID-19 Risk. With any in-person interaction, there is a risk of coming in contact with the coronavirus. Every researcher in the lab is frequently tested for COVID-19 and is conducting daily self-screening. There will be no more researchers in the lab than what is required to successfully complete the data collection sessions. Further, there are numerous precautions being taken by the members of the laboratory to reduce in-person contact and risk of exposure. All participants will be required to show their GuideSafe passports prior to entry into the building and will be required to complete a COVID-19 screening upon entry into the Sport Biomechanics Laboratory. COVID-19 screening form for all participants will be kept in the laboratory and used as a tracking system if researchers ever needed to get in contact with previous participants about exposure risks. All participants will be escorted into and out of the lab to reduce the number of interactions they may encounter in the Kinesiology building. Upon entry into the building and into the lab, participants and researchers will be required to wear face masks and sanitize hands before and after touching any surfaces. You will wash your hands thoroughly with soap and water before entering the lab space. You will also be asked to wear a mask for the entirety of the familiarization period and the data collection.

There will be tape marking 6 ft social distancing spaced within the lab where you and researcher can remain at a safe distance away from each other for all aspects of the data collection process other than the few minutes it takes to place retroreflective markers on the participant and take the markers off. One investigator will be within six feet of you in order to place/remove retroreflective markers on your body and put the harness around your abdomen. The markers and harness have been wiped down with alcohol wipes. You will also be asked to bring a towel to wipe up any sweat you accumulate during the data collection. The force plates you will be standing on have been cleaned as well. When not necessary to be closer, investigators will remain more than six feet away from you. Sanitizing protocols will be in place to ensure that all tools and surfaces being used during this data collection are cleaned and sanitized prior to and following each time you or a researcher comes in contact with them. Following the completion of the data collection, all surfaces in the lab will be sanitized.

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Participant's Initials

Page 1 of 4

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Protocol # 19-446 EP 1912

General Information
You are invited to participate in a research study conducted in the Sport Biomechanics Laboratory under the direction of Drs. Wendi Weimar and Christopher Wilburn. Participation is voluntary, meaning you do not have to take part. Procedures, risks, and benefits are fully described in the body under the consent form.

Purpose: The purpose of this study is to examine the role of the preparatory arm swing on the kinetics and kinematics of vertical and horizontal jumping. The aim of the study is to compare vertical and horizontal jump performance with a rapid preparatory arm swing and vertical and horizontal jump performance without the preparatory arm swing.
Duration: Two lab visit lasting 1 hour and 30 minutes.

Involvement in this Study Includes:

Surveys on demographics, injury history,

general well-being and activity level.

Familiarization with obtaining arch height in

loaded and unloaded positions.

Familiarization with jumping vertically and horizontally.

Risks: Minor risks involve injury due to jumping and landing. Researchers will supervise participants at all points of the study. Minor risks involved with COVID-19. Researchers have devised sanitizing and social distancing protocol in accordance with current safety guidelines of health officials.

Benefits: No direct benefits.

Alternatives: Not to participate in this study.

You were selected as a participant because you are (1) between the ages of 19-35, (2) currently are in good health, (3) without injury within the last six months, (4) and do not have a neuromuscular conditions that would prohibit you from performing maximal volition jumps.
You have been invited to participate in a research study that will investigate the influence of preparatory arm swing on the performance outcomes of horizontal and vertical jumping tasks. Your participation in this study could assist with developing a better understanding and provide a method of understanding the relationship between arm swing, jump performance and mechanics. You have been selected as a potential participant because you are in good health, without an injury to the lower extremity within the last six months, and do not have allergies to adhesives.

What will be involved if you participate? If you agree to participate in this research study, you will be invited to come to the Sports Biomechanics Laboratory for approximately an hour and 30 minutes on two separate days. The first daywill serve as a familiarization period. Prior to being familiarized with the dynamic tasks, you will be given a health screening questionnaire to affirm your ability to physically complete the tasks. Additionally, anthropometric measures of your height, weight, arch height and limb lengths will be obtained. Then you will be provided the opportunity to be familiarized and practice the preparatory motions associated with the data collection.

During the second data collection you will to complete four jumping tasks in a randomized order. The vertical jumping task will consist of two conditions, jumping without arm swing and jumping with a

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Participant's Initials

preparatory arms wing. During the preparatory arm swing, you will be instructed to swing your arms back and forth in a quick manner, at least three times.
The horizontal jumping task will consist of two conditions, jumping without arm swing and jumping with a preparatory arm swing. During the preparatory arm swing, you will be instructed to swing your arms back and forth in a quick manner, at least three times. Three trials of each condition will be performed. After completing all conditions successfully, you will be thanked for your participation.
Are there any risks or discomforts? While participating in this study it is possible that you might incur muscle soreness, a joint sprain or a muscle strain. However, injuries are unlikely due to care taken to warm-up and that you are performing a task that is part of your usual activities. In the event you sustain an injury during participation; there is no current plan to cover the medical cost associated with the injury related to this study.
If you change your mind about participating, you can withdraw at any time during the study. Any data that may have been collected that can be associated with you, will be destroyed immediately and withdrawn from the study. Your decision about whether or not to participate or to stop participating will not jeopardize your relations, both present and future, with the Sport Biomechanics Laboratory, School of Kinesiology, Auburn University Athletic Department, or Auburn University.
Confidentiality. Any information obtained in connection with this study that can be identified with you will remain confidential. The information obtained from this project will be used for presentations at scientific conferences and published in scientific journals.
If you have any questions, please ask them now or please feel free to contact Wendi Weimar (weimawh@auburn.edu).

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Participant's Initials

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu or phone at (334)- 844 -5966.
HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____________________	____________________	__________
Participant's Printed	Name Participant's Signature	Date
Investigator Conducting Consent Printed Name	Investigator's Signature	Date

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Appendix B. Recruitment Documentation

RECRUITMENT SCRIPT (verbal, in person)

Arm Swing Project, Sport Biomechanics Laboratory, Kinesiology Building, Room 020.

My name is ___________, and I am a_________________ from the Department of Kinesiology at Auburn University. I would like to invite you to participate in my research study to investigate the influence of preparatory movements on horizontal and vertical jumps. You may participate if you 19-30 y/o healthy, recreationally active adult (min. 5hr/week of recreational sport). If you have a history of an injury that kept you from recreational sport for more than 1 day in the last 6 months or if you have an allergy to adhesives you cannot be a participant. Further, you must be willing to come to the lab for 2 sessions in the same week (Session 1 will be 30 minutes and session 2 will be an hour.

During session 1, you will be asked to review, and if you consent to be a participant, sign the approved documentation and will be asked to complete a health screening questionnaire to ensure that you are able to successfully complete the tasks. Next several measurements will be taken (height, weight, arch height and limb lengths) and you will be introduced to the required movements and given the opportunity to practice the horizontal and vertical jumps with and without the preparatory arm swing.

During session 2, you will be asked to complete four jumping tasks in a randomized order. There are 2 jumping tasks (vertical and horizontal jumping tasks) and there are 2 conditions: (1) jumping with your usual jumping motion; and (2) jumping with an extra preparatory arms wing. During the preparatory arm swing, you will be instructed to swing your arms back and forth in a quick manner, at least three times before jumping. Three trials of each condition will be performed.

While we are asking that you jump to the best of your ability, since you are working within your capability we do not anticipate any exaggerated injury risk, but you are performing a ballistic movement and injuries can occur. If at any time you feel uncomfortable about continuing you can leave the study (with your data and information) without any retribution.

Please know that we have enacted cleaning protocols in an effort to protect you from virus' and bacteria.

If you would like to participate in this research study, please reach out to Imani Hill (inh0005@auburn.edu) to schedule a time for your participation.

Do you have any questions?

If you have any questions you can reach out to Imani Hill (inh0005@auburn.edu) or Dr Weimar (weimawh@auburn.edu).

E-MAIL INVITATION FOR EXPERIMENT

Arm Swing Project, Sport Biomechanics Laboratory, Kinesiology Building, Room 020.

My name is ___________, and I am a_________________ from the Department of Kinesiology at Auburn University. I would like to invite you to participate in my research study to investigate the influence of preparatory movements on horizontal and vertical jumps. You may participate if you 19-30 y/o healthy, recreationally active adult (min. 5hr/week of recreational sport). If you have a history of an injury that kept you from recreational sport for more than 1 day in the last 6 months or if you have an allergy to adhesives you cannot be a participant. Further, you must be willing to come to the lab for 2 sessions in the same week (Session 1 will be 30 minutes and session 2 will be an hour.

During session 1, you will be asked to review, and if you consent to be a participant, sign the approved documentation and will be asked to complete a health screening questionnaire to ensure that you are able to successfully complete the tasks. Next several measurements will be taken (height, weight, arch height and limb lengths) and you will be introduced to the required movements and given the opportunity to practice the horizontal and vertical jumps with and without the preparatory arm swing.

During session 2, you will be asked to complete four jumping tasks in a randomized order. There are 2 jumping tasks (vertical and horizontal jumping tasks) and there are 2 conditions: (1) jumping with your usual jumping motion; and (2) jumping with an extra preparatory arms wing. During the preparatory arm swing, you will be instructed to swing your arms back and forth in a quick manner, at least three times before jumping. Three trials of each condition will be performed.

While we are asking that you jump to the best of your ability, since you are working within your capability we do not anticipate any exaggerated injury risk, but you are performing a ballistic movement and injuries can occur. If at any time you feel uncomfortable about continuing you can leave the study (with your data and information) without any retribution.

Please know that we have enacted cleaning protocols in an effort to protect you from virus' and bacteria.

If you would like to participate in this research study, please reach out to Imani Hill (inh0005@auburn.edu) to schedule a time for your participation.

Do you have any questions?

If you have any questions you can reach out to Imani Hill (inh0005@auburn.edu) or Dr Weimar (weimawh@auburn.edu).

Thank you for your consideration

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Research Participants Needed

What: The Sport Biomechanics Laboratory is conducting a study observing the impact of a preparatory arm swing on the latissimus dorsi and surrounding muscles in addition to force production during a vertical and horizontal jump.

Eligibility:

- 19-30 y/o healthy, recreationally active adult (min. 5hr/week of recreational sport)
- No history of injury that kept you from recreational sport for more than 1 day in the last 6 months.
- Willing to come in for 2 different sessions
  - Session 1 ~ 30 minutes, session 2 ~ 1 hour (Has to be in the same week)
- No allergy to adhesive

How: Infrared motion capture system using retro-reflective markers placed on anatomical landmarks will record kinematic data. Participants will have a random selection of vertical and horizontal jump trials with and w/o preparatory arm swing. Each jump trial will begin on the AMTI force places and data will be collected prior to and during the jump phase.

Where: Sport Biomechanics Laboratory KINE 020

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For more information, please contact:
Dr. Wendi Weimar - weimawh@auburn.edu
Imani Hill –inh0005@auburn.edu
Jerad Kosek - jjk0026@auburn.edu

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