THE EFFECT OF FATIGUE ON CENTER OF PRESSURE AND IMPULSE DURING A SINGLE LEG BOUND

A THESIS
Submitted to the Faculty of the School of Graduate Studies and Research of California University of Pennsylvania in partial fulfillment of the requirements for the degree of Master of Science

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNATURE PAGE</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>METHODS</td>
<td>8</td>
</tr>
<tr>
<td>Research Design</td>
<td>8</td>
</tr>
<tr>
<td>Subjects</td>
<td>9</td>
</tr>
<tr>
<td>Preliminary Research</td>
<td>10</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>10</td>
</tr>
<tr>
<td>Procedures</td>
<td>12</td>
</tr>
<tr>
<td>Hypotheses</td>
<td>15</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>15</td>
</tr>
<tr>
<td>RESULTS</td>
<td>17</td>
</tr>
<tr>
<td>Demographic Data</td>
<td>17</td>
</tr>
<tr>
<td>Hypotheses Testing</td>
<td>18</td>
</tr>
<tr>
<td>Additional Findings</td>
<td>20</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>24</td>
</tr>
<tr>
<td>Discussion of Results</td>
<td>24</td>
</tr>
<tr>
<td>Conclusions</td>
<td>28</td>
</tr>
<tr>
<td>Recommendations</td>
<td>29</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>31</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>35</td>
</tr>
</tbody>
</table>
Borg 15 RPE Scale (C4) ..............................68
Test Score Sheet (C5) ...............................70
Institutional Review Board (C6) .................72
REFERENCES ........................................77
ABSTRACT ..........................................81
LIST OF TABLES

1. Means and Standard Deviations for the average, anterior/posterior, medial/lateral, and 95% ellipse for Center of Pressure .................................................. 19

2. T-test results for the Center of Pressure average, Center of Pressure anterior/posterior, Center of Pressure medial/lateral, as well as, 95% ellipse for Center of Pressure measures before fatigue and after fatigue . . 19

3. Means and Standard Deviations for Peak Impulse . . 20

4. T-test results for the Peak Impulse before fatigue and after fatigue .................................................. 20

5. Means and Standard Deviations of genders and COP measurements when not fatigued and when fatigued. . . 22

6. Results of 2x2 ANOVA examining effects of gender on COP when fatigued and when not fatigued . . . . . . . . 22

7. Results of 2x2 ANOVA examining the between subjects effects on COP when fatigued and when not fatigued . . 22

8. Means and Standard Deviations of genders and Impulse measurements when fatigued and when not fatigued . . 23

9. Results of 2x2 ANOVA examining effects of gender on Impulse when fatigued and when not fatigued. . . . . . . 23

10. Results of 2x2 ANOVA examining the between subjects effects on Impulse when fatigued and when not fatigued.24
INTRODUCTION

Fatigue and its relationship to athletic performance has been studied for many years. When it comes to performance, fatigue is thought of as the inability to perform a specific task to one’s best abilities. Studies have shown that fatigue negatively affects various measures of performance, yet the specific methods by which it affects performance haven’t been fully elucidated. While performing any task involving the legs, fatigue may affect many important factors such as balance, muscular strength, endurance and power.

Fatigue is considered as something that every person experiences at some point in every day. Athletes are especially susceptible to fatigue every time that they perform, whether it is at practice or in a contest. Since they are at a greater risk to fatigue, these athletes must still be able to excel even in a fatigued state. The ability to perform work or sport activities under fatigued conditions is of great importance. Fatigue resistance is important because most injuries tend to occur at the end of
the day or game. The reason may be because the particular athlete has been exposed to the high risk for a longer time, or because fatigue has created a decrease in their performance.

Two important performance measures that can be affected by fatigue include center of pressure and impulse. Center of pressure can be defined as the way force is distributed throughout the foot. When an individual is not fatigued, pressure is typically distributed evenly throughout the entire foot while impulse is defined as the forces generated at the foot as the foot comes into contact with a surface. Impulse affects performance because of the potential for injury it possesses. If the person either over compensates or doesn’t compensate enough for a higher force, they may be at an increased risk for injury.

Fatigue may be placed into different categories. Commonly it is categorized in two separate ways: fatigue caused by peripheral weakness, and fatigue caused by a progressive failure of voluntary neural drive. Peripheral fatigue is more commonly considered as muscular fatigue. Progressive failure of voluntary neural drive is considered to be central fatigue. Central fatigue can be described as more of a psychological aspect of fatigue, in that it may originate from a lack of drive or motivation. This lack of
motivation and psychological aspect is not related to the intentions of the current study. Muscular fatigue has been shown to contribute to delays in muscle activation, and decreased energy stores. Central fatigue has been shown to contribute to changes in balance, changes in stride cadence, and decreases in proprioception although most of the results are inconclusive.

Fatigue has been measured in different ways. It is important that the measurement of fatigue is accurate because the conclusions drawn from the studies are based on these measurements. One of the most common methods to measure fatigue is to identify the point in which they can no longer maximally exert a force. When a person can no longer produce the same force which they produced before, they are considered to be fatigued. This method is also a common way to create fatigue. If a person sustains a particular activity over an extended period of time, their muscles will eventually fatigue. Fatigue may also be measured by use of the Borg 15 point rating of perceived exertion (RPE) scale. The Borg scale has been shown to be valid and reliable and closely related to a person’s maximal oxygen consumption (VO$_2$). Fatigue may be induced via a functional fatigue protocol. The present study will utilize one of these
protocols. This protocol has been used by other research studies and is intended to fatigue muscles of both the upper and lower extremities. The protocol consists of seven stations. The first station consisted of five minutes of moderate jogging, the second and sixth station were straight line sprinting for two minutes, station 3 consisted of two minutes of push-ups, station 4 consisted of two minutes of sit-ups, station 5 was three minutes of 12 inch step-ups.\textsuperscript{15}

Center of foot pressure is also considered as balance measured at the foot. The ability to keep force and weight evenly distributed throughout the foot is essential in the prevention of injuries. At any point in time, if the center of pressure is altered, that said person is at a higher risk for injury. The person is at risk for injury because they are left to compensate for a change in balance. This compensation may result in a momentary lapse of proprioception leading to injury.

The measurements of horizontal center of pressure are usually sampled at 5Hz (cycles per second) during recording periods. The information gathered allows a measurement of the displacement of the center foot pressure (CFP) movements (sway path) and the sway presented in an anterior-posterior and lateral axis.\textsuperscript{9} When data is
presented, lower frequencies tend to represent equal CFP movements. The measurements are measured in millimeters (mm) from the deviations from the center.

Impulse deals with the downward forces generated at the foot. While running, the forces are 3-5 times a person’s body weight. It is important that the body is able to distribute these forces evenly throughout the body, because if the forces are too high in one region the body may become injured.

Impulse is measured by first defining when the measurements will be taken. Initial contact is defined as the time when forces exceed 10 Newtons (N) and toe-off is defined as the point when forces dropped below 10 N. Maximal forces are also calculated during the stance phase and normalized body weight. Data may also be collected also during the impact phase of landing, taking the force measurement 100 milliseconds after initial contact with the platform. It is important that impulse is normalized to one’s body weight because a person who weighs 200 pounds is going to have a different peak impulse than one who is 100 pounds.

There are different ways in which impulse and center of pressure may be measured on the force platform. One way is to record the measurements while a person is static on
the force platform.\textsuperscript{6,7,9-12,16,20-24} Static motion in an athlete or active person is not the preferred measurement. Another way to measure the two values is to have a person drop from a heightened box onto the force platform.\textsuperscript{2,18,19,25,26} The drop jump is used to simulate a jumping activity in an athlete such as a volleyball or basketball player. One final way to measure impulse and center of pressure is to have a person jump on a single leg (usually dominant) onto the force platform.\textsuperscript{27,28} The single leg bound is a functional movement that may potentially provide accurate measurements. When a person hops on one leg, they simulate the way that many injuries occur, such as non-contact anterior cruciate ligament (ACL) injuries occur.\textsuperscript{18} Non-contact ACL injuries occur when rotation occurs from a landing without contact with another person.

Studies have been inconclusive regarding the effects of fatigue on center of pressure and impulse. These two factors are important because they may be related to the number of injuries that occur in athletic contests.\textsuperscript{16,20-24}

The purpose of the present study was to examine how fatigue affects one’s center of pressure and impulse measurements while performing a single leg bound on a force platform. The research questions were as follows: 1) Will the center of pressure increase when a person is fatigued
and 2) Will the impulse measurement increase when a person is fatigued?
METHODS

Research Design

This project was a quasi-experimental, within subjects design. The independent variable was the fatigue condition, whether the person is fatigued or not fatigued. The dependent variables were Center of Pressure and Impulse measurements, as measured by a force platform. Subjects were tested on two days and were randomly assigned to the fatigued condition on day one or day two. The strengths of this study were the use of within-subject design as subjects served as their own control. The test results were limited to generalizing the data to active people and not athletes. The active people may not be able to perform the functional activity of a single leg hop once they become fatigued.
Subjects

This study utilized volunteer college students who indicated they were moderately active. Moderately active was defined as those who indicated they work out at least 3 times per week for at least 30 minutes each session. Subjects were recruited by the researcher via email solicitation of undergraduate and graduate Athletic Training Education Program students. The participants were volunteers in the Athletic Training graduate and undergraduate program who considered themselves to fit the criteria. Subjects that had suffered a lower extremity injury such as a sprain, strain or fracture in the past six months were eliminated from the study as well. Lower extremity injuries ranged from ankle, knee and hip injuries. Also, any subject who had suffered a concussion in the past six months was eliminated as well. With a six month limit, injuries should be completely healed, eliminating any possibility of the injury altering the results. All subjects signed an Informed Consent (Appendix C1) form prior to participation in the study.
Preliminary Research

The purpose of preliminary research was to finalize methods for the study. The preliminary research determined the length of time it took to complete a trial for each independent subject. It was important to determine the length of time it took to complete a trial for the purpose of setting up appointment times for each subject. It also allowed the researcher to become proficient in the use of the force platform and the netforce software used with the force platform.

Instrumentation

A Demographic Sheet (Appendix C2), Functional Fatigue Protocol (Appendix C3), Borg 15 point RPE Scale (Appendix C4), a stop watch, Test Score Sheet (Appendix C5), and a Force Platform (Appendix C6) were used in this study.

Testing Instrument

To measure center of pressure and impulse, the researcher used a force platform for this study. The force platform has been used in many studies to measure both center of pressure and impulse. For this study, impulse
was defined as the peak force (corrected for body weight) generated by the subject when they came in contact with the force platform while performing a single leg bound. Center of pressure changes were measured in centimeters (cm) from the center point of their landing foot.

A functional fatigue protocol was used in this study and can be found in Appendix (C3). This protocol consisted of 7 stations with the first station used for moderate jogging in place for 5 minutes. Stations 2 and 6 were set up for straight line sprinting for two minutes at each station. Station 3 consisted of two minutes of push-ups, station 4 consisted of two minutes of sit-ups and station 5 was 3 minutes of 12 inch step-ups, and station 7 was the time it took the individual to recover walking from the gymnasium to the testing classroom. Station 7 changed from the original protocol to eliminate too much rest for the individual. Walking from the gym to the testing room should have allowed sufficient rest.

The Borg RPE scale (C4) was used following the sixth station of the protocol. It was intended for the subject to rate their perceived exertion. Once the subject reported a number of 13 or higher, they were considered to be fatigued. The Borg RPE scale is the person’s rate of perceived exertion, the subject rates how they feel they
have exerted themselves during their activity. The RPE scale was created in 1970 and has been considered one of the easiest ways to measure perceived exertion. The values range of 6 to 20 and are closely related to variables such as working heart rate, and oxygen consumption, both physiological variables that increase as exercise intensity increases. Generally, the number a person reports is ten times their exercising heart rate for example, if a person reports the number 14 their heart rate is 140.\textsuperscript{29} The values have been shown to correlate closely with maximal percentages of VO\textsubscript{2} consumption and heart rate.

Procedures

This study was approved by the California University of Pennsylvania Institutional Review Board (IRB). The subjects were volunteers from the Athletic Training Education Program. As the participants came in on the day of testing they were informed of the study and given a consent form (Appendix C1) to sign prior to participation. Subjects were also given a demographic data sheet (Appendix C2) to fill out, and the researcher determined their current exercise and injury status. If any subject did not exercise at least 3 days per week for 30 minutes or more,
or had suffered an injury to their lower extremity in the last six months he/she was eliminated from participation. Also any subject who had suffered a concussion in the last six months were eliminated as well. No subject was eliminated because of injury reasons.

Subjects who met all requirements were scheduled for two days of testing. If a subject did not show on the second day they were sent an email and reminded of their participation. If the subject did not respond, they were replaced in the study. No subjects were lost because of failure to return. Once they came in and signed their informed consent, they were instructed to draw a slip of paper from a hat. In the hat was an even number of papers that said either fatigue or not fatigued. There were equal numbers of papers, so the subjects had an equal opportunity to receive either condition. Once the paper was drawn, the subject was instructed about their jump onto the force platform. Each subject was instructed to stand on an “x” mark with both feet placed 2 feet from the force platform. The subject was then asked to hop onto the force platform landing on their dominant foot. They were required to hold the landing for 5 seconds prior to jumping off the force platform. The 5 second landing was used to allow for enough time to record their center of pressure and forces.
Subjects were then instructed to hop from the force platform and land on two feet, onto an “x” placed 2 feet from the force platform. Each subject was allowed to perform 3 trials to familiarize themselves with the test.

Regardless of the condition the subject was under, fatigue/not fatigued; they completed a 5 minute warm-up on a treadmill set at 3.5mph. If a subject was under the fatigued condition, they were administered the fatigue protocol as previously described. Following the sixth station, they were asked to report their fatigue level using the Borg RPE scale. If their number reported was 13 or higher, the subject was considered fatigued. If the subject reported a number lower than 13, the subject was instructed to repeat stations 1 and 2 of the fatigue protocol and then instructed to report their fatigue level again. If the subject was still not fatigued, they were to repeat station 3 and 4 followed by 5 and 6 if still not fatigued.

Immediately following the fatigue protocol, the subject was instructed to stand on the “x” mark in front of the force platform on two feet. The subject was then instructed to hop and land on one foot on the force platform and land on that dominant foot. The landing was then held for 5 seconds for the trial to count. If a
subject touched the force platform with their other foot or fell over, the trial was considered failed and the subject was then instructed to repeat the trial. Once the subject held the landing for 5 seconds, they were instructed to hop from the platform and land on the "x" mark with both feet. The subject was then instructed to repeat the same procedure for trials 2 and 3. Following the third trial, the subject was asked their RPE level again. Also, following the third trial, the subject was instructed on when to return for more testing, or when they were finished with testing. Data from the trials were recorded onto the Test Score Sheet (Appendix C5).

Hypotheses

The following hypotheses were tested in this study:

1) The Center of Pressure (ability to keep force evenly distributed) measure will increase under fatigued conditions compared to non fatigued conditions, indicating a decrease in balance.

2) Impulse (forces) will increase under fatigued conditions compared to non fatigued conditions, indicating a decrease in ability to absorb force.
Data Analysis

Difference scores for both variables were calculated under both the fatigued condition and non-fatigued condition. Peak impulse and center of pressure measurements were averaged for the 3 trials. A matched pair t-test was used to determine the difference between the condition (fatigue/non fatigue) to the dependent variables (center of pressure/impulse). This data analysis was performed by using the SPSS 14.0 statistical software package at an alpha level of $\leq 0.05$. 
RESULTS

The purpose of the study was to examine the effects of fatigue on balance as measured by Center of Pressure (COP) and force dissipation as measured by Impulse on an individual while performing a single leg bound onto a force platform. Subjects were tested twice, once when not fatigued and once immediately following a functional fatigue protocol. Both balance and force scores were measured by using data collected by the Net Force software associated with the force platform. The following section contains the data collected throughout the study.

Demographic Data

There were 15 subjects who were a part of the study. Of the 15, 9 were males and 6 were female. All subjects indicated they participated in physical activity for at least 3 days per week for at least 30 minutes each session, and all subjects stated they had not sustained a musculoskeletal injury or concussion in the past 6 months.
The subjects had a mean weight of 1254.9 (128.1kg) ± 227.1 (23.2kg) Newtons and a mean age of 22.1 ± 1.6 years.

Hypothesis Testing

Hypothesis testing was performed utilizing the data collected from the 15 subjects who met the specified criteria. All of the hypotheses were tested at the \( P \leq .05 \) alpha level.

Hypothesis 1: The Center of Pressure (ability to keep force evenly distributed) measure will increase under fatigued conditions compared to non-fatigued conditions, indicating a decrease in balance.

The data for average COP before fatigue/post fatigue were found by using a matched pair t-test. Mean COP scores under different test conditions are found in Table 1. The results for the matched pair t-test are found in Table 2 and showed a significant difference in Center of Pressure when comparing conditions (\( t(14) = -7.508, P < .001 \)).
Table 1. Means and Standard Deviations for the average, anterior/posterior, medial/lateral, and 95% ellipse for Center of Pressure

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP avg NF</td>
<td>2.160</td>
<td>.511</td>
<td>15</td>
<td>.132</td>
</tr>
<tr>
<td>COP avg F</td>
<td>2.946</td>
<td>.538</td>
<td>15</td>
<td>.139</td>
</tr>
<tr>
<td>COP a/p NF</td>
<td>1.452</td>
<td>.774</td>
<td>15</td>
<td>.200</td>
</tr>
<tr>
<td>COP a/p F</td>
<td>2.100</td>
<td>.778</td>
<td>15</td>
<td>.201</td>
</tr>
<tr>
<td>COP m/l NF</td>
<td>.981</td>
<td>.316</td>
<td>15</td>
<td>.082</td>
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<tr>
<td>COP m/l F</td>
<td>1.411</td>
<td>.630</td>
<td>15</td>
<td>.163</td>
</tr>
<tr>
<td>Ellipse NF</td>
<td>66.624</td>
<td>21.604</td>
<td>15</td>
<td>5.578</td>
</tr>
<tr>
<td>Ellipse F</td>
<td>92.259</td>
<td>26.948</td>
<td>15</td>
<td>6.958</td>
</tr>
</tbody>
</table>

Note: NF = Not Fatigued, F = Fatigued

Table 2. T-test results for the Center of Pressure average, Center of Pressure anterior/posterior, Center of Pressure medial/lateral, as well as, 95% ellipse for Center of Pressure measures before fatigue and after fatigue

<table>
<thead>
<tr>
<th></th>
<th>95%</th>
<th>95%</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COP avg NF</td>
<td>-1.010</td>
<td>-.561</td>
<td>-7.508</td>
<td>14</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>COP avg F</td>
<td>-.935</td>
<td>-.362</td>
<td>-4.852</td>
<td>14</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>COP a/p NF</td>
<td>-.715</td>
<td>-.144</td>
<td>-3.225</td>
<td>14</td>
<td>.006</td>
</tr>
<tr>
<td>COP a/p F</td>
<td>-33.775</td>
<td>-17.496</td>
<td>-6.755</td>
<td>14</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Note: COP = Centimeters

Hypothesis 2: Impulse (force) will increase under fatigued conditions compared to non-fatigued conditions, indicating a decrease in ability to absorb force.

The data for peak Impulse before fatigue/post fatigue were found by using a matched pair t-test. Peak impulse scores under different test conditions are found in Table
3. The results for the matched pair t-test are found in Table 4 and showed a significant difference in peak impulse when comparing conditions \( t(14) = -2.605, P = .021 \).

**Table 3. Means and Standard Deviations for Peak Impulse**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulse NF</td>
<td>2868.090</td>
<td>15</td>
<td>1269.016</td>
<td>327.658</td>
</tr>
<tr>
<td>Impulse F</td>
<td>3539.921</td>
<td>15</td>
<td>977.072</td>
<td>252.279</td>
</tr>
</tbody>
</table>

Note: Impulse = Newtons

**Table 4. T-test results for the Peak Impulse before fatigue and after fatigue**

<table>
<thead>
<tr>
<th></th>
<th>95% Confidence Lower</th>
<th>95% Confidence Upper</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impulse NF</td>
<td>-1225.023</td>
<td>-118.638</td>
<td>-2.605</td>
<td>14</td>
<td>.021</td>
</tr>
<tr>
<td>Impulse F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional Findings

Further tests were conducted to determine if there were relationships between COP in an anterior/posterior and medial/lateral direction and fatigue condition. Also, further tests were conducted to determine relationships on the 95% ellipse and fatigue condition. The 95% ellipse is defined as the area where 95% of the person’s pressure dots fall within upon contact with the force platform.
The data for COP anterior/posterior, medial/lateral, and 95% ellipse before fatigue/post fatigue were found by using a matched pair t-test. Mean COP scores under different test conditions are found in Table 1. The results for the matched pair t-test are found in Table 2 and showed a significant difference in COP anterior/posterior when comparing conditions (t(14) = -4.852, P < .001), COP medial/lateral when comparing conditions (t(14) = -3.225, P = .006), and 95% ellipse (t(14) = -6.755, P < .001). The significance values indicate that the person’s COP in each direction and 95% ellipse increased when fatigued. The person had a greater difficulty in maintaining balance.

Also, further analysis was conducted to determine if there was an effect of gender on the two dependent variables. The purpose was to examine if males or females had different results under the two fatigue conditions.

Potential differences due to gender were examined by using a 2x2 ANOVA. The results of the 2x2 ANOVA examining the effect of gender and fatigue condition on COP are found in Table 6 and showed no significant difference in COP between genders regardless of condition. However, there was a difference between fatigue and the COP measure, although that was already found. The 2x2 ANOVA for COP
when not fatigued and when fatigued was ($F = 1.156, P = .302$).

**Table 5.** Means and Standard Deviations of genders and COP measurements when not fatigued and when fatigued

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP Male</td>
<td>2.237</td>
<td>.497</td>
<td>9</td>
</tr>
<tr>
<td>COP Female</td>
<td>2.044</td>
<td>.555</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>2.160</td>
<td>.511</td>
<td>15</td>
</tr>
<tr>
<td>COPF Male</td>
<td>2.931</td>
<td>.519</td>
<td>9</td>
</tr>
<tr>
<td>COPF Female</td>
<td>2.967</td>
<td>.617</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>2.946</td>
<td>.538</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 6.** Results of 2x2 ANOVA examining effects of gender on COP when fatigued and when not fatigued

<table>
<thead>
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<td>.094</td>
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<tr>
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<td>13</td>
<td>.081</td>
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**Table 7.** Results of 2x2 ANOVA examining the between subjects effects on COP when fatigued and when not fatigued

<table>
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The examination of the effect of gender and fatigue condition on peak impulse are found in Table 9 and showed no significance when not fatigued or when fatigued.

Differences were found between fatigue and the impulse
measure though, which was previously stated. The 2x2 ANOVA for peak impulse when not fatigued and when fatigued was (F = .120, P = .734).

Table 8. Means and Standard Deviations of genders and Impulse measurements when fatigued and when not fatigued

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
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<tr>
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<tr>
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<tr>
<td>ImpulseF Female</td>
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<tr>
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<td>1269.016</td>
<td>15</td>
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</table>

Table 9. Results of 2x2 ANOVA examining effects of gender on Impulse when fatigued and when not fatigued

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<tr>
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<th>df</th>
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<th>F</th>
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Table 10. Results of 2x2 ANOVA examining the between subjects effects on Impulse when fatigued and when not fatigued

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DISCUSSION

The following section is divided into three subsections: Discussion of Results, Conclusions, and Recommendations.

Discussion of Results

Fatigue and its relationship to athletic performance have been studied for years. It's been found that athletes are especially susceptible to fatigue because most injuries tend to occur at the end of a game or practice.¹ There are many areas in which fatigue may affect an individual, two of them are balance, and force production. When fatigued, it is critical to be able to still succeed, especially at the end of the contest. Therefore, conditioning is critical to prevent injuries.¹,³,⁵,⁸,¹²,¹³ The purpose of this study was to examine the effects on a person’s center of pressure (COP) or balance and impulse or peak force when fatigued. Each subject was tested against themselves when fatigued and when not fatigued because this eliminated the need for control subjects.
It was hypothesized that the person’s COP would increase under the fatigued condition. This means it would be more difficult to maintain balance when fatigued as opposed to not being fatigued. Another hypothesis was that the person’s impulse, or ability to absorb force, would increase under the fatigued condition. Their peak force would increase and therefore they would be more prone for an injury to occur. Measurements in this study were done on a force platform and the data was analyzed using Net Force software associated with it. Statistical analysis revealed significant differences upon the measurements when fatigued.

During the fatigue protocol, it was the researcher’s subjective view that each participant appeared to be moderately fatigued. Some of the subjects reported that balance was more difficult to maintain when jumping onto the platform after fatigue. Once fatigued, a few of the subjects fell off the platform during their jump and had to repeat their jump.

The results found were very similar to those reported by, Augustsson et al\textsuperscript{3}, Gerlach et al\textsuperscript{14}, and Simoneau et al\textsuperscript{20}. These studies all found significant decrements in balance and following fatigue. The study by Augustsson et al,
observed joint angles and discovered decreases in the joint angle of the knee as well\(^3\).

It is important to note that the fatigue protocols in all of these studies were different. But, all had the same result of decreased balance when fatigued. For example, the fatigue protocol in Gerlach et al\(^{14}\), was an exhaustive treadmill run. The client was to run continuously until they could continue no longer. Whereas, the fatigue protocol in Simoneau et al\(^{20}\), used a treadmill at a fast walk for 5 minutes. An interesting fatigue protocol was used by Strang and Berg\(^{24}\), this study used a repetitive deadlift movement, to simulate heavy box lifting. However, this particular study found no differences in the fatigue group, when compared to the control group. These findings do not support the facts that fatigue produces a decrease in balance ability. This could be due to the fact that fatigue was induced to only the low back and not the legs.

A few studies have been done which only looked at impulse and their effects following fatigue. Seegmiller and McCaw\(^4\), Hodgson et al\(^{13}\), and Orishimo\(^{25}\) all looked at the effects on impulse. While Seegmiller and Hodgson looked at impulse, they did not examine the effects once fatigued. Seegmiller examined the effects of an ankle brace on
impulse. The Hodgson study examined the effects of wearing ankle braces to impulse. This study found that no significant increases occurred when wearing a brace compared to not wearing one. In the Orishimo study, they observed the effects of fatigue on impulse. However, this study observed the effects on impulse from a drop landing. The study found that fatigue produced a significant increase in impulse.

Another study that should be pointed out is the one by Cowley et al. This study looked at the ground reaction forces of female basketball and female soccer athletes. The results showed that the female athletes had greater valgus moments in their dominant legs while cutting. It is important to note this because of the mechanism for non-contact ACL injuries. If a female athlete becomes fatigued, they may have an increased susceptibility for injuring their ACL while cutting. The results were similar to the 2x2 ANOVA findings that there was significance in peak impulse between males and females when fatigued.

The results found in the present study matched closely with the above studies but also expanded on the studies as well. The results found indicated a increase in the anterior/posterior axis, medial/lateral axis and an increase in the 95% ellipse. Also the present study
expanded the other studies because an increase in impulse was found indicating the decrease in ability to absorb force.

Conclusions

This study revealed that there is a significant effect on the body’s force production and ability to maintain balance when fatigued. Subjects performed three jumps onto the force platform un-fatigued and following a fatigue protocol. Results showed that there was a significant decrease in COP and peak impulse. With this knowledge, it is important for athletic trainers and coaches to ensure their athletes are properly conditioned and properly rested. When the athlete is conditioned, they will be able to perform at the height of their ability, without affecting force production or balance. Also, if the athlete is rested at the appropriate time, they will be able to excel at the end of the game when they are needed most.
It is important for coaches as well as Certified Athletic Trainers to notice when athletes are fatigued. The recent literature on this topic also support diminished abilities once fatigued; however, there are still aspects that need to be further examined. The literature also indicates an increase in injury risk when fatigued. For example, the number of studies looking at the effects of force production when fatigued is lacking and need to be further addressed to determine its exact effects.

One recommendation for future research would be to look at the effects of impulse when fatigued further. There are only a few studies that have been done showing its effects, but not in great depth. Force production is important to maintain once fatigued because it may mean the difference of winning a contest or not. If similar studies show the same effects, it would provide further support for these ideas.

Another recommendation would be to perform the same experiment on athletes. Although the subjects were moderately active, they did not approach that elite level as athletes. Athletes may already be in a peak condition and properly conditioned, therefore the effects may not be the same. If the results were found to be the same, it
would support the ideas of diminished abilities once fatigued. It would be interesting to perform the same study using both athletes and active individuals, to determine whether or not the effects were the same. With this comparison, it would support to idea of relating this information to both athletes and the active public.

One last recommendation would be to perform the same experiment on just females. With our results, we were able to determine a significant difference in impulse once fatigued, with relation to males and females. It has been proven in numerous studies that females are more susceptible to tearing their ACL than males. One reason could be that the females have a greater loss of ability in maintaining balance and producing force, therefore they are more susceptible. But it could also fall along the lines that females do not land properly and therefore are at a greater risk. If the study was repeated with video monitors, the landing could be monitored to determine if fatigue puts them at a greater risk.
REFERENCES


APPENDIX A

Review of the Literature
Fatigue and its relationship to athletic performance has been studied for many years. Fatigue is the inability to perform a specific task to one’s best abilities. Studies have shown that fatigue negatively affects performance; however, the specific ways in which it affects performance have not been fully studied. While performing any task involving the legs, fatigue may affect many important factors such as balance, muscular strength, endurance and power.

Two important performance measures that can be affected by fatigue include center of pressure and the impulse. Center of pressure can be defined as the way force is distributed throughout the foot. When an individual is not fatigued, pressure is typically distributed evenly throughout the entire foot. Impulse is defined as the forces generated at the foot as the foot comes into contact with a surface. Impulse affects performance because of the potential for injury that may accompany it. If the person either over compensates or doesn’t compensate enough for a higher force, they are at risk for injury. Impulse and its relationship to fatigue and performance have not been studied.
This Review of the Literature will focus on four sections: 1) Fatigue, 2) Center of Pressure, 3) Impulse, and 4) Single Leg Bound. Following the Review of the Literature will be a summary.

Fatigue

Fatigue is considered something that every person experiences at some point every day. Athletes are especially susceptible to fatigue every time they perform, whether it is at practice or in a contest. They are at an increased risk because the athletes are performing high-risk moves they may not be able to perform. Elite athletes may be exposing their body to forces in which the body may not be able to handle. Since they are at a greater risk to fatigue, these athletes must still be able to excel even in a fatigued state. The ability to perform work or sport activities under fatigued conditions is of great importance. Fatigue is important because most injuries tend to occur at the end of the day or game.¹ Fatigue may contribute to injury in that the particular athlete has been exposed to the high risk for a longer time, or because fatigue has created a decrease in their performance.
Muscular Fatigue

One type of fatigue is muscular fatigue. Various aspects of muscular fatigue have been studied including energy supply, muscle coactivation, and mechanisms underlying force reduction in skeletal muscle. Energy is supplied either aerobically (with oxygen) or anaerobically (without oxygen) in skeletal muscle. The anaerobic processes have a higher power but a lower capacity than the aerobic processes. These anaerobic systems are known as the adenosine triphosphate phosphocreatine system (ATPPcr) and fast glycolysis. The ATPPcr system lasts for the first 10-15 seconds of activity, and the fast glycolysis lasts until nearly 3 minutes of sustained activity. ATP is an essential process in the production of energy. The maximal capacity of ATP generation (at a certain exercise intensity) sets the limit of exercise duration.

Muscle co-activation is the initiation of other muscles to assist in the production of a force. The antagonist muscles (those opposite of producing the force) and agonist muscles (those producing the force) work together. Muscle co-activation is pronounced during high-intensity activity. For example, there is a stable ratio between activation of the knee flexors and extensors during isometric contractions, and this ratio is maintained during
a fatiguing task despite the increase in agonist drive.\textsuperscript{3} Fatigue produced by short tetany (muscle spasms), produces a force decline divided into two components: a reduction of the cross-bridges’ ability to generate force (which occurs early) and a reduction of the sarcoplasmic reticulum Ca\textsuperscript{2+} release, (which develops late in fatigue).\textsuperscript{4} One idea contributing to the reduction of cross-bridge formation is attributed to lactic-acid formation. The reduction of sarcoplasmic reticulum Ca\textsuperscript{2+} release in late fatigue correlates with a decline of ATP.\textsuperscript{4} As the exercise continues ATP sources continue to deplete.

Fatigue Categorization

Fatigue can also be categorized into fatigue caused by peripheral weakness, and fatigue caused by a progressive failure of voluntary neural drive.\textsuperscript{6} Peripheral fatigue is more commonly considered as muscular fatigue. While progressive failure of voluntary neural drive is considered to be central fatigue. Central fatigue can be described as more of a psychological aspect of fatigue, in that it may originate from a lack of drive or motivation.\textsuperscript{7} Since the study plans on eliciting muscle fatigue, this lack of motivation and psychological aspect is not related to the intentions of the current study. Muscular fatigue has been
shown to contribute to delays in muscle activation, changes in balance, changes in stride cadence and decreases in proprioception although most of the results are inconclusive.

Fatigue Measurement

Measuring fatigue has been done in different ways. It is important that the measurement of fatigue is accurate because the conclusions drawn from the studies are based on these measurements. One of the most common ways to measure fatigue is to identify the point in which they can no longer maximally exert a force. When a person can no longer produce the same force which they produced before, they are considered to be fatigued. This way is also common in creating fatigue. If a person sustains a particular activity over an extended period of time, their muscles will eventually fatigue.

Center of Pressure

Center of foot pressure is also considered as the balance at the foot. The ability to keep the force and weight evenly distributed throughout the foot is essential in the prevention of injuries. At any point in time, if
the center of pressure is altered, that person is at a higher risk for injury. Persons are at risk for injury because they are left to compensate for a change in balance. This compensation may result in a momentary lapse of proprioception leading to injury.

The measurements of horizontal center of pressure are measured on a force plate composed of a steel plate supported by three monoaxial load cells.\textsuperscript{19} Data is usually sampled at 5Hz during recording periods. The information gathered allows a measurement of the displacement of the center foot pressure (CFP) movements (sway path) and the sway presented in an anterior-posterior and lateral axis.\textsuperscript{13} When data is presented, lower frequencies tend to represent equal CFP movements. Software used with the force platform analyzes a person’s center of balance by measuring the different points with which their foot comes in contact with the platform.\textsuperscript{20} A force platform is also occasionally used in conjunction with a monitor that moves a red cross as their center of pressure changes. This allows a person to have immediate feedback and visual changes necessary to keep the cross in the box (20mmx20mm).\textsuperscript{21} Measurements are then obtained as to how long a person takes to correct their center of pressure.
Another method in which center of pressure is measured, is through special inserts in the shoes which give the same recordings. A shoe insert with four switches is used to determine ground contact times and center of pressure during two experimental runs.\textsuperscript{12}

Center of Pressure Measurement

Studies use time as a form of measurement for their values when determining center of pressure. Data is sampled at 5 Hz during recording periods of 20s; they then measured displacement in anterior-posterior and lateral axis. This procedure eliminates 10% of the extreme points of sway caused by involuntary movements.\textsuperscript{13} Another study had a person stand with their dominant leg on a force platform while measurements were taken for 25s. The researchers then measured postural sway in the medial-lateral and anterior-posterior directions.\textsuperscript{20} Subjects are usually instructed to maintain balance remaining as stable as possible while the measurements are recorded. It is apparent that most of the measurements are recorded over a length of time as a person remains static on the force platform. These measurements are then recorded with a ruler in millimeters (mm) to determine the distance a person has deviated from the center.
Center of Pressure Injuries

Injuries may be predisposed if the center of pressure deters from being equal to excessive medially, laterally, anteriorly, or posteriorly. If the forces required for the correction of an unstable placement of the foot are delayed due to fatigue then the ankle joint is at risk for injury. Studies suggest that if an individual is suffering from central fatigue it may induce the deterioration of cognitive functions. The individual may have a more difficult time in performing a more complex task.

Balance is an issue affected by every movement made. There are many aspects that affect balance such as proprioception, ear problems, outside sources (i.e. medication, alcohol use) and injury. An injury to the head for example, can greatly affect one’s balance. An injury to the head may cause a person to be unable to control their movements in a “normal” fashion. Injuries to the ankle can affect balance as well. The ankle may feel as though it is “giving way” during weight-bearing activity, such as, running, walking, or even standing. When an ankle feels as though it is “giving way” a person’s balance will also be affected. Balance may be affected when a person has suffered an injury to the knee as well. If a person
has suffered an injury to either collateral or cruciate ligament, they may feel as though they are falling forward/backward or left/right. With these sensations, a person’s balance may not be the same as it was previously. When performing a task such as lifting, a person may overcompensate and lose their balance. With this loss of balance, the person may either fall and hurt their low back or attempt to “recheck” their balance and hurt their low back.\(^5\) Loss of balance may be the cause of injuries or it may be because of an injury.

Static center of pressure against dynamic center of pressure is a concept that should often be considered. Static center of pressure is a force distributed while the foot remains unmoved. Many of the studies have been done statically.\(^{13,16,20,21}\) These particular methods allow the development of more conclusive results because an individual is guaranteed adequate contact length time. Contact length time is the amount of time the foot is in contact with a surface. In measuring dynamic center of pressure, it is important to ensure a reliable measurement and long enough contact time with the force platform. Most studies evaluating dynamic center of pressure have been done by identifying stride characteristics.\(^{12,15,17,22}\) These
particular studies are more important for demonstrating functional movements.

Impulse

Impulse deals with the forces generated at the foot. When doing any other activity then walking, the forces are much higher. While running, the forces are 3-5x a person’s body weight.\(^5\) It is important that the body is able to distribute these forces evenly throughout the body, because if the forces are too high the body may become injured.

**Impulse Measurement**

Impulse is measured by first defining when the measurements will be taken. Generally, it is measured at initial contact and toe off from the force plate. Initial contact is defined as the time when forces exceed 10 N and toe-off is defined as the point when forces dropped below 10 N. Maximal forces are also calculated during the stance phase and normalized body weight.\(^2^3\) Data is collected also during the impact phase of landing, taking the impulse measurement 100 milliseconds after initial contact with the platform.\(^2^4\) Peak force output and peak power output is normalized per body weight (normal levels are compared to the weight), the duration of contact on the platform and
time to peak force are also defined as time parameters.\textsuperscript{2} It is important that impulse is normalized to one’s body weight because a person who is 200 pounds is going to have a different peak impulse than one who is 100 pounds. Although forces are generally much higher when doing any other activity than walking, a person’s body weight also plays an important role in the force they produce.\textsuperscript{25}

When a force is greater than the tissues of the body can account for, an injury may occur. These forces are produced any time the foot comes into contact with a surface. Whether a person is making cutting tasks on the soccer field or landing after a jump playing volleyball, they generate high forces from the ankles through the legs.\textsuperscript{23,26} Valgus movements at the knee have been shown to occur during cutting or landing in female athletes. Peak forces, knee valgus moments, and knee valgus angles play an important role in identification of ACL injury risk.\textsuperscript{23} When fatigued, a person may be more susceptible to sustaining a valgus moment, therefore making them more susceptible to injury. The valgus movements must be corrected and as mentioned earlier, fatigue has been shown to decrease neuromuscular control, therefore it is more difficult to correct the valgus movements to the lower extremity.
Impulse Injuries

Injuries are created when the force (impulse) is too great for the body to handle. Injury rates may be influenced by the speed at which an athlete performs a skill, given that most non-contact ACL injuries occur at high velocity.\textsuperscript{27} When a person performs a cut at such a high speed, this impulse generated may be too great and a ligament injury may occur. Neuromuscular training has been performed with athletes in attempts to reduce injury rates. The training was conducted during the preseason and has shown to reduce the rate of non-contact ACL injuries in trained versus untrained female athletes.\textsuperscript{28} The particular neuromuscular training was found to decrease peak impulse during landings. Since impulse and injuries were decreased after this training, it appears that a reduction in injuries may occur because of a reduction of impulse. It is important to study whether forces increase when a person is fatigued since injuries have been found to occur with greater forces.

Single Leg Bound

There are different ways in which impulse and center of pressure may be measured on the force platform. One way
is to record the measurements while a person is static on the force platform.\textsuperscript{10,11,13,16,19-21,29-31} Static means that a person stands on the force platform for a predetermined length of time while measurements are recorded. Static motion doesn’t measure a functional movement of the person being tested. Another way to measure the two values is to have a person drop from a heightened box onto the force platform.\textsuperscript{2,6,23,24,32} The drop jump is used to simulate a jumping activity in an athlete such as a volleyball or basketball player. These measurements are then recorded over a period of time to identify peak force and postural deviations. One final way to measure impulse and center of pressure is to have a person jump on a single leg (usually dominant) onto the force platform.\textsuperscript{33,34} The single leg bound is a functional movement that should provide accurate measurements. When a person hops on one leg, they simulate the way that most non-contact ACL injuries occur.\textsuperscript{23} The injury caused is serious and causes a person to miss an extended length of time.

When performing a single leg bound many biomechanical factors come into play. The musculature at the ankle, knee and hip must be strong enough in order for the person to take off and also must be capable to absorb impact when landing. For example the gluteal muscles at the hip must
be strong enough to control internal rotation at the hip. Single-leg hops are used clinically to assess knee function in patients following knee injury or surgery, as it is thought that single-leg hops represent an activity which places high demands on the ability of the leg musculature to generate substantial knee joint movement and power during the take-off. No studies have been performed investigating absorbed power values for the knee during single-leg hop landings. The maintenance of stability becomes difficult when landing on one leg. It is difficult for a person to land perfectly on two feet every time, especially those who are physically active. When landing from a single-leg hop, the musculature across the hip, knee and ankle perform isometric, eccentric and concentric contractions to absorb an impact. In addition to absorbing impact, the musculature must also act on the joints to prevent abnormal deviations. When the muscles are able to resist these deviations, injuries become less likely to occur.

Summary

Fatigue and its affects on performance have been thoroughly studied. At times, it has been shown to have no
effects on performance, yet other times, it has been shown to negatively affect performance. Center of pressure and impulse have been studied individually, however, the two have not been studied together. Center of pressure is the distribution of force throughout the foot when coming in contact with a surface. Whereas impulse is the force generated at the body when coming into contact with a surface. When performing an activity such as a single leg bound, it is crucial that center of pressure remains even in the prevention of injury. It is also important that impulse does not increase while performing a single leg bound while a person is fatigued. However, in certain real-life situations it is almost guaranteed that impulse will increase. Impulse becomes a difficult thing to control for in these situations. Fatigue may cause forces generated to be much higher, therefore the need to absorb these forces may also increase. Performing a single leg bound to examine these forces may be more of a functional movement rather than statically standing on the force platform. Injury rates may decrease if a coach is aware of the effects of force production and balance when a person is fatigued.
APPENDIX B

The Problem
The Problem

Statement of the Problem

The purpose of this study was to determine if fatigue induced by functional activity negatively affects center of pressure and impulse measurements. Subjects were administered a functional fatigue protocol to determine its affects while performing a single leg hop onto a force platform.

Studying the effects of fatigue is important because most injuries tend to occur at the end of the game. By understanding the effects of fatigue we may be able to mitigate its effects. Also, with the study we may be able to make vital suggestions in ways to deal with fatigue and may be able to prevent injuries. These injuries may come at the end of the game when the person is too fatigued. Therefore, when fatigued it should be more difficult to maintain center of pressure and absorb a high peak force bounding onto a force platform.

Definition of Terms

The following terms were operationally defined for this study:
1) Center of pressure – central point of pressure that is applied to the foot during standing on the ground.\textsuperscript{36}

2) Impulse – the force created at the foot when it comes into contact with a surface.\textsuperscript{5}

3) Central Fatigue – fatigue caused by progressive failure of voluntary neural drive.\textsuperscript{6}

4) Functional Fatigue Protocol – protocol which contains exercises mimicking athletic activity, which may result in the 15-point Borg RPE score of 13 or above.\textsuperscript{35}

5) Muscle fatigue – when a muscle no longer can produce a contraction as it had previously done.\textsuperscript{6}

Basic Assumptions
The following will be basic assumptions of the study:

1) The subjects will be adequately fatigued following the completion of the functional fatigue protocol (FFP).

2) The equipment will be calibrated and work properly during the study.

3) The subjects will report their fatigue score honestly and appropriately and the test score will adequately indicate fatigue.

4) Testing instruments will be valid and reliable.

5) The prescreening fitness level will minimize subjects’ variability for the FFP.
Limitations of the study

1. The test results may be limited to generalizing the data to active people and not athletes.
2. Subjects may not adequately report their fatigue on the Borg RPE scale.
3. Subjects may have a difficult time performing a single-leg bound and holding while fatigued.

Significance of the study

The scope of this study was to expand the understanding of functional fatigue and its affects on center of pressure and impulse measurements in moderately active individuals. During exercise or athletic performance, a person’s center of pressure is constantly altered. The ability to maintain one’s center of pressure is a measure of whole body neuromuscular control. Once the center of pressure exceeds its limit, a person may lose balance or become injured. Also, during exercise a person may no longer be able to generate the same peak force or absorb ground reaction forces following fatigue. Many authors have studied the relationship between fatigue and center of pressure. Some have also examined the relationship between fatigue and impulse. However,
there is a limit in the number of studies examining the effects while performing a single leg bound onto a force platform.

The single leg bound is unique because it is a functional movement that should be studied. When a person hops on one leg, they simulate the forces that can result in many athletic injuries, such as non-contact ACL injuries. These types of injuries caused is serious and causes a person to miss an extended length of time. These findings may demonstrate that when fatigued a person has a more difficult time maintaining center of balance and absorbing a high peak force. This may contribute to a decrease in performance and an increase in incidence of injury.
APPENDIX C

Additional Methods
APPENDIX C1

Informed Consent
Informed-Consent Form

1. Michael R Goodman, has requested my participation in a research study at California University of Pennsylvania. The title of the research is “The Effect of Fatigue on Center of Pressure and Impulse”.

2. I have been informed that the purpose of the research is to compare the effects of Center of Pressure and Impulse between a fatigue condition and non-fatigue condition in Graduate and Undergraduate Athletic Training Education Program students.

3. My participation will involve performing a single leg bound onto a force platform under fatigue and non fatigue conditions. I understand that my participation is completely voluntary and I may choose to not participate following the first day of testing. The fatigue protocol is 20 minutes of exercise including jogging, sprinting, push-ups, sit-ups and step-ups. The testing under both conditions will be conducted on two different days at Hamer Hall’s athletic training lab.

4. I understand that there are foreseeable risks or discomforts to me if I agree to participate in the study. The possible risks include but are not limited to discomfort from exercise or a fall from the force platform where the risks will be minimized by a spotter. I also understand that there is potential discomfort brought on by muscle soreness which may persist for two (2) to three (3) days. These risks are no more than would be normally encountered in a work out program.

5. I understand that in the case of an injury or persisted muscle soreness, I can expect to receive treatment or care in Hamer Hall’s Athletic Training Facility which will be provided by the researcher Michael R. Goodman who administer emergency and/or rehabilitative care. I also understand that if critical care is needed, I may be referred to an emergency facility.

6. I understand that there are no feasible alternative procedures available for this study.

7. I understand that the possible benefits of my participation in the research are contribution to existing research and may aid in reducing injury due to fatigue.

8. I understand that the results of the research study may be published but my name or identity will not be revealed. In order to maintain confidentiality of my records, Michael R. Goodman will maintain all documents in a secure location which only the student researcher or research advisor may access.
9. I have been informed that I will not be compensated for my participation.
10. I have been informed that any questions I have concerning the research or my participation in it, before or after my consent, will be answered and my individual scores or abstract of the study will be informed after completion of the study by:
   Michael Goodman
   947 Cross St Apt 2
   California PA 15419
   443-623-3914
   Goo3469@cup.edu
   Or by the graduate thesis advisor:
   Robert H. Kane
   Kane@cup.edu

11. I understand that written responses may be used in quotations for publication but my identity will remain anonymous.
12. I have read the above information. The nature, demands, risks, and benefits of the project have been explained to me. I knowingly assume the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime without penalty or loss of benefit to myself. In signing this consent form, I am not waving any legal claims, rights, or remedies. A copy of this consent form will be given to me upon request.

   Subjects Name: ________________________    Date: _________

   Subjects Signature: _____________________    Date: _________

13. I certify that I have explained to the above individual the nature, purpose, potential benefits, possible
risks of participation in this study, have answered any
questions that have been raised, and have witnessed the above
signature.

14. I have provided the subject/participant a copy of
this signed consent document if requested.

Investigator’s Signature: __________________________

Date:_________
APPENDIX C2

Demographic Sheet
Demographic Sheet

Subject Name: ______________________ Date: ____________

Age: ____________

Height: ____________

Weight: ____________

Gender: ____________

How many times per week do you work out?

On average how long do you work out during each session?

Have you sustained an injury to your head diagnosed as a concussion in the last 6 months?

Have you sustained any musculoskeletal injury to your lower extremities in the last 6 months?
APPENDIX C3

Functional Fatigue Protocol
Functional Fatigue Protocol

Station 1: Moderate jogging for 5 minutes

Subjects jogged at their own pace but not a slow pace for 5 minutes. If they appeared to not jog fast enough, they were encouraged to jog faster.

Station 2: Straight-line sprinting for 3 minutes

Subjects sprinted 30 meters down a basketball court as fast as they could with verbal feedback to maintain speed. They were allowed to take a break between each sprint for no longer than 10 seconds. Once the time reached 10 seconds, subjects were encouraged to start again.

Station 3: Push-ups for 2 minutes

Subjects were to do as many push-ups as they could in 2 minutes. If they felt too exhausted to continue, they were instructed to hold the up position until time expired.

Station 4: Sit-ups for 2 minutes

Subjects were to do as many sit-ups as they could in 2 minutes. If they felt too
exhausted to continue, they were instructed to hold the up position until time expired.

Station 5: 12-in step-ups for 3 minutes

Subjects were to do step-ups at a moderate pace for 3 minutes. Moderate pace was approximately 100 steps per minute. If the subject felt too exhausted to continue, they were allowed to rest for no longer than 10 seconds, and were encouraged to continue.

Station 6: Straight-line sprinting for 3 minutes

Subjects sprinted 30 meters down a basketball court as fast as they could with verbal feedback to maintain speed. They were allowed to take a break between each sprint for no longer than 10 seconds. Once the time reached 10 seconds, subjects were encouraged to start again.

Station 7: Slow pace jogging from gym to test room

This served as a cool down subjects were instructed to continue moving from the gymnasium, downstairs to the testing room.
Subjects were instructed to take no longer than 3 minutes to make it from the gymnasium to the testing room.
APPENDIX C4

Borg 15 RPE Scale
APPENDIX C5

Test Score Sheet
Data Collection Sheet

Subject #: _____________________

Sex: ______

Weight (Newtons): ____________________

Peak Impulse (Newtons): ______________

Average Center of Pressure (cm): _____________

Average Center of Pressure along X (cm): __________

Average Center of Pressure along Y (cm): __________

Area of 95% Elipse (cm): _____________
APPENDIX C7

Institutional Review Board
PROTOCOL for Research Involving Human Subjects

Institutional Review Board (IRB) approval is required before beginning any research and/or data collection involving human subjects.

(Reference IRB Policies and Procedures for clarification)

Project Title: The Effect of Fatigue on Center of Pressure and Impulse

Researcher/Project Director: Michael Goodman

Phone #: 443-633-5914  E-mail Address: poop3469@cup.edu

Faculty Sponsor (if required): Dr. Robert H. Kane

Department: Health Science and Sports Studies

Project Dates: 11/07 to 6/08

Sponsoring Agent (if applicable):

Project to be Conducted at: California University of Pennsylvania

Project Purpose: ☑ Thesis  ☐ Research  ☐ Class Project  ☐ Other

Keep a copy of this form for your records.

Required IRB Training

The training requirement can be satisfied by completing the online training session at http://cme.nci.nih.gov/. A copy of your certification of training must be attached to this IRB Protocol. If you have completed the training at an earlier date and have already provided documentation to the California University of Pennsylvania Grants Office, please provide the following:

Previous Project Title

Date of Previous IRB Protocol

Draft, April 7, 2005
1. Provide an overview of your project-proposal describing what you plan to do and how you will go about doing it. Include any hypothesis(ies) or research questions that might be involved and explain how the information you gather will be analyzed. For a complete list of what should be included in your summary, please refer to Appendix B of the IRB Policies and Procedures Manual.

I will be looking at the effect of fatigue on Center of Pressure and Impulse. Fifteen (N=15) healthy graduate and undergraduate students in the Athletic Training Education Program are expected to participate in this study. Volunteer subjects will sign the informed consent form and their indicated first day of testing. Any subjects who do not participate in physical activity at least 3 times per week for 30 minutes per session will be excluded from this study. Also any subjects who have suffered an injury to their lower extremity or have suffered a concussion within the last six months will be excluded from the study. The testing will be performed twice, both under a fatigued and non-fatigued condition. The functional fatigue protocol will include jogging, sprinting, sit-ups, push-ups and step-ups (Appendix C3). The researcher will then instruct the subject to hop onto a force plate platform and land on one foot. They will be instructed to hold this single leg position for five seconds. The subjects will perform 3 trials and peak impulse and center of pressure scores will be averaged for the three trials. For data analysis, difference scores will be calculated for center of pressure and impulse under both fatigued and non-fatigued conditions. A paired t-test will be used to determine the difference between condition (fatigue/normal), and impulse and center of pressure measurements. SPSS 14.0 will be used for data analysis. The following are the research hypothesis: (1) Center of Pressure will increase under fatigued conditions compared to non-fatigued conditions; (2) Impulse will increase under fatigued conditions compared to non-fatigued conditions.

2. Section 46.11 of the Federal Regulations state that research proposals involving human subjects must satisfy certain requirements before the IRB can grant approval. You should describe in detail how the following requirements will be satisfied. Be sure to address each area separately.

   a. How will you ensure that any risks to subjects are minimized? If there are potential risks, describe what will be done to minimize these risks. If there are risks, describe why the risks to participants are reasonable in relation to the anticipated benefits.

       The possible risks include discomfort due to exercise or a fall from the force plate platform while performing the test where the risks will be minimized by the researcher who will serve as a spotter. Muscle soreness may occur following the fatigue protocol and may persist for 2-3 days following exercise. The activity is no more than the student would endure during their traditional work-out program. In the case of an injury the researcher (certified athletic trainer) will perform the necessary actions to treat the injury.

   b. How will you ensure that the selection of subjects is equitable? Take into account your purpose(s).

       Be sure you address research problems involving vulnerable populations such as children, prisoners, pregnant women, mentally disabled persons, and economically or educationally disadvantaged persons. If this is an in-class project describe how you will minimize the possibility that students will feel coerced.

       The selection of subjects will be strictly done on a volunteer basis. All subjects will be recruited via email and asked to participate in a research study. Only subjects who have met the criteria will be eligible (work out 3 times 30 minutes per week, no injuries within 6 months and no concussions) Also once I get 15 subjects to commit to the study I will have filled my requirements for the study. Only graduate and undergraduate students in the Athletic Training Education Program will be used therefore no subjects will be prisoners, pregnant or children.

   c. How will you obtain informed consent from each participant or the subject’s legally authorized representative and ensure that all consent forms are appropriately documented? Be sure to attach a copy of your consent form to the project summary.

       An informed consent form will be signed and completed by the subjects on the first day of testing. The form will be signed prior to their test. A copy of the form is attached with this form. Each signed form will be kept by the tester.

   d. Show that the research plan makes provisions to monitor the data collected to insure the safety of all subjects. This includes the privacy of subjects’ responses and provisions for maintaining the security and confidentiality of the data.
Expected to come in for 2 days of testing to be under the fatigue and non-fatigue conditions. All collected data which will be identified by research number will be kept in a secure location in which only the researcher and research advisor will have access to.

3. Check the appropriate box(es) that describe the subjects you plan to use.

- [ ] Adult volunteers
- [X] CAL University Students
- [ ] Other Students
- [ ] Prisoners
- [ ] Pregnant Women
- [ ] Physically Handicapped People
- [ ] Mentally Disabled People
- [ ] Economically Disadvantaged People
- [ ] Educationally Disadvantaged People
- [ ] Fetuses or fetal material
- [ ] Children Under 18
- [ ] Neonates

4. Is remuneration involved in your project? [ ] Yes or [X] No. If yes, Explain here.

5. Is this project part of a grant? [ ] Yes or [X] No If yes, provide the following information:
   Title of the Grant Proposal ____________________________
   Name of the Funding Agency __________________________
   Dates of the Project Period __________________________

6. Does your project involve the debriefing of those who participated? [ ] Yes or [X] No
   If Yes, explain the debriefing process here.

7. If your project involves a questionnaire interview, ensure that it meets the requirements of Appendix ___ in the Policies and Procedures Manual.
Project Director's Certification
Program Involving HUMAN SUBJECTS

The proposed investigation involves the use of human subjects and I am submitting the complete application form and project description to the Institutional Review Board for Research Involving Human Subjects.

I understand that Institutional Review Board (IRB) approval is required before beginning any research and/or data collection involving human subjects. If the Board grants approval of this application, I agree to:

1. Abide by any conditions or changes in the project required by the Board.
2. Report to the Board any change in the research plan that affects the method of using human subjects before such change is instituted.
3. Report to the Board any problems that arise in connection with the use of human subjects.
4. Seek advice of the Board whenever I believe such advice is necessary or would be helpful.
5. Secure the informed, written consent of all human subjects participating in the project.
6. Cooperate with the Board in its effort to provide a continuing review after investigations have been initiated.

I have reviewed the Federal and State regulations concerning the use of human subjects in research and training programs and the guidelines. I agree to abide by the regulations and guidelines aforementioned and will adhere to policies and procedures described in my application. I understand that changes to the research must be approved by the IRB before they are implemented.

Professional Research

Project Director's Signature

Department Chairperson's Signature

Student or Class Research

Student Researcher's Signature

Supervising Faculty Member's Signature if required

Department Chairperson's Signature

ACTION OF REVIEW BOARD (IRB use only)

The Institutional Review Board for Research Involving Human Subjects has reviewed this application to ascertain whether or not the proposed project:

1. provides adequate safeguards of the rights and welfare of human subjects involved in the investigations;
2. uses appropriate methods to obtain informed, written consent;
3. indicates that the potential benefits of the investigation substantially outweigh the risk involved.
4. provides adequate debriefing of human participants.
5. provides adequate follow-up services to participants who may have incurred physical, mental, or emotional harm.

Approved    □ Disapproved

Chairperson, Institutional Review Board

Date

Draft, April 7, 2005
REFERENCES


9. Cowley H, Ford K, Myer G, Kernozek T, Hewett T. Differences in Neuromuscular Strategies Between Landing and Cutting Tasks in Female Basketball and


18. Ochsendorf D, Mattacola C, Arnold B. Effect of Orthotics on Postural Sway after Fatigue of the


ABSTRACT

TITLE: THE EFFECT OF FATIGUE ON CENTER OF PRESSURE AND IMPULSE DURING A SINGLE LEG BOUND

RESEARCHER: Michael R. Goodman

ADVISOR: Dr. Robert Kane

DATE: 4/24/08

RESEARCH TYPE: Master’s Thesis

PURPOSE: The purpose of this study was to determine the effects of fatigue on Center of Pressure and Peak Impulse, while performing a single leg bound onto a force platform.

PROBLEM: Recent research has shown that negative effects on physical performance may be associated with fatigue. These effects include difficulty in maintaining balance, producing force, or absorbing force which may lead to injury.

METHODS: Fifteen subjects volunteered for this study. Each subject was tested on 2 different days. Subjects were randomly assigned to day one condition. All subjects performed a 5 minute warm-up at 3.5 mph on a treadmill prior to testing. If fatigued, the subject went through a fatigue protocol and then reported their RPE. Subjects performed 3 jumps and their data was averaged for the 3 trials.

FINDINGS: There was a significant difference in center of pressure measurement ($t(14) = -7.508, P < .001$) and impulse measurement ($t(14) = -2.605, P = .021$) when fatigued.

CONCLUSION: This study revealed that fatigue significantly affected a person’s center of pressure and force production during a single leg bound.