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Lower Limb Force Asymmetries during Landing and Jumping Exercises

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LOWER LIMB FORCE ASYMMETRIES DURING LANDING AND JUMPING EXERCISES

by

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Simon Cone, M.S.

Western Michigan University, 2020

Significant asymmetries can exist between the lower limbs' force production during the take-off phase of bilateral jumping exercises. Some studies have indicated that similar asymmetries can exist during the landing phase as well. It has not been demonstrated if the magnitude and/or direction of this imbalance is alike during the landing (L) and take-off (TO) phase of a jumping exercises. The main purpose of this study was to determine if there is a difference in the asymmetry that occurs during the L and TO phases. In order to quantify the degree and describe the direction (left. vs. right) of the occurring asymmetry, the vertical ground reaction force (vGRF) produced by each leg was measured during execution of vertical-jump (VJ), drop-jump (DJ), and drop-landing (DL) exercises. 11 recreationally trained individuals completed 3 VJ, DJ, and DL trials while two force plates recorded kinetic data. A repeated measures ANOVA was used to compare the asymmetry levels measured during all phases of the VJ, DJ, and DL. A significant difference was found between the levels of asymmetry displayed during the L and TO phases ($p<.05$). These findings suggest that there is greater asymmetry in the vGRF each leg experiences during landing than during take-off.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Lower-limb asymmetry occurs when there is a difference in the strength, power, or force an individual's legs express. Due to multiple factors that can contribute to this imbalance, some amount of asymmetry is to be expected in most people during any type of lower-body movement (Fort-Vanmeerhaeghe et al., 2016; Lake et al., 2011; Girard et al., 2017). The level of asymmetry present between a person's legs during a given movement has previously been analyzed using an index of asymmetry (AI) which calculates the imbalance as a percentage (Fort-Vanmeerhaeghe et al., 2016; Jordan et al., 2015; Carpes et al., 2010; Newton et al., 2006).

Wide variety has been reported in the amount of asymmetry that is displayed by individuals during bilateral lower-body movements (Fort-Vanmeerhaeghe et al., 2016, Lake et al., 2011). Multiple factors such as participation in certain sports, previous lower-body injuries, differences in leg length, and being female have been linked to elevated asymmetry (Markou et al., 2006; Jordan et al., 2015; Friberg & Kvist, 1988; Hewett et al., 2010). Overall, previous research has suggested that an imbalance higher than 10-15% may result in additional stress being placed on one leg, ultimately increasing an individual's injury risk and potentially inhibiting their performance (Hoffman et al., 2007; Paterno et al., 2007; Hewit et al., 2012).

Research has established that in all ACL injuries occurring during sports participation, 70% happen due to noncontact causes (Griffin et al., 2000; Norcross et al, 2013). These injuries were found to happen most often during periods of landing, rapid decelerating, and pivoting or cutting (Griffin et al., 2000; Norcross et al., 2013). During such maneuvers, eccentric muscle contractions control the lower body joints, allowing the kinetic energy of the body to be absorbed (Norcross et al., 2013).

Despite the importance of lower body energy absorption for injury prevention, research on lower-body asymmetries has primarily focused on the concentric phase of the exercise (Fort-Vanmeerhaeghe et al., 2016; Flanagan et al., 2007; Newton et al., 2006). One research study that examined lower body asymmetries during a DJ utilized two force plates to measure VGRF. Peak VGRF was measured at each foot-ground interface during the landing and the take-off phases. In a group of individuals who had undergone an ACL repair, a significant level of asymmetry was found between the operated and non-operated legs during both the landing ($p=0.001$) and take-off ($p=0.03$) phases. This study did not directly compare the levels of asymmetry that occurred during the take-off and landing, however (Paterno et al., 2007).

In addition, to the author's knowledge, it has not been investigated how the complexity of a jumping exercise could affect the level of asymmetry an individual demonstrates. Ebben et al., classified the intensity of several jumping exercises, based factors that included the ground reaction forces during the take-off and landing. Previous research has shown that as the intensity increases when preforming a back squat, the level of lower body asymmetry decreases, but it has not been investigated whether this is true for jumping exercises (Lake et al., 2011).

The main purpose of this study was to evaluate the asymmetries expressed during the TO and L phases of the DJ, VJ and DL exercises to determine if there is a significant difference in the imbalance that is expressed during the two phases. Additionally, comparisons were made between exercise conditions to determine if exercise selection has an impact on lower body asymmetry. It was hypothesized that (1) the asymmetry would significantly differ between the landing and take-off phases and (2) the asymmetry would significantly differ between the exercise conditions.

METHODS

Experimental Approach to the Problem

This study was designed to measure the inter-leg asymmetry that was present during DL, VJ, and DJ exercises. Each participant performed 3 trials of each exercise. Two force plates recorded vGRF data at each foot-ground interface during the execution of the 3 exercises. Peak vGRF data from the 3 trials were averaged for each phase of each exercise for statistical analysis (Ford et al., 2003). An asymmetry index (AI) was calculated for each phase of each exercise in order to quantify the imbalance as a percentage.

Subjects

11 Western Michigan University students were recruited to participate in this study (10 males and 1 female). Subjects were all between the ages of 18-28, had an average body mass index of 25.3±2.8 kg/m^2, and at least two years of athletic experience. In addition, any individual with a lower body injury in the previous six months was excluded from participating. Subject demographics (mean ±SD) are listed in Table 1. The procedures and risk of the study were explained to the participants prior to written consent being given.

Table 1. **Subject Demographics**

Age	Height (cm)	Body Mass (kg)	BMI
23.4 ±1.3	177.8 ±8.3	80.4 ±12.2	25.3 ±2.8

Procedures

Participants reported to the lab on one occasion. Before data collection began, height and weight were measured, the exercises were demonstrated, and participants performed a short warm-up. For the warm-up, participants pedaled on a Monark cycle ergometer at a self-selected pace for five minutes, and then performed 3 practice trials of each exercise in order of increasing complexity, (DL, VJ, DJ). This also served to familiarize the subjects with the technique of each exercise.

Following the warm-up, subjects preformed 3 trials of each exercise for data collection. The order the exercises were performed in was randomized. Two 1000-Hz force plates (Model Optima; Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to capture vGRF independently from each foot. The height of the box that was used for the DL and DJ was 31 cm, as has been previously published (Schmitt et al., 2016).

For the DL exercise participants were instructed to step off the stool, and land with one foot on each force plate. For the VJ exercise the participants were instructed to stand with one foot on each force plate and perform a countermovement jump with maximal effort, landing with one foot on each force plate. For the DJ exercise, subjects stood on the stool, stepped off and landed as in the DL, but then immediately preformed a countermovement jump with maximal effort, landing again with one foot on each force plate.

Since there are 2 landings during the DJ, the first was referred to as L1 and the second as L2. If part of either foot landed off of the force plate during a trial it was repeated. The leg that demonstrated the greater peak VGRF value was considered the dominant leg for statistical analysis.

Statistical Analysis

The AI for each phase was calculated using the peak VGRF value for each leg. The equation: (dominant leg – non-dominant leg)/dominant leg X100 was used (Fort-Vanmeerhaeghe et al., 2016; Carpes et al., 2010; Newton et al., 2006; Impellizzeri et al 2007; Jordan et al., 2015).

A repeated measures analysis of variance was used to determine whether significant differences existed between the asymmetry that was measured during the different conditions: VJ-TO, VJ-L, DJ-L1, DJ-TO, DJ-L2, and DL-L. For a significant effect, post hoc pairwise comparison tests were performed.

Data was initially analyzed using Microsoft Excel (Microsoft, Redmond, WA). Statistical analysis was conducted using IMB SPSS Statistics version 25 (IBM, New York), and the α level set a priori to .05.

RESULTS

VJ-TO demonstrated a significantly lower AI than VJ-L, DJ-L1, DJ-L2, and DL-L ($F=7.735$; $p<.05$). Additionally, DJ-TO showed a significantly lower AI than VJ-L, DJ-L1, DJ-L2, and DL ($F=7.735$; $p<.05$). No significant difference was found between VJ-TO and DJ-TO. Furthermore, there were no significant differences between landing phases. Group AI data (mean±SD) for all phases of the three exercises and is presented in Figure 1.

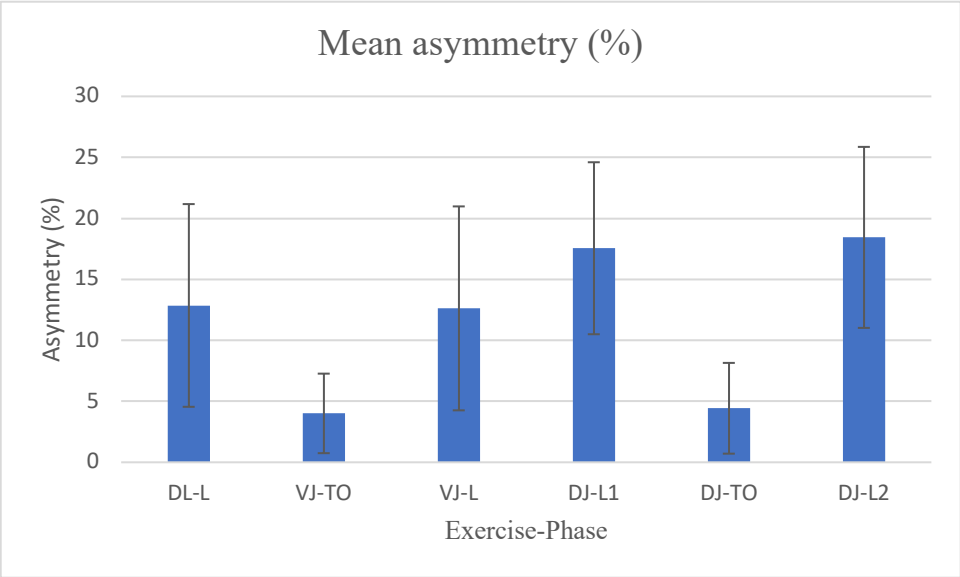

Figure 1. Asymmetry results
DL-L=Drop-Landing-Landing; VJ-TO=Vertical Jump-Take off; VJ-L=Vertical Jump-Landing; DJ-L1=Drop Jump-1st Landing; DJ-TO=Drop-Jump-Take-off; DJ-L2=Drop-Jump 2nd landing

DISCUSSION

The purpose of this study was to evaluate and compare the average asymmetry present during the take-off and landing phases of the VJ, and DJ exercises. A significant difference was found between the asymmetry levels during the TO and L phases of both VJ and DJ. No significant differences were found between exercises.

To the author's knowledge this is the first study to directly compare the asymmetry measured during the landing and take-off phases of different jumping exercises. The results of this study indicate that lower-body asymmetry is higher during a phase of force absorption compared to a phase of force production. In addition, in this study an overall higher mean peak vGRF was observed during landings than during take-offs, which was in agreement with previous research (Ebben et al., 2011). Increased asymmetry, combined with exposure to higher total forces, could be a mechanism that helps to explain the high incidence of ACL injuries that occur during landing movements.

We also compared the direction the asymmetry occurred in during the landing and jumping phases. Leg dominance was determined by the side that experienced the higher peak VGRF. During the TO phases, 2 individuals demonstrated no imbalance during either VJ-TO or DJ-TO. Besides these 2 subjects, all individuals demonstrated directional agreement between the VJ-TO and DJ-TO. During the landing phases all individuals demonstrated some imbalance during all conditions. Only 4 participants demonstrated agreement across all four landing phases in regard to leg preference This suggests that there may be greater variability in which side is placed under the greatest stress during landings compared to take-offs. Additional research is needed to verify these findings.

Six participants demonstrated agreement in side preference between the TO and L of the VJ exercise. In addition, during the DJ, 8 participants demonstrated agreement in side preference between L1 and TO, and 5 participants demonstrated agreement between TO and L2. Two participants demonstrated side agreement during all 6 conditions. DJ-L1 and DJ-TO demonstrate the highest amount of agreement in side preference. During the DJ, the leg that absorbed more force during L1 would be better positioned to display more force during the TO due to the stretch shortening cycle (Komi, 2005).

The vGRF data collected during this study is similar to what has been reported in previous work (Paterno et al., 2007; Jordan et al., 2015; Ebben et al., 2011). Data from one DJ trial is depicted in Figure 2. Multiple studies have reported VGRF data during DJ exercises that was similar to the data we collected (Paterno et al. 2007; Ebben et al., 2011; Schmitt et al, 2015). In addition, the vGRF patterns recorded during the VJ in this study agree with those reported by Jordan et al., 2015. Figure 3 depicts vGRF data from a VJ trial in which approximately 15% asymmetry was recorded along with a left-leg dominance during both TO and L.

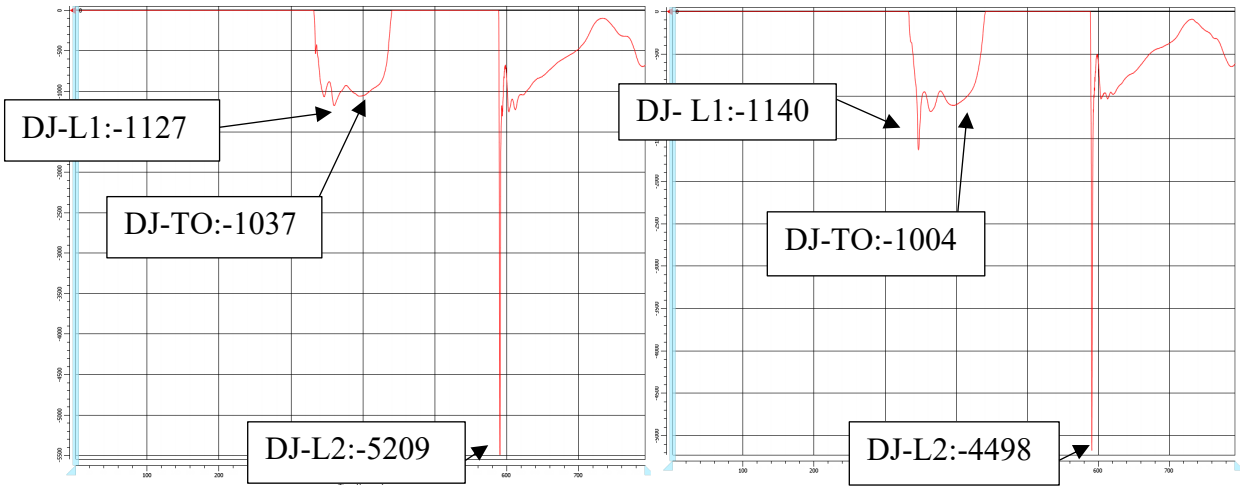

Figure 2*. Drop jump data

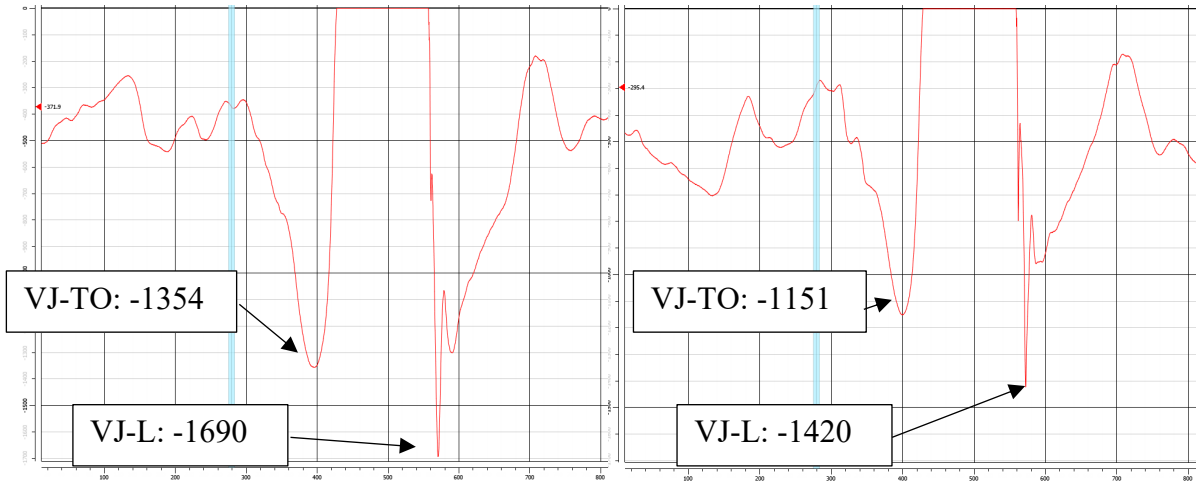

Figure 3*. Vertical jump data

***** In figures 2 and 3 VGRF is measured in newtons. The left graph depicts the left leg and the right graph shows the right leg. The force plates read the vertical ground reaction force data as negative along the Y-axis.

Excessive asymmetry can increase the likelihood of lower body injuries occurring in both the stronger leg and the weaker leg. It has been suggested that the weaker limb may not have the ability to handle repeated exposure to submaximal forces, and the stronger limb may experience supramaximal forces in an attempt to compensate (Ford et al., 2003). Indeed, it was found in a sample of competitive skiers who had previously undergone ACL repair, that the contralateral

knee more often experienced an ACL injury than the repaired knee. (Paterno et al., 2007). Leg asymmetry exceeding 10-15% has been considered to be an injury risk and has also been used as a criterion for return to sport following ACL injuries (Paterno et al., 2007).

The results of the current study indicate that asymmetry testing done for injury prevention purposes should include some measure of eccentric asymmetry. Caution should be used when applying the results of this study to populations of highly trained athletes, however. Research has shown that an athlete's level of training can impact their level of asymmetry. It has been suggested that athletes with more experience may display lower asymmetry levels due to enhanced neuromuscular movement patterns (Fousekis et al., 2010). The sample that we studied was only recreationally trained, which could impact the levels of asymmetry that were found. Additionally, the majority of this sample was male, so it was not possible to determine if the results are applicable to females.

In conclusion, during jumping exercises, lower body asymmetry was found to be greater during landing than during take-off. Also, asymmetry did not differ significantly between exercises. Additional studies are needed to verify these findings in athletic populations of both genders.

Practical Application

The results of this study suggest that asymmetry is greater during the landing phase than during the take-off phase of jumping exercises. Strength coaches should consider using both concentric and eccentric asymmetry tests when screening athletes to assess their relative injury risk. This information could help strength coaches better design injury prevention programs for their athletes.

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Appendix A: Informed Consent Document

Informed Consent
Western Michigan University
Human Performance and Health Education

Principal Investigator: Dr. Sangwoo Lee
Student Investigator: Simon Cone
Title of Study: **"**Lower limb force asymmetries during landing and jumping exercises."

STUDY SUMMARY: This consent form is part of an informed consent process for a research study and it will provide information that will help you decide whether you want to take part in this study. Participation in this study is completely voluntary.
The purpose of the research is to compare the ground reaction forces of each leg during the take-off and landing of different jumping exercises. This research will serve as Simon Cone's thesis for the requirements of a master's degree in Exercise Physiology. If you take part in the research, you will be asked to sign this consent form, allow measurements of height and weight, perform 3 drop-landings, 3 vertical jumps, and 3 depth-jumps.
Your time in the study will take approximately 1 hour and 15 minutes. Possible risk and costs to you for taking part in the study may be accidental injury and some muscle soreness. Potential benefits of taking part may be a slight increase in lower body power production ability, and knowledge of the level of asymmetry between legs. Your alternative to taking part in the research study is not to take part in it.

You are invited to participate in this research project titled "Lower limb asymmetries during landing and jumping exercises" and the following information in this consent form will provide more detail about the research study. Please ask any questions if you need more clarification and to assist you in deciding if you wish to participate in the research study. You are not giving up any of your legal rights by agreeing to take part in this research or by signing this consent form. After all of your questions have been answered and the consent document reviewed, if you decide to participate in this study, you will be asked to sign this consent form.

What are we trying to find out in this study?
The primary purpose of this study is to compare the ground reaction forces between the legs during the landing and take-off phases in order to investigate if the same leg is dominant during each phase. The secondary purpose of this study is to establish whether increasing the intensity of a jumping exercise will increase the symmetry of force production between the legs during the movement.

Who can participate in this study?
You may participate in this study if you are between the ages of 18-28 and have at least 2 years of experience playing a sport at a high school or college level. Also, you must have a BMI under 30. You may not participate if you have had a lower body injury in the last 6 months.

Where will this study take place?
Research will take place in the biomechanics laboratory located on the 1st floor of Western Michigan's Student Recreation Center.

What is the time commitment for participating in this study?
The overall time commitment for this study is estimated to be 1 hour and 15 minutes. All data collection will take place during one session. The first 15 minutes will be spent going over the informed consent and requirements of the study, and the next hour will be spend warming-up and preforming the jumping/landing exercises.

What will you be asked to do if you choose to participate in this study?
If you choose to participate in this study, you will be asked to sign this informed consent form. Your height and weight will be measured to calculate your BMI. You will then be led through a short warm-up. After the warm-up you will perform 3 reps of each exercise for familiarization, and then 3 reps of each exercise for data collection.

What information is being measured during the study?
The measurements that will be taken are height, weight, and ground reaction force produced by each foot.

What are the risks of participating in this study and how will these risks be minimized?
There are certain risks associated with participation in this study. You may experience some muscle soreness over the next 3-4 days following the study. Also, you may be at risk of an accidental injury. These risks will be minimized by performing a warm-up before plyometric exercises. A researcher will also be present during the session. It is important that you disclose any lower body injuries as these could increase your risk of injury during participation. If you feel uncomfortable at any time during the study you have the right to stop participation at any point.
As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however, no compensation or additional treatment will be make available to you except as otherwise stated in this consent form.

What are the benefits of participating in this study?
You may see a slight increase in lower-body power as a result of participating in this study. You will also gain knowledge about your level of lower-limb asymmetry

Are there any costs associated with participating in this study?
If you do not have a WMU parking pass you will be required to pay for parking at he SRC.
Is there any compensation for participating in this study?
Participants will not be compensated for participating in this study

Who will have access to the information collected during this study?
Your personal data will be kept confidential and stored in the principal investigator's office at WMU in the department of Human Performance and Health Education for at least 3 years after the conclusion of the study. The results of the study may be presented at a conference or

published. Your identity will be kept confidential at all times by assigning you an identifying number that will be used for the data analysis. Only the investigators will have access what your number is.

What will happen to my information collected for this research after the study is over?
The information collected about you for this research will not be used by or distributed to investigators for other research.

What if you want to stop participating in this study?

You can choose to stop participating in the study at anytime for any reason. You will not suffer any prejudice or penalty by your decision to stop your participation. You will experience NO consequences either academically or personally if you choose to withdraw from this study. The investigator can also decide to stop your participation in the study without your consent.

Should you have any questions prior to or during the study, you can contact the primary investigator, Dr. Sangwoo Lee at 269-387-2546 or sangwoo.lee@wmich.edu or the student investigator, Simon Cone at 734-645-0616 or simon.m.cone@wmich.edu. You may also contact the Chair, Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.

This consent document has been approved for use for one year by the Western Michigan University Institutional Review Board (WMU IRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

_____

Please Print Your Name

_____ _____

Participant's signature Date

Appendix B: Recruitment Flyer

Research Participants needed

This experimental study will be examining lower-limb asymmetries during landing and jumping. Participants will be asked to perform 3 drop landings, 3 vertical jumps, and 3 drop jumps onto two adjacent force plates to measure ground reaction forces. All data will be collected during one session that will take about 1 hour and 15 minutes.

We are looking for participants who are between 18-28 years old, have no lower body injuries, and have a BMI below 30. Participants must have at least 2 years of experience playing a sport at the high school or college level.

If you are interested in learning more, please contact Simon Cone at simon.m.cone@wmich.edu

Appendix C: Recruitment Email

Hello, I am conducting my thesis research project on lower-limb asymmetries during landing and jumping. Individuals who are between 18-28 years old, have 2 years of athletic experience, have no lower body injuries, and have a BMI below 30 are invited to participate.

If you agree to participate you will be asked to perform 3 drop landings, 3 vertical jumps, and 3 drop jumps onto two adjacent force plates to measure ground reaction forces. All data will be collected during one session that will take about 1 hour and 15 minutes.

If you are interested in learning more, we can schedule a meeting where you can ask any questions you would like, and we can go through the informed consent together.

WESTERN MICHIGAN UNIVERSITY

Institutional Review Board
FWA00007042
IRB00000254

Date: October 28, 2019

To: Sangwoo Lee, Principal Investigator
Simon Cone, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair

Re: IRB Project Number 19-10-27

This letter will serve as confirmation that your research project titled "Lower Limb Force Asymmetries During Landing and Jumping" has been **approved** under the **expedited** category of review by the Western Michigan University Institutional Review Board (IRB). The conditions and duration of this approval are specified in the policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes to this project (e.g., ***add an investigator, increase number of subjects beyond the number stated in your application, etc.***). Failure to obtain approval for changes will result in a protocol deviation.

In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the IRB for consultation.

The Board wishes you success in the pursuit of your research goals.

A status report is required on or prior to (no more than 30 days) October 27, 2020 and each year thereafter until closing of the study.

When this study closes, submit the required Final Report found at https://wmich.edu/research/forms.

Note: All research data must be kept in a secure location on the WMU campus for at least three (3) years after the study closes.

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