The Effects of a Cognitive Dual Task on Jump-Landing Mechanics

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the faculty of
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This thesis titled

The Effects of a Cognitive Dual Task on Jump-Landing Mechanics

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Abstract

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The Effects of a Cognitive Dual Task on Jump-Landing Mechanics

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Background: Several studies have investigated biomechanical deficits in jump landing; however, these studies are often performed in a laboratory with little distraction to the participant. Injury has been shown to occur during sport-specific distraction where the individual is cognitively loaded during motor performance. Purpose: The purpose of this study was to determine the effect of a cognitive task on jump-landing mechanics.

Methods: A dual-task design was used to determine the effects a cognitive dual task on the tuck-jump assessment and peak vertical ground reaction force in 20 participants. There were three cognitive conditions (no cognitive task, easy cognitive task, and difficult cognitive task). Results: There were significant differences in overall tuck-jump score from baseline to easy cognitive task and baseline to difficult cognitive task. The cognitive dual task elicited statistically significant changes in overall tuck-jump score across the conditions with tuck-jump score increasing from 3.52 ± 1.64 baseline to 4.37 ± 1.25 with the easy cognitive task to 4.67 ± 1.24 with the difficult cognitive task. No significant differences were found in vGRF across the three conditions. Conclusion: The dual-task conditions affected jump-landing mechanics as measured by the tuck-jump score. Although there was a decrease in vGRF, no statistical significance was found over the three conditions.
Preface

Chapter 3 contained within the thesis document serves as a prepublication manuscript. This manuscript has been formatted to meet the guidelines set forth by the *Journal of Athletic Training* and Thesis and Dissertation Services at Ohio University. The heading style and reference citation style follow the guidelines of the AMA Manual of Style (10th ed., 2007).
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Chapter 1: Introduction

Sports such as football, basketball, and soccer have a high incidence of athletic injuries, with the highest portion to the lower extremity. Ankle sprains, muscle strains, and ligamentous damage to the knee are all injuries sustained by athletes while participating in sports. In an epidemiological study conducted by Hootman et al, researchers found that more than 50% of all reported injuries were to the lower extremity for both practices and games, with knee and ankle injuries accounting for the majority of those injuries. Due to the prevalence of injury in sport and risk for reinjury, specifically in those who underwent anterior cruciate ligament reconstruction (ACLR), the need for injury prevention programs continues to grow.

Injury prevention is an essential part of the services athletic trainers and other healthcare providers can deliver to their patients. Strengthening muscles, improving balance and coordination, and increasing flexibility are all measurable outcomes that can be achieved by the athlete to improve their performance and decrease risk of injury. However, other aspects of injury occurrence such as neurocognitive factors are just beginning to play a role in injury prevention programs. Despite these efforts, preventing injury in athletic populations is not an easy task. There are several other variables, like reaction time and sport-specific distractions, which need to be considered in order to obtain a more accurate understanding of athletic injury.

In order to make better sense of this issue, several researchers have performed studies analyzing landing mechanics in order to determine predisposing factors to lower extremity injury, such as anterior cruciate ligament (ACL) injury. Typically, these
studies are performed in a controlled laboratory setting with little distraction affecting landing mechanics. However, athletes often have to multitask and divide their attention while participating in their respective sport, such as throwing or catching a ball while landing. According to the “limited capacity theory” of attention, if two tasks are performed together they both compete for attention, which may affect the performance of one or both.\(^{11}\)

In addition, recent evidence has emerged to support an association between brain function measured by a computerized neurocognitive test, like the ImPACT battery, and knee injury risk.\(^ {12}\) Also, although neurocognitive changes have customarily been linked to concussions, deficits in cortically driven reaction time, processing speed, and visual and verbal memory may also indicate weakened ability for neuromuscular control.\(^ {8}\) Effectively, it may be possible to screen athletes by assessing their ability to perform sport-specific activities while also sustaining a cognitive load, a concept referred to as dual-tasking.

Due to this association, it is pertinent to further study the potential relationship of dual-tasking during a jump-landing technique, such as a double-leg or single-leg jump, on the risk of injury, specifically in the lower extremity. Measuring any changes in kinetic and kinematic data during landing would progress the understanding of sport-specific injury. This can be accomplished by measuring lower extremity biomechanical data, which can be gathered by using three-dimensional (3-D) motion analysis, the Landing Error Scoring System (LESS),\(^ {13}\) or the tuck-jump assessment.\(^ {14}\) In light of current evidence, the purpose of this study was to determine the effects of a cognitive dual task
on jump-landing mechanics as determined by the tuck jump in healthy and active individuals.

**RESEARCH QUESTIONS AND HYPOTHESIS**

1. **Effect of dual task:** How does a cognitive dual task affect landing mechanics?
   a. Landing mechanics like peak vertical ground reaction force (vGRF), knee valgus, and hip and knee flexion will increase due to the limited capacity theory.

2. **Dual task and injury risk:** Does the cognitive dual task increase the number of biomechanical errors during a jump landing?
   a. Completing a cognitive dual task will result in a higher overall score on the tuck jump, indicating an increased risk of lower extremity injury.

3. **Effect of cognitive difficulty:** Is there a difference between easy and difficult cognitive dual tasks when comparing landing mechanics between the two?
   a. The difficult dual task will result in a greater decrease in landing mechanics (ie, increased knee valgus, hip and knee flexion) compared to the easy task.

**INDEPENDENT VARIABLES**

1. **Dual Task**
   a. Baseline task (control).
   b. Easy cognitive task.
   c. Difficult cognitive task
DEPENDENT VARIABLES

1. Overall tuck-jump score (0-9).
2. Peak vertical ground reaction force (vGRF).

ASSUMPTIONS

1. Evaluation of the video data was consistent for each participant.
2. All participants will give full effort.
3. Gravity will remain constant.

LIMITATIONS

1. Participants with a high baseline tuck-jump score may not see a difference in their score during the dual-task application because the scoring does not allow for variation within biomechanical errors.

DELIMITATIONS

1. Participants were students at Ohio University who were healthy and physically active individuals.
2. Measurements were obtained during a single testing session rather than requiring participants to report on three separate occasions to complete trials for each condition.
Chapter 2: Review of Literature

Sports such as football, basketball, and soccer lead to a high incidence of athletic injuries to the lower extremity, which may be due to the frequency of high-risk movements, such as cutting, jumping, rapid deceleration, and overall player contact. Injuries sustained by players, such as noncontact ACL sprains or ruptures, often occur while avoiding contact or reacting suddenly to the sporting environment. However, the most common mechanism of injury is landing after jumping when the knee is hyperextended and in a valgus, or “knock-kneed,” position. Therefore, the best method for measuring an individual’s predisposition to a noncontact injury is through biomechanical examination and analysis of one’s jump-landing technique.

In addition to the analysis of jump landing, research also suggests ACL injuries occur within a 1 m proximity of another player and other distracting factors. The authors of this study concluded that a preventative program to enhance knee control not only should focus on avoiding valgus motion, but also should include distractions like those seen in game situations. Although preventative programs have improved, they may still lack something integral to preventing injuries.

Despite these efforts to correct biomechanical errors, other variables like reaction time and the brain’s cognitive ability need to be taken into account in order to obtain a more accurate understanding of injury. Recent evidence supports an association between brain function gauged by a computerized neurocognitive test, like the ImPACT battery, and knee injury risk. Also, although neurocognitive changes have customarily been linked to concussions, deficits in cortically driven reaction time, processing speed, and
visual and verbal memory may also indicate weakened ability for neuromuscular control.\textsuperscript{8} This link may help to explain the reasoning behind the ACL injuries sustained in proximity to other players and sport-specific distractors.

Due to this association, it is extremely pertinent to further study the potential relationship of dual-tasking during a jump-landing technique on the risk of injury, specifically in the lower extremity, while measuring any changes in kinetic and kinematic data. This can be accomplished by measuring lower extremity biomechanical data gathered from 3-D motion analysis, the Landing Error Scoring System (LESS), or the tuck-jump assessment. Therefore, reaction time, dual-tasking, jump-landing techniques, and evaluating lower extremity biomechanics will be discussed in the following review of literature.

**REACTION TIME**

Neurocognitive tasks, like those assessing reaction time, processing speed, visual memory, and verbal memory, are well established in the neuropsychology literature as indirect measures of cortical performance.\textsuperscript{12} Situational awareness, arousal, and attentional resources may influence these aforementioned areas of neurocognitive function, thus affecting the complex integration of visual, auditory, and somatosensory stimuli required for neuromuscular control.\textsuperscript{12} Although neurocognitive changes have traditionally been related to concussions,\textsuperscript{19,20} deficits in reaction time, processing speed, and visual and verbal memory may also suggest weakened ability for neuromuscular control, thus increasing the potential of an individual’s risk to noncontact injury.\textsuperscript{12}
Generally, athletes have better reaction times than nonathletic populations, but reaction times can worsen when the number of distracting stimuli increases. An individual’s reaction time can also worsen when executing memory and fine motor skills in conjunction with a gross motor task, such as walking. Also, auditory stimuli has the ability to affect reaction time with motor tasks. These deficits in reaction time and processing speed may influence individuals’ ability for neuromuscular control, especially when exposed to a more dynamic sporting environment, like those seen in athletic competition.

In a study performed by Swanik et al, researchers found that neurocognitive differences may be associated with the loss of neuromuscular control and coordination errors, thus predisposing certain athletes to noncontact ACL injuries. Additionally, athletes who suffered noncontact ACL injuries had significantly slower reaction times and processing speeds, as well as lower visual and verbal memory scores.

Herman et al conducted a study in which participants were screened using the Concussion Resolution Index (CRI), a neurocognitive test that provides information regarding simple reaction time, complex reaction time, and processing speed. Participants were then grouped into high performers (HP) and low performers (LP) based upon their CRI scores and asked to perform an unanticipated jump-landing task. It was found that the LP group demonstrated significantly altered neuromuscular performance as compared to the HP group during the landing phase while completing the landing task, which included a higher vGRF.
DUAL-TASKING

Dual-tasking acts as a distraction that decreases motor performance and is very useful in understanding postural control. According to the “limited capacity theory” of attention, if two tasks are performed together they both compete for attention, which may affect the performance of one or both. Evidence also suggests that the performance of a cognitive task while walking reduces gait velocity, and this has been termed the dual-task cost (DTC). An everyday example of this can be seen when someone is texting while walking. The DTC of walking has been uniquely correlated with cognitive and mobility functions, such that those with worse cognitive function or mobility generally have a larger DTC. Essentially two separate tasks cannot be performed to the best of one’s ability simultaneously.

There are several different ways in which a dual task can be implemented. In a study performed by Foley et al, participants were subjected to a cognitive dual task in which they were required to perform a digit recall and tracking task, both separately and then simultaneously. The performance measures to assess DTC were the proportion of digits recalled accurately and the number of circles (used in the tracking task) crossed by the pencil.

Additionally, other forms of dual tasks include the auditory Stroop task. This task involves participants recognizing a speaker’s voice that was modified by “high pitch” and “low pitch” when uttering the words “high” and “low.” For example, if the speaker uses the word “high” with “low pitch,” participants should answer with word “low” as soon as they hear the question. Outcome variables for this study were changes in gait step
length, width, and time under various velocities and with and without the dual cognitive task. Primary findings indicated that in individuals with ACLR step width may be sensitive to cognitive load.

Polskaia et al\textsuperscript{26} carried out a study to determine the effect of varied complexity of dual tasks on postural control in young adults. Both auditory and visual tasks were utilized during this experiment. The easy visual cognitive task consisted of a sequence of 30, 3-digit numbers presented on a computer screen. Participants were instructed to count the total number of times a preselected digit appeared in the given sequence. The task required participants to simultaneously search for the specified digit in each 3-digit number and keep a running total. Each 3-digit number was presented every 2 seconds.\textsuperscript{26}

**Dual-Tasking and Jump Landing**

Since takeoff before a jump and the subsequent landing are controlled by the central nervous system, dual-task effects are most pronounced if participants are requested to respond to reaction signals during these times.\textsuperscript{22} In dual-tasking, either the cognitive task or the motor task will take priority over the other. Mohamadi et al\textsuperscript{27} found that patients with ACLR appeared to sacrifice their cognitive performance in order to optimize their performance on postural stability.

Similarly, in a research study conducted by Shinya et al\textsuperscript{22}, participants took part in a dual task with a single-leg landing. The overall goal of this study was to investigate the attentional demand during a single-leg landing after a jump. The cognitive dual task used involved pushing the right or left custom-made button as soon as a go-signal was presented on an LED screen to measure reaction time during the single-leg landing.
Researchers found that greater ground reaction force and acceleration were observed during single-leg landing under conditions in which participants were required to react to visual stimuli.

Additionally, in a study performed by Krosshaug et al.,\textsuperscript{18} which examined the mechanisms of ACL injury in basketball, it was found that players who sustained an injury were typically within 1 m of another player and other distracting factors. These factors included the player’s focus of attention such as the basket rim, opponent, and ball. The authors concluded that a preventative program to enhance knee control should not only focus on avoiding valgus motion, but also include distractions like those seen in game situations. Due to the association of reduced cognitive processing ability to sport-specific distractions and the subsequent injury that follows, we propose, landing biomechanics, when coupled with a cognitive dual task, will be influenced in some form or another.

**JUMP LANDING**

**Double-Leg Jump**

There are several different methods in which a double-leg jump can be performed, although the drop vertical jump (DVJ) and stop jump are probably the most commonly utilized.\textsuperscript{9,10,28,29} These jump-landing techniques are typically used in accordance with a motion analysis to measure changes in landing mechanics.

In a study performed by Norcross et al.,\textsuperscript{30} researchers sought to determine whether significant relationships existed between lower extremity energy absorption and biomechanical factors related to ACL injury. In order to accomplish this, researchers had
participants perform a double-leg jump landing while measuring lower extremity biomechanics and force-plate data. Primary findings indicated that lower extremity energy absorption during a jump landing is related to biomechanical factors that have been related to ACL injury. Researchers concluded that modifying lower extremity energy absorption may be a potential intervention technique to alter biomechanical factors associated with noncontact ACL injuries.

**Single-Leg Jump**

In a single-leg drop-landing task, subjects land with a significantly larger ground reaction force, increased knee valgus angle at initial contact, a decreased peak knee flexion angle, and a decreased knee flexion angle and angular velocity at initial contact compared to a double-leg drop-landing task. Thus, utilizing a single-leg jump technique rather than a double-leg jump technique may increase the risk of lower extremity injury in athletes.\textsuperscript{13}

In a study performed by Dingenen et al,\textsuperscript{31} researchers investigated whether two-dimensional measured angles during the single-leg drop vertical jump (DVJ) could help identify noncontact knee injury risk in a population of female athletes. In order to accomplish this, researchers had participants drop off a box of 10 cm with one leg, followed by a maximum vertical jump on the same leg. Participants were given instruction to jump as high as possible by attempting to reach an overhead target at an unobtainable height of 300 cm with both hands. Trials were not valid if participants jumped off the box instead of dropping, if the nonsupporting leg touched the ground, if they reached with only one hand, or if they clearly lost balance or fell during the test.
Primary findings of this study indicated that female athletes landing with a combination of increased knee valgus and lateral trunk motion in the direction of the stance limb during the single-leg drop vertical jump may be used to detect increased noncontact knee injury risk.

EVALUATING LOWER EXTREMITY BIOMECHANICS

Three-Dimensional Motion Analysis

    Kinetics is the study of forces that cause motion, like torque and gravity, and can be classified into two groups: linear and angular motion. Kinematics is the study of movement like displacement, time, and velocity. Typically when measuring kinetic and kinematic data, an 8-camera motion capture system and a force platform is utilized. Reflective markers are usually placed on the lower limbs of subjects depending on what variables are measured. A Vicon camera system can capture the light reflected off the reflective markers and record even the most diminutive change in position. Three-dimensional (3-D) kinematic and kinetic data are often utilized during an assortment of landing tasks. In a study measuring the effects of two landing techniques on knee kinematics and kinetics, three different landing conditions were utilized: natural landing, soft landing, and landing with increased knee flexion at initial ground contact.

The Landing Error Scoring System

    The Landing Error Scoring System (LESS) is an economical clinical assessment tool that was developed to provide a standardized instrument to identify patients at high risk of ACL injury. This tool uses two standard video cameras for identifying potentially high-risk movement patterns (“errors”) during a jump-landing maneuver. Through video
analysis of frontal and side views, it allows the clinician to assess lower extremity and trunk positioning during a jump-landing task.\textsuperscript{33}

The LESS has 17 scored items to evaluate the landing from both the sagittal and frontal views. The LESS score is a count of errors on a range of easily observable items of the jump-landing movement, with scores ranging from 0-17. A higher LESS score signifies more errors and, subsequently, a poorer jump-landing technique.\textsuperscript{33} Items measured in the LESS include knee flexion at initial contact, hip flexion at initial contact, trunk flexion at initial contact, ankle plantar flexion at initial contact, medial knee position at initial contact, lateral trunk flexion at initial contact, stance width, foot position, symmetric initial foot contact, and displacement of knee flexion, hip flexion, trunk flexion, and medial knee joint displacement.\textsuperscript{34}

In a study measuring the validity and reliability of the LESS, the researchers’ findings revealed good-to-excellent interrater and intrarater reliability.\textsuperscript{35} Researchers found the interrater reliability to be 0.84 and 0.71, respectively. These numbers indicate the LESS to have good interrater reliability. The intrarater reliability for the LESS was found to be 0.91 and 0.42, respectively. These numbers indicated the LESS to have excellent intrarater reliability. It is also important to note that the testers for this study underwent a comprehensive training program. Additionally, in a study conducted by Onate et al,\textsuperscript{16} excellent validity and excellent expert vs. novice interrater reliability of the LESS was found.

The LESS also appears to be a sensitive clinical assessment tool of jump-landing biomechanics when compared to the gold standard of 3-D motion analysis,\textsuperscript{13} and may be
a useful clinical assessment tool. This tool could be utilized during large-scale screenings to identify those at risk for noncontact ACL injury and other serious lower extremity injury.35

**Tuck Jump**

The tuck-jump exercise may be useful for the identification of lower extremity technical flaws during plyometric activity.36 This activity requires a high level of effort from participants, which makes it an excellent tool to readily identify potential deficits. Additionally, the tuck jump may be used to assess improvement in lower extremity biomechanics as users progress through training programs. Items analyzed and scored during tuck-jump performance include ligament dominance, quadriceps dominance, leg dominance or residual injury deficits, trunk dominance, and technique perfection.36 The tuck jump is scored on a scale of 0-9, where a high tuck-jump score indicates a poor tuck-jump trial and a low tuck-jump score indicates an excellent tuck-jump trial.

Subsequently, these scored items can be broken down even further. Ligament dominance examines the lower extremity valgus at landing and whether foot placement is shoulder width apart. Quadriceps dominance looks at excessive landing contact noise while leg dominance takes note of if the thighs are equal side to side during flight, if foot placement is parallel, and if foot contact timing is equal. Trunk dominance can be examined by seeing if participants’ thighs reach parallel at the peak of their jump, if there is a pause between jumps, and if jumpers do not land in the same footprint. Technique perfection examines the decline of perfect technique prior to 10 seconds.
To perform the tuck jump, participants started in an athletic position, with feet shoulder-width apart standing on the force platforms. The jump was initiated with a slight crouch downward while extending their arms behind them. They then swung their arms forward as they simultaneously jumped straight up and pulled their knees up as high as possible. At the highest point of the jump, participants were in the air with thighs parallel to the ground. After landing, participants immediately began the next tuck jump.

In a study carried out by Herrington et al, the researchers sought to establish the intra- and intertester reliability of the tuck jump. They found the intratester reliability to be $k = 0.81$, which is very good to excellent. The intertester reliability was found to be $k = 0.86$, which is also very good to excellent. Researchers concluded that the tuck jump shows very good—excellent intra- and intertester reliability when the test was analyzed from video.

**TASK SELECTION RATIONALE**

Due to the temporal demands of a dual task during a jump landing, the assessment must be long enough to allow time for sufficient cognitive challenge. The tuck jump has shown to be a reliable and valid tool to assess landing neuromuscular control changes. A key feature of the tuck jump is that it is performed for a 10-second duration, giving adequate time to measure the effects of the dual task on landing. Although the LESS is also a reliable and valid tool, DVJ is typically utilized and lasts but a couple seconds. The duration of the DVJ is not long enough to implement a dual task in a challenging and effective manner.
However, it is important to note the possibility of a ceiling effect to occur during the tuck-jump scoring process. For example, if a participant already has a poor (high) tuck-jump score at baseline, implementing a dual task during the next tuck-jump trial may not result in a different overall tuck-jump score. Therefore, it is important to incorporate other measurable variables when utilizing the tuck jump.
Chapter 3: The Effects of a Cognitive Dual Task on Jump-Landing Mechanics

**Context:** Athletic injuries typically occur within a dynamic sporting environment with distracting factors. Limited research has examined the effects of a cognitive dual task on jump-landing mechanics in a laboratory setting.

**Objective:** To examine the effects of an easy and difficult dual task on jump-landing mechanics in healthy, physically active individuals.

**Design:** Within-subjects repeated measures study.

**Setting:** Laboratory.

**Participants:** Twenty male (N = 10) and female (N = 10) subjects (age: 22.4 ± 1.314 years; height: 1.71 ± .10 m, weight: 71.75 ± 11.96 kg) who participated in exercise at least 3 hours a week, had experience jumping, were not suffering from lower extremity or back injury within the 3 months prior to participation, had no history of ACL reconstruction or lower extremity surgery, and had no history of neurocognitive disorder, concussion within 1 year of participation, or psychological distress.

**Data Collection and Analysis:** Data was collected by the primary investigator from the Ohio University Campus population. All data were manually checked for inclusion by the primary investigator. Participants were asked to complete a tuck-jump trial over 3 cognitive conditions (control, easy, difficult).

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1 This chapter represents a prepublication manuscript to be submitted to the *Journal of Athletic Training* (May, 2016). Authors are: Amber J. Schnittjer, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Jae Yom, PhD (School of Applied Health Sciences and Wellness, Ohio University, Athens); Janet Simon, PhD, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); and Dustin Grooms, PhD, AT, CSCS (School of Applied Health Sciences and Wellness, Ohio University, Athens).
**Results:** There were significant differences in overall tuck-jump score from baseline to easy cognitive task and baseline to difficult cognitive task. The cognitive dual task elicited statistically significant changes in overall tuck-jump score over the conditions with tuck-jump score increasing from 3.52 ± 1.64 baseline to 4.37 ± 1.25 with the easy cognitive task to 4.67 ± 1.24 with the difficult cognitive task. No significant differences were found in vGRF across the 3 conditions.

**Conclusions:** The dual-task conditions affected jump-landing mechanics as measured by the tuck-jump score. Although there was a mean decrease in vGRF, no significant differences were found across the 3 conditions.

**Key Words:** dual task, jump landing, musculoskeletal injuries, tuck jump

**Word Count:** 298

**Key Points**

- Tuck-jump score is sensitive to detecting changing in jump-landing biomechanics when paired with a cognitive dual task.

- There was no significant difference in peak vertical ground reaction force across the 3 dual-task conditions.
Sports such as football, basketball, and soccer have a high incidence of athletic injuries, with the highest portion to the lower extremity.\textsuperscript{1–3} Ankle sprains, muscle strains, and ligamentous damage to the knee are all injuries sustained by athletes while participating in sports. In an epidemiological study conducted by Hootman et al,\textsuperscript{3} researchers found that more than 50% of all reported injuries were to the lower extremity for both practices and games, with knee and ankle injuries accounting for the majority of those injuries. Due to the prevalence of injury in sport, the need for injury prevention programs continues to grow.

Injury prevention is an essential part of the services athletic trainers and other healthcare providers can deliver to their patients. Strengthening muscles, improving balance and coordination, and increasing flexibility are all measurable outcomes that can be achieved by athletes to improve their performance and decrease risk of injury.\textsuperscript{4–6} However, other aspects of injury occurrence such as neurocognitive factors are just beginning to play a role in injury prevention programs. Despite these efforts, preventing injury in athletic populations is not an easy task. There are several other variables, like reaction time and sport-specific distractions, which need to be considered in order to obtain a more accurate understanding of athletic injury.

In order to make better sense of this issue, several researchers have performed studies analyzing landing mechanics in order to determine predisposing factors to lower extremity injury, such as anterior cruciate ligament (ACL) injury.\textsuperscript{7–9} Typically, these studies are performed in a controlled laboratory setting with little distraction affecting landing mechanics. However, athletes often have to multitask and divide their attention
while participating in their respective sport, such as throwing or catching a ball while landing. Recent evidence has emerged to support an association between brain function measured by a computerized neurocognitive test, like the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), and knee injury risk. Also, although neurocognitive changes have customarily been linked to concussions, deficits in cortically driven reaction time, processing speed, and visual and verbal memory may also indicate weakened ability for neuromuscular control. Effectively, it may be possible to screen athletes by assessing their ability to perform sport-specific activities while also sustaining a cognitive load, a concept referred to as dual-tasking.

Due to this association, it is pertinent to study the potential relationship of dual-tasking during a jump-landing technique, such as a double-leg or single-leg jump, on the risk of injury, specifically in the lower extremity. Measuring any changes in kinetic and kinematic data during landing would progress the understanding of sport-specific injury. Therefore, the purpose of this study was to evaluate jump-landing mechanics, as assessed by the tuck-jump scoring system, and peak vertical ground reaction force (vGRF) across three dual-task conditions: baseline (no cognitive task), easy cognitive task, and difficult cognitive task. This information may help to identify individuals at increased risk of injury by assessing high-risk movement patterns under a cognitive load.
METHODS

Participants

Twenty participants were recruited to participate in this study. The sample was taken from the Ohio University community. After the initial screening and enrollment, participants read and signed an informed consent before data collection. Subjects who completed the study were provided with $20 in compensation for their time. The study was approved by Ohio University’s institutional review board. This was a within-subjects repeated measures study. Each participant acted as its own control and received both the easy and difficult cognitive dual task while completing the tuck jump. Table 1, illustrated below, gives the demographic information regarding the participant group.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Males (N = 10)</th>
<th>Females (N = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>1.79 ± .03</td>
<td>1.64 ± .01</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>80.88 ± 5.42</td>
<td>63.78 ± 3.03</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>22.4 ± .42</td>
<td>22.4 ± .42</td>
</tr>
</tbody>
</table>

*Data are reported as mean ± SD.

**Inclusion and exclusion criteria.** To be considered eligible for this study, participants had to meet the following criteria:

1. Male or female between the ages of 18 and 30 years.

2. Healthy and active individuals who participated in exercise at least 3 hours per week and had experience in sport or training activity that requires jumping.

3. Not experiencing symptoms from a lower extremity or back injury within the 3 months prior to participation.
4. No previous history of ACL reconstruction or lower extremity surgery.

5. No previous history of neurocognitive disorder, concussion within last year, or psychological distress.

Procedures

Participants reported to the Biomechanics Laboratory in the Life Science Research Facility for the testing session. Before enrolling in the study, participants were asked to complete a survey to determine eligibility. Participants who responded “yes” in the survey to having a cardiovascular, neuromuscular, musculoskeletal, or a general medical condition were disqualified from the study. In addition, participants not engaging in sufficient physical exercise (3 hours per week) and with little-to-no experience jumping in sport, training, or exercise were also disqualified. A within-subjects repeated measures study in a controlled laboratory setting was conducted to assess jump-landing biomechanics using the tuck jump in all three of these conditions on each participant within the same testing session: baseline (ie, control) task, easy cognitive task, and difficult cognitive task. Cognitive conditions were randomized using a random number generator. Each participant completed 3 trials of the tuck jump per condition while jumping on the force platform.

Tuck Jump. The jump-landing task utilized in this study was the tuck jump. To perform the tuck jump, participants started in an athletic position, with feet shoulder-width apart standing on the force platforms. The jump was initiated with a slight crouch downward while extending their arms behind them. They then swung their arms forward as they simultaneously jumped straight up and pulled their knees up as high as possible.
At the highest point of the jump, participants were in the air with thighs parallel to the ground. After landing, participants immediately began the next tuck jump. This process was carried out for 10 seconds for each trial. There were 3 trials for each dual task (control, easy, difficult). Two minutes of rest were given between trials to account for fatigue. Prior to participation, the participants were given 3 test trials of 10 seconds each with 2 minutes of rest in between trials to become accustomed to the jump-landing task. Participants were disqualified from the study if they felt uncomfortable with the task, were exhausted extensively despite long rest periods, or were unable to complete the task for the full 10 seconds. No participants were disqualified from the study based on these criteria.

**Dual Task.** The dual task utilized in this study consisted of both an easy cognitive dual task and a difficult cognitive dual task. The easy cognitive task consisted of digit recall of a string of 5 numbers and the difficult cognitive task consisted of arithmetic of a string of 5 numbers. Both strings of numbers appeared on a screen for the duration of the tuck-jump trial at a rate of 1 digit per 2 seconds, with 5 digits in the sequence for a total of 10 seconds. The string of random numbers changed for each trial and each level of dual task and the order in which the participant completed each condition was randomized via a random number generator.

Determining the ideal interstimulus interval for motor-cognitive dual-tasking can be challenging. The decision is based on population (young vs old), pathology (stroke), and specific motor and or cognitive task. The interstimulus interval used in the aforementioned study was 2 seconds. Broglio et al. found that the interstimulus interval
can affect the human capability to react under dual-task conditions. If the stimulus was faster than 1 to 1.5 seconds, then the increase in errors was drastic. This increase can make a task nearly impossible for even many healthy individuals. Therefore, 2 seconds is the typical interstimulus interval where a majority of healthy individuals are capable of completing the task with a moderate challenge.

Participants were asked to memorize and repeat the string of numbers for the easy cognitive task at the end of the trial. For the difficult cognitive task, participants were asked to mentally add a string of numbers during the duration of the tuck jump and then to report the sum of all numbers at the end of the trial. Prior to data collection on the testing day, the participants were familiarized with both levels of the cognitive task without the tuck jump. The numbers utilized in the practice trials were not the same as the numbers used in the actual experiment.

**Tuck-Jump Analysis.** Two cameras were utilized to video record the participants during their tuck-jump trials. The cameras recorded the participant in both the frontal and sagittal plane. Analysis of the tuck-jump performance was based on the criteria established by Myer et al. Video analysis was typically slowed to half-time to accurately score the trial. The scoring was denoted by either 0 (not present) or 1 (present). Scores could range from 0-9 and any occurrence of the variables in at least one jump over the span of the 10-second trial was considered to be present. Figure 1 illustrates 3 of the 9 different items analyzed during the tuck-jump assessment.
Figure 1. Tuck jump. Tuck jump (left) illustrates valgus, or a “knock-kneed” position at landing. Tuck jump (middle) illustrates thighs are not equal side-to-side during flight. Tuck jump (right) illustrates correct position for thighs parallel at peak of jump. Photographs by the author.

Data Acquisition

Demographic data including age, sex, height, weight, and activity level were all collected within the screening survey. The total score of the tuck jump was calculated from criteria listed in the scoring sheet and ranges from 0-9. A trained evaluator watched each trial in order to calculate an overall score based on a standardized set of scoring criteria. The tuck-jump assessment includes lower extremity valgus at landing; if the thighs did not reach parallel or they were not equal side-to-side; if foot placement was not shoulder width apart; if foot placement was not parallel (front to back); and, if foot contact timing was not equal. Other items included in the assessment were any pause between jumps, excessive landing contact noise, technique declined prior to 10 seconds, and if the participant did not land in the same foot print (excessive in-flight motion). In
addition to the biomechanical factors analyzed, whether there was a cognitive task error (ie, if the participant correctly recalled or added the string of digits) was also included in the tuck-jump score, therefore making the score range from 0-9 for the control task and 0-10 for the easy and difficult conditions. Cognitive error was included in overall tuck-jump score to illustrate the combined kinematic and neurocognitive changes over the 3 dual-task conditions.

Ground reaction forces were obtained using a Bertec 600 x 1200 mm force platform (Bertec Inc, Columbus, Ohio). Data taken from the force platform included peak vertical ground reaction forces (vGRF). Peak GRF was calculated by using the jump with the highest vGRF within the trial, which was then averaged across the 3 trials for each condition. All trials were kept regardless of whether the participant had jumps that didn’t land directly on the force platform. Participants were encouraged to try to stay on the force platform and if they found themselves jumping off during the trial, they were instructed to jump back to the center of the plate.

Statistical Analysis

Descriptive statistics were calculated for all dependent variables. Separate repeated measures ANOVA were conducted for each dependent variable. Each repeated measures ANOVA has one within-subjects factor time (control, easy cognitive, and difficult cognitive). Alpha level was set at $P < 0.05$ for all analyses.

RESULTS

Two one-way repeated measures ANOVAs were conducted to determine whether there were statistically significant differences in Peak GRF and overall tuck-jump score
throughout 3 different cognitive conditions (baseline, easy, difficult). There were no outliers and the data were normally distributed as assessed by boxplot and Shapiro-Wilk test ($P > .05$), respectively. The assumption of sphericity was not violated for either dependent variable, as assessed by Mauchly’s test of sphericity, vGRF ($\chi^2_{(2)} = 1.315, P = .518$), and tuck-jump score ($\chi^2_{(2)} = .751, P = .687$). The cognitive dual task elicited statistically significant changes in overall tuck-jump score across the conditions, $F_{(2,38)} = 26.484, P < 0.001$, partial $\omega^2 = 0.46$, with tuck-jump score increasing from $3.52 \pm 1.64$ baseline to $4.37 \pm 1.25$ with the easy cognitive task to $4.67 \pm 1.24$ with the difficult cognitive task. Post hoc analysis with a Bonferroni adjustment revealed that tuck-jump score was statistically significantly increased from baseline to easy cognitive task (.85 (95% CI, .461 to 1.239) $P < .0005$), and from baseline to difficult cognitive task (1.15 (95% CI, .686 to 1.614) $P < .0005$), but not from easy cognitive task to difficult cognitive task (.3 (95% CI, -.135 to .735) $P = .258$).

The cognitive dual task elicited no statistically significant changes in vGRF over the conditions, $F_{(2,38)} = 1.163, P = .323$, partial $\omega^2 = 0.005$, with vGRF decreasing from $5.97 \pm 1.17$ baseline to $5.88 \pm 1.12$ with the easy cognitive task to $5.798 \pm 1.15$ with the difficult cognitive task.
Figure 2. Peak vGRF over dual-task conditions for each participant. Values are normalized to body weight.

**DISCUSSION**

To the best of our knowledge, this is the first study to explore the relationship between the tuck jump and a cognitive dual task. The findings of differences between baseline tuck-jump score and easy cognitive task, and baseline tuck-jump score and difficult cognitive task confirmed the study hypothesis. No significant differences were observed in vGRF.

**Tuck-Jump Performance**

On average, the dual-task conditions elicited higher tuck-jump scores. This increase across conditions may indicate weakened neuromuscular control and high-risk movement patterns, which are associated with an increased risk of lower extremity injury.
Previous studies have also demonstrated similar findings, supporting that there may be an increased risk of injury after experiencing altered neurocognitive states.\textsuperscript{10,14–16}

In a study performed by Swanik et al,\textsuperscript{10} researchers found that neurocognitive differences may be associated with the loss of neuromuscular control and coordination errors, thus predisposing certain athletes to noncontact ACL injuries. Athletes who suffered noncontact ACL injuries had significantly slower reaction times and processing speeds, as well as lower visual and verbal memory scores.\textsuperscript{10} Also, athletes with lower visual attention abilities may have more trouble interpreting conflicting information when confronted with unexpected events.\textsuperscript{10}

Additionally, in a study performed by Krosshaug et al,\textsuperscript{17} which examined the mechanisms of ACL injury in basketball, it was found that players who sustained an injury were typically within 1 m of another player and other distracting factors. These factors included players’ focus of attention such as the basket rim, opponent, and ball. Due to this association between decreased neurocognitive ability and loss of neuromuscular control, we can conclude that the increase in tuck-jump scores within the cognitive dual-task conditions may have affected participants’ visual attention, increasing biomechanical errors.

No significant increase in easy cognitive tuck-jump scores to difficult cognitive tuck-jump scores was demonstrated. This may be due to individuals’ adaptation to the cognitive dual task. It may be possible that some participants responded to the “easy” cognitive task with as much difficulty as the “difficult” cognitive task and vice versa.
Essentially, participants’ individual perception of difficulty could have contributed to differences between easy cognitive and difficult cognitive.

**Peak Vertical Ground Reaction Force**

Although there were no significant differences in mean vGRF, a slight decrease was displayed over the conditions, with the highest vGRF sometimes being displayed in the baseline task (see Figure 2). It was hypothesized that this may be due to participant jump height and subsequent landing. It may be possible that the easy and difficult cognitive tasks may have been distracting enough to decrease jump height. This is supported by the limited capacity theory, which simply states that if two tasks are performed together they both compete for attention, which may affect the performance of one or both.\(^\text{18}\) Additionally, in some cases, the opposite also seems to be true, with the largest vGRF being displayed in the difficult cognitive task condition.

Herman et al conducted a study in which participants were screened using the Concussion Resolution Index (CRI), a neurocognitive test that provides information regarding simple reaction time, complex reaction time, and processing speed.\(^\text{16}\) Participants were then grouped into high performers (HP) and low performers (LP) based upon their CRI scores and asked to perform an unanticipated jump-landing task. It was found that the LP group demonstrated significantly altered neuromuscular performance in both kinetic and kinematic measures, as compared to the HP group during the landing phase while completing the landing task, which included a higher vGRF.

Our study did not screen participants based upon neurocognitive test scores, so it is unknown whether this had any effect on vGRF values. However, it may be possible
that potential HP did not see significant changes in vGRF across conditions due to their ability to adapt to both cognitive and neuromuscular demands. Additionally, the opposite may be true for potential LP.

**Clinical Implications**

The tuck-jump exercise may be useful for the identification of lower extremity technical flaws during plyometric activity.\textsuperscript{19} This activity requires a high level of effort from participants, which makes it an excellent tool to identify potential biomechanical flaws. Additionally, the tuck jump may be used to assess improvement in lower extremity biomechanics as users progress through training programs. Due to its usefulness in identifying potential deficits both present and over time, the findings of this study may be useful to screen for individuals at risk of lower extremity injury utilizing the tuck jump when paired with a cognitive task, such as the two used in this study.

The screening would then identify those individuals who may have poor neuromuscular control when cognitively loaded. This identification would then allow the individual to participate in some type of dual-task training to address the deficit. This preventative training may be beneficial for improving neuromuscular control, subsequently decreasing the risk of injury. Implementation of a preventative program may help to address current concerns regarding injury prevention programs in that it more thoroughly addresses the neurocognitive component to injury and not just biomechanical deficits and muscle imbalances.
Limitations

This study was not without limitations. Due to the binary scoring system used for the tuck jump, participants with a high baseline tuck-jump score may not have seen a difference in their score during the dual-task application. The scoring does not allow for variation within biomechanical errors. However, one can argue that a high baseline tuck-jump score puts participants at increased risk of lower extremity injury without dual-task application and would likely display the same or even more exaggerated biomechanical errors when cognitively loaded.

Additionally, the nature of the tuck jump, when paired with the cognitive task, sometimes caused some participants to jump off the force plate, decreasing or losing any kinetic data being collected. The participants were always encouraged to try to stay on the force plate when jumping.

Future Research

Future research is needed to determine the exact difficulty of a dual task and how each individual perceives the difficulty and adapts to it; how adding a neurocognitive screening tool would affect the study in its current state; and, how to best develop and incorporate a dual-task training method for individuals with decreased ability to dual task.

CONCLUSION

When paired with a cognitive dual task, the tuck jump is sensitive in detecting kinematic changes. There was a significant increase in tuck-jump score from baseline to easy cognitive task and baseline to difficult cognitive task, but no significant increase
from easy to difficult. No significant differences in vGRF were detected. These results may serve to provide healthcare providers with a useful tool for screening those at increased risk of lower extremity injury, specifically when cognitively loaded.

REFERENCES


Chapter 4: Conclusion

Our study provides support that, when paired with a cognitive dual task, the tuck jump is sensitive in detecting kinematic changes between dual-task conditions. There was a significant increase in tuck-jump score from baseline to easy cognitive task and baseline to difficult cognitive task, but no significant increase from easy to difficult. No significant differences in vGRF were detected. These results may serve to provide healthcare providers with a useful tool for screening those at increased risk of lower extremity injury, specifically when cognitively loaded.

Future research is needed to determine the exact difficulty of a dual task and how each individual perceives the difficulty and adapts to it. Also, it would be worth determining how the incorporation of a neurocognitive screening tool would affect the study in its current state and how to best develop and integrate a dual-task training method for individuals with decreased ability to dual task.
References


Appendix A: Specific Aims

Strengthening muscles, improving balance and coordination, and increasing flexibility all improve athletic performance and decrease their risk of injury.5–7 A key anterior cruciate ligament (ACL) injury risk target is landing kinematics.8–10 Typically injury risk classification is performed in a controlled laboratory setting with little cognitive demand or distraction. However, athletes often have to maintain movement control under cognitive loads, such as throwing or catching or keeping track of player positions or game strategy, though this dual-task aspect of sport has not been assessed in the laboratory.

These key cognitive aspects of motor control, like reaction time and sport-specific distractions, need to be considered in order to obtain a more accurate understanding of athletic injury. Recently there has been evidence to support an association between brain function measured by a computerized neurocognitive test, like the ImPACT battery, and knee injury risk.12 Also, although neurocognitive changes have customarily been linked to concussions, deficits in cortically driven reaction time, processing speed, and visual and verbal memory may also indicate weakened ability for neuromuscular control.8 Effectively, it may be possible to screen athletes by assessing their ability to perform sport-specific activities while also sustaining a cognitive load, a concept referred to as dual-tasking.

Due to this association, it is pertinent to further study the potential relationship of dual-tasking during a jump-landing technique on the risk of injury, specifically in the lower extremity, while measuring any changes in kinetics and kinematics. This can be accomplished by measuring lower extremity biomechanical data gathered from using three-dimensional (3-D) motion analysis, the Landing Error Scoring System (LESS), which is a useful and economical clinical tool to determine those at increased risk for ACL injury,13 or the tuck-jump assessment.14 In light of current evidence, the purpose of this study is to determine the effects of a cognitive dual task on jump-landing mechanics as determined by the tuck jump.

The goal of this research is to further determine the relationship between dual-tasking and risk of injury by establishing a means that can identify at-risk populations in order to prevent injury. This will be accomplished by examining any shifts in comprehensive landing mechanics during a tuck-jump task while simultaneously performing a cognitive dual task. It is hypothesized that participants completing a tuck-jump task while simultaneously performing a difficult cognitive dual task will display differences in landing mechanics as compared to an easy or lack of cognitive task. Since athletes often have to execute spur of the moment decisions during the flight phase of their jump, potentially hindering their reaction time and altering landing mechanics, it is important to try and simulate this mechanism to determine if there is a relationship between cognitive load and jump-landing mechanics. To test the hypothesis, approximately 20 participants will perform a tuck-jump task while completing three conditions: a control (baseline) task, an easy cognitive task, and a difficult cognitive task. Landing mechanics will be measured using the tuck-jump assessment and peak vertical
ground reaction force will be collected using a force plate. In order to achieve these outcomes, I propose the following specific aims:

**Aim 1: To measure changes in comprehensive landing mechanics during the dual task.** This aim will be accomplished by utilizing the tuck-jump assessment, Norxion Inertial Measurement Units (IMU) systems, and force platforms.

1.1 Kinetic data will be measured using a force platform.
1.2 Kinematic data will be measured using the IMU systems.
1.3 The tuck-jump assessment is a biomechanical tool that encompasses a multitude of biomechanics measures to determine landing mechanics. These items include lower extremity valgus at landing, thighs do not reach parallel at peak of jump, thighs are not equal side to side during flight, foot placement not shoulder width apart during landing, foot placement not parallel (front to back) during landing, and foot contact timing not equal. Excessive landing contact noise, pauses between jumps, technique declines prior to 10 seconds, and excessive in-flight motion.
## Appendix B: Data Procedures Checklist

<table>
<thead>
<tr>
<th>BIOMECHANICS LAB SESSION</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consent Form and Equipment Set Up</td>
<td>7 min</td>
</tr>
<tr>
<td>Tuck Jump Practice Trials</td>
<td>8 min.</td>
</tr>
<tr>
<td>• Three Trials 10 sec. each</td>
<td></td>
</tr>
<tr>
<td>• 2 minute rest between trials</td>
<td></td>
</tr>
<tr>
<td>Dual-Task Familiarization</td>
<td>3 min.</td>
</tr>
<tr>
<td>• Easy Task: string of numbers→three trials</td>
<td></td>
</tr>
<tr>
<td>• Difficult Task: arithmetic→three trials</td>
<td></td>
</tr>
<tr>
<td>Randomization of Dual-Tasks</td>
<td>2 min.</td>
</tr>
<tr>
<td>Session 1</td>
<td>8 min.</td>
</tr>
<tr>
<td>Control: Tuck Jump + No Dual-Task</td>
<td></td>
</tr>
<tr>
<td>• Three Trials-10 sec. each</td>
<td></td>
</tr>
<tr>
<td>• 2 minute rest between trials</td>
<td></td>
</tr>
<tr>
<td>Session 2</td>
<td>8 min.</td>
</tr>
<tr>
<td>Tuck Jump + Easy Cognitive Task</td>
<td></td>
</tr>
<tr>
<td>• Three Trials-10 sec. each</td>
<td></td>
</tr>
<tr>
<td>• 2 minute rest between trials</td>
<td></td>
</tr>
<tr>
<td>Session 3</td>
<td>8 min.</td>
</tr>
<tr>
<td>Tuck Jump + Difficult Cognitive Task</td>
<td></td>
</tr>
<tr>
<td>• Three trials-10 sec. each</td>
<td></td>
</tr>
<tr>
<td>• 2 minute rest between trials</td>
<td></td>
</tr>
</tbody>
</table>

Total Time: 45 min
## Appendix C: Data Collection and Surveys

<table>
<thead>
<tr>
<th>Tuck Jump Assessment</th>
<th>Baseline (no cognitive task)</th>
<th>Easy Cognitive Task</th>
<th>Difficult Cognitive Task</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Thighs do not reach parallel (peak of jump)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Thighs not equal side-to-side (during flight)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foot placement not parallel (front to back)</td>
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<td></td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pause between jumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Does not land in same footprint (excessive inflight motion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive Task Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Default Question Block

Thank you for your interest in our research study!

This study investigates the effects of a cognitive dual-task on jump landing mechanics in healthy, active individuals.

You are not agreeing or consenting to to be enrolled in the study at this time, this survey is just to determine eligibility.

If you are selected to participate in this study you will come into the Biomechanics Laboratory in Grover Center on the Ohio University Campus for testing. During this testing you will be video recorded so that your movement can be analyzed. Movement to be performed includes a series of repeated jumps. This testing will take approximately 50 minutes.

Risks or discomforts that you might experience are fatigue from jumping, however you will be given adequate recovery time.

This study is important to science because the potential results may lead to a preventative rehabilitation program that directly targets the ability to dual task in order to improve neuromuscular control. The improvement in neuromuscular control would not only lower potential healthcare costs related to injury for the patient, but also improve the overall injury rate.

You may not benefit, personally by participating in this study.
Your study information will be kept confidential by having all data stored in a secured and locked file within the faculty advisor’s laboratory. The laboratory will be locked at all times with restricted access.

Filling out this survey is voluntary, you may quit this survey any time by exiting your browser.

If you have any questions, please e-mail myself at as688714@ohio.edu.

If you feel that this is something you would like to take part in, then please proceed with the rest of the survey. By continuing, you are agreeing that:

- you will complete the survey honestly and to the best of your knowledge
- you are interested in potentially taking part in the above mentioned study and/or wish to learn more about it

Yes, I would like to continue
No, I would not like to continue

How tall are you?

Feet

Inches

How much do you weigh? (lbs)

Are you Male or Female?

Male

Female

How old are you?
Have you had any of the following **General Medical** conditions either currently or in the past? Please check all of the following that apply:

- Allergies
- Cancer
- Cognitive (memory) deficit
- Currently pregnant or nursing
- Diabetes
- Bio-medical device (Implants, Pacemaker, etc.)
- Scoliosis
- Uncorrected visual impairment
- Other

Have you had any of the following **Cardiovascular** conditions either currently or in the past? Please check all of the following that apply:

- Stroke
- High Blood Pressure
- Heart Attack
- Sickle Cell Trait
- Heart Murmur
- Heart Disease
- Cardiac Arrhythmia (Irregular Heart Beat)
- Other

Have you had any of the following **Neurological** conditions either currently or in the past? Please check all of the following that apply:

- Epilepsy/Seizures
- Diabetic Neuropathy
Concussion OR Traumatic Brain Injury
Cerebral Palsy
Balance Disorder
Vertigo
Multiple Sclerosis
Other

Have you ever had a surgery or a severe injury to your lower extremity? (ligament, tendon, bone, cartilage)
Yes
No

If you have answered OTHER to any of the above questions, or wish to explain any of your answers to the above questions, please feel free to explain below:

If you answered YES to having had surgery or a severe injury to your lower extremity please explain below:

What is your primary physical activity and how many hours a week do you do it?

Please mark your answer for each item that best describes your activity
<table>
<thead>
<tr>
<th>Activity</th>
<th>Less than one time in a month</th>
<th>One time in a month</th>
<th>One time in a week</th>
<th>2 or 3 times in a week</th>
<th>4 or more times in a week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running: running while playing a sport or jogging</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Cutting: changing directions while running</td>
<td>○</td>
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<td>○</td>
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<td>○</td>
</tr>
<tr>
<td>Decelerating: coming to a quick stop while running</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Pivoting: turning your body with your foot planted while playing a sport; For example: skiing, skating, kicking, throwing, hitting a ball (golf, tennis, squash), etc.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please select your current activity level

Level 10: Competitive sports- soccer, football, rugby (national elite)

Level 9: Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball

Level 8: Competitive sports- racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing

Level 7: Competitive sports- tennis, running (competitive), motorcars speedway, handball

Level 7: Recreational sports- soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running

Level 6: Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times a week

Level 5: Work- heavy labor (construction, etc.)

Level 5: Competitive sports- cycling, cross-country skiing

Level 5: Recreational sports- jogging on uneven ground at least twice weekly

Level 4: Work- moderately heavy labor (truck driving, etc.)

Level 3: Work- light labor (nursing, etc)

Level 2: Work- light labor; walking on uneven ground possible but impossible to backpack or hike
Level 1: Work- sedentary (secretarial, etc.)
Level 0: Sick leave or disability pension because of knee problems

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Appendix D: Instrument Reliability

In a study carried out by Herrington et al, the researchers sought to establish the intra and intertester reliability of the tuck jump. They found the intra-tester reliability to be $k=0.81$, which is very good/excellent. The intertester reliability was found to be $k=0.86$, which is also very good/excellent. Researchers concluded that the tuck jump shows very good—excellent intra and intertester reliability when the test is analyzed from video.
Appendix E: Power Analysis

A power analysis was conducted with an effect size of \(\eta^2 = 0.4\). Using a 1 group by 3 conditions model where \((1-\beta) = 0.8\) and \(\alpha \leq 0.05\), the number of participants needed was 20.
Appendix F: Pilot Data

The data depicted below in Figure 3 illustrates a pilot of the methods discussed in Chapter 3. No force plate data was collected, but the participant did complete all three conditions (baseline, easy cognitive task, difficult cognitive task) while performing the tuck jump. Video was taken from the frontal and sagittal planes and was reviewed to accurately score the tuck jump over the 10 second testing trial.

Primary findings of this pilot showed no change in overall tuck-jump score from baseline to the easy cognitive task. However, there was an increase in tuck-jump score during the difficult cognitive task. The increase in the overall tuck-jump score illustrates the decrease in jump-landing performance, which was suspected according to the limited capacity theory.11

Conclusions taken from the data indicated that the tuck-jump assessment alone might not be sensitive to changes in landing biomechanics, especially if the participant already has a poor baseline tuck-jump score.
<table>
<thead>
<tr>
<th>Tuck Jump Assessment</th>
<th>Baseline (no cognitive task)</th>
<th>Easy Cognitive Task</th>
<th>Difficult Cognitive Task</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremity valgus at landing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Thighs do not reach parallel (peak of jump)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Thighs not equal side-to-side (during flight)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Foot placement not parallel (front to back)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Foot contact timing not equal</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Excessive landing contact noise</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pause between jumps</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Technique declines prior to 10 seconds</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Does not land in same footprint (excessive in-flight motion)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Pilot data sheet denotes evaluated criteria over 3 conditions for the tuck-jump assessment. Boxes marked with a “1” indicate that the participant did have that deficit, while a “0” indicated no deficit for that criterion.