THE RELATIONSHIP BETWEEN FUNCTIONAL FATIGUE AND LIMITS OF STABILITY IN DIVISION II COLLEGIATE ATHLETES

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

BY

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California, Pennsylvania
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THESIS APPROVAL

Graduate Athletic Training Education

We hereby approve the Thesis of

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I would like to take this opportunity to thank the many people who played an important role in the completion of this thesis. First, I would like to thank my advisor Dr. Rebecca Hess and the members of my committee: Dr. Ben Reuter and Dr. Marc Federico. Their knowledge, input, and experience was invaluable to the success of this product.

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INTRODUCTION

Since maintaining some level of equilibrium is involved in almost all forms of movement, balance, especially dynamic balance, is a factor which has the most influence on the athletic performance. Balance is defined as the ability to maintain the center of gravity (COG) within the base of support. During the athletic performance, one’s COG changes because the base of support is constantly changed. Therefore, better control of the balance may lead to better performance. On the other hand, fatigue may decrease athletic performance. As many injuries seem to occur at the later stage of the game, fatigue is related to athletic injury occurrence as well as athletic performance. While many authors have found that fatigue negatively affects static and dynamic balance ability, there are limited studies that have examined dynamic Limits of Stability (LOS) as measured by Biodex Balance System (BBS) under the fatigue condition.

Fatigue is associated with the decline in muscle tension or force capacity with repeated stimulation, including perceptual deterioration for achieving desired exercise outcome due to increased difficulty or discomfort. The precise aetiology of muscular fatigue
remains unknown.\textsuperscript{12,13} Fatigue can be addressed as central and/or muscular.\textsuperscript{14} Central fatigue occurs when the central nervous system (CNS) can no longer stimulate the motor neuron to fire, even when the muscles are still able to contract.\textsuperscript{14} Muscle fatigue occurs when the muscle no longer responds to the stimulation due to factors such as the accumulation of lactic acid and/or depletion of cellular energy reserves.\textsuperscript{14} The time between the stimulus and the electrical response in skeletal muscle, and the time between the electrical response and force generation by the muscle are delayed.\textsuperscript{15} As a result, fatigue may lead to increased reaction and movement time for muscle contraction.\textsuperscript{15}

Various protocols have been used to induce fatigue such as the localized muscle fatigue protocol, isokinetic fatigue protocol (IFP), and functional fatigue protocol (FFP).\textsuperscript{3-10,16} While the IFP has been used traditionally, a more recent development of FFP has been studied.\textsuperscript{3,4,6} The concept of a FFP was developed to use close kinetic chain exercises, which are more similar to sport specific movements, to induce similar fatigue symptoms that the player feels during athletic events.\textsuperscript{6} On the other hand, it is difficult to evaluate the general level of fatigue due to differences in inducing fatigue. Some researchers have used the 15-point Borg Rating of Perceived Exertion (RPE) scale to determine
The functional fatigue level. The 15-point Borg RPE scale has been used to indicate the level of physical strain as various physiological signals coming from all body parts are integrated into a perceived exertion. Because of its simplicity, the 15-point Borg RPE scale can predict exercise intensity on the athletic field and sport rehabilitation, as well as during research.

The Biodex Balance System (BBS) has been used as an effective device to measure balance. Researchers have used the BBS to measure dynamic bilateral and unilateral postural stability on an unfixed surface, as well as dynamic LOS. LOS is defined as the maximum angle a body is able to lean from vertical to all directions without falling or changing their base of support. The dynamic LOS test on the BBS assesses how smoothly and quickly a person is able to lean to one’s LOS but does not measure the maximal angle of lean. Since balance is maintained via the feedback sensory control circuit between the CNS and the musculoskeletal system, and feed-forward mechanism compiled from previous motor experience, any disruption of these procedures due to fatigue may affect balance. On the other hand, one study concluded that the contribution of the visual sensory might be more of a contributing factor than that of fatigue for static balance.
Recently, authors have used dynamic balance tests with FFP because they want to create conditions similar to those of competition. However, reliability and validity of the FFPs are questionable. On the other hand, there are limited studies concerning the LOS, or relationship between fatigue and LOS. Therefore, the purpose of this study was to examine how functional fatigue affects LOS as measured by the BBS in Division II collegiate athletes. The research questions were as follows: (1) Will the LOS overall score decrease due to functional fatigue and (2) Will the LOS total time to complete test increase due to functional fatigue?
METHODS

The purpose of this study was to provide information about how functional fatigue affects LOS in Division II collegiate athletes. The following sections were discussed: Research Design, Subjects, Preliminary Research, Instrumentation, Procedures, Hypotheses, and Data Analysis.

Research Design

This study used a quasi-experimental, within-subject design. The independent variable was condition (functional fatigue/non-fatigue). Functional fatigue was determined by using the 15-point Borg RPE score. The dependent variables were overall LOS score, and time to complete the test as measured by the BBS. The strengths of this study were the use of the within-subjects design as subjects served as their own control, and the unique use of the dynamic LOS test. Testing was administered two times, and testing order under each condition (fatigue/non-fatigue) was randomized to control test effect. The generalizability of test results may be limited to the Division II collegiate, and perhaps soccer, athletes.
Subjects

Fourteen (N = 14: Male = 8 and Female = 6) healthy National Collegiate Athletic Association (NCAA) Division II collegiate athletes from California University of Pennsylvania Men’s and Women’s soccer team participated in this study. The sample was obtained by announcing the concept of this study to athletes by oral and written document. Subjects were asked to participate in this study voluntarily by the researcher. Subjects were screened for fitness level using the Tecumseh step Test\textsuperscript{21} (Appendix C1) and the Push-Up Muscular Endurance Test\textsuperscript{22} (Appendix C2). Subjects that scored into good or excellent level for both tests were included in the study. All subjects were currently able to fully participate in their sport. Any subjects who suffered from any visual, vestibular, balance disorder, serious lower extremity injury and/or a concussion within the last six months were not included in the study. All subjects read and signed the informed consent form (Appendix C3) prior to this study.
Preliminary Research

Preliminary research was designed to obtain the information that would provide the researcher with an appropriate time and intensity for the FFP using Division II healthy collegiate athletes. Wilkins et al\textsuperscript{3} established their own FFP which was able to induce adequate functional fatigue in 27 male Division I collegiate athletes as measured by the 15-point Borg RPE scale. Susco et al\textsuperscript{4} induced the fatigue in the same way as Wilkins using 100 recreational active college students. The same protocol was reviewed in the preliminary research. During preliminary trials, the correlation between the 15-point Borg RPE scale and working heart rate (WHR) was assessed. Two healthy collegiate athletes representative of the desired sample were the test subjects. It was determined that 15 point or above out of a total 20 would serve as adequate fatigue.\textsuperscript{3,4}

The effective test difficulty of LOS was also obtained through the preliminary research. Although BBS offers three level of difficulty 50\%, 75\%, and 100\% (least to most difficult) during practice trails, only 50\% of stability level can be selected for testing. Therefore, researcher tested the effectiveness of the LOS test under 50\% of
difficulty level, and determined that this level would be a valid means testing LOS.

Instruments

The instruments used in the study included: demographic sheet (Appendix C4), the BBS, the FFP (Appendix C5), the 15-point Borg RPE scale (Appendix C6), and test score sheet (Appendix C7). Test data such as overall LOS score and time to complete the test was obtained by the BBS. The BBS is a device used to measure the dynamic balance on a platform moving in all directions up to 20°.18,19 The BBS is also used to measure the LOS by requiring subjects move their COG to a target indicated on the screen in any direction under their own control.18 The LOS is defined as a maximum range a person is able to lean in all directions without falling.18,19 LOS test score is represented by the overall LOS score and total time to complete test.18 To calculate the overall LOS score, the following formula is used.

\[
\text{LOS score} \% = \frac{\text{Straight line distance to target}}{\text{Actual distance traveled}} \times 100
\]

\[
\text{Overall LOS score} = \frac{\sum_{i=1}^{8} (\text{LOS scores})}{8}
\]
Higher scores and in a shorter time to complete the test indicate better control of subject’s COG within their LOS. According to Hinman, reliability of the LOS test on BBS can range from .77 to .89, and is comparable in terms of coefficients reported the Functional Reach test and LOS test using the NeuroCom systems, which has ranged from .73 to .92. The percentage LOS is the proportion of one’s angular displacement of COG compared to average LOS. Therefore, percentage of normal LOS in the anterior-posterior direction, for example, is concluded by dividing subject’s stability index by a normal standard value of $12^\circ$ and multiplying that number by 100. During the testing, 50% of LOS difficulty was used.

An established FFP (Appendix C5) was used in this study. The FFP contained seven stations: station one was moderate jogging for five minutes, station two was three minutes of straight-line sprint, station three was two minutes of push-ups, station four was two minutes of sit-ups, station five was three of minutes 12-in (30.48cm) step-ups, station six was again three of minutes straight-line sprint, and station seven was again moderate jogging for two minutes. More specific instructions within the FFP were
designed by the researcher and included to minimize variability between subjects’ performance.

Adequate fatigue was determined using the 15-point Borg RPE scale (Appendix C6), described by G.V. Borg in 1970. This scale is an effective and reliable tool for measuring physical stress or fatigue level. According to Borg, the 15-point RPE scale is simplest and most effective to measure the perceived exertion. The scale values range from six to 20 which increase linearly with the intensity of the exercise. These values are related to physiological variables such as Working Heart Rate (WHR) and oxygen consumption, which increase linearly with intensity of exercise as well. These values have coincided with 75% to 90% of maximum Vo2 consumption and heart rate. Garcin et al reported very high correlation coefficients (0.95 to 1.00) of between test and retest 15-point Borg RPE scores. The test was reliable during the exercises until exhaustion. A score of 15 or above was considered as an adequate fatigue for this study.
Procedures

The study was approved by the California University of Pennsylvania Institutional Review Board (IRB) (Appendix C8). Subjects were obtained from athletes at California University of Pennsylvania Men’s and Women’s soccer team. Prior to the announcement of the study and their involvement in the study, approval was received from the coaches and reserved the time of announcement. Then, the researcher explained the concept of the study to each team at the appointed date and offer the informed consent form (Appendix C3) for them to understand the need and risks of involvement in the study. Qualifications for the subjects, which were mentioned at the subject section, and date of informational meeting was also announced. An informational meeting and pre-screening test was set up at several times before the testing. During these meetings, qualifications for the subjects were presented again. Once understanding and approving, they signed the informed consent form and completed the demographic sheet (Appendix C4). Subjects who signed informed consent form were assessed for their fitness level using the Tecumseh step test and Push-up muscular endurance test.
All subjects who fulfilled all qualifications completed two test sessions on two different days. To determine which test the subjects would perform, the researcher let them pick up one of the two sheets, which are describing testing conditions (fatigue or non-fatigue) at the date of the first session. Subjects would not know which test they conducted at the first day of the study session. Prior to beginning the study, the researcher explained the test procedure and method. The researcher instructed each subject to stand on the BBS platform and maintain their balance on the unstable platform while chasing the moving target in any directions. During the test, eight target boxes show up on the BBS screen. The researcher provided all subjects 10 minutes of warm-up and two practice sessions for them to get used to LOS testing on the BBS and to minimize the learning effects. Before the test, all subjects reported their fatigue level to the researcher by using 15-point Borg RPE score as baseline. Then, they performed the dynamic LOS test on the BBS. Once the subject completed all eight targets, the test ended and the time of the testing session was automatically recorded. Immediately after the test, all subjects reported their fatigue level to the researcher again.
After LOS testing, the subjects under the non-fatigue condition rested for 20 minutes and the subjects under the functional fatigue condition were instructed to begin the FFP. Subjects under the functional fatigue condition performed FFP (Appendix C5) after the pre-LOS test. During the functional fatigue exercise, the researcher pushed each subject verbally for them to put as much effort as they could. Immediately after the rest or fatigue session, subjects reported their fatigue level and were instructed to perform LOS testing on the BBS. After completing the post-LOS testing, the subjects reported their fatigue level. They then were dismissed and asked to come back in one week to complete a second and final testing session following the same procedure. Every test score, and 15-point RPE score were recorded on the test score sheet (Appendix C7).

Hypotheses

The following hypotheses were tested in this study:

1) The LOS overall score will decrease due to functional fatigue.

2) The LOS total time to complete test will increase due to functional fatigue.
Data Analysis

Difference scores were calculated for both dependent variables under both conditions. A paired t-test was used to determine the difference between condition (fatigue/non-fatigue) for the dependent variables, LOS overall score and LOS total time to complete test. This data analysis was performed using the SPSS 12.0 statistical software package at an alpha level of $\leq 0.05$. 
RESULTS

The purpose of the study was to examine how functional fatigue affects dynamic LOS as measured by the BBS in Division II collegiate athletes. Subjects were tested prior to and immediately following 20 minutes of functional fatigue protocol and 20 minutes of rest. Balance ability was measured by the LOS overall score and the LOS total time to complete test on the BBS.

Demographic Data

Out of 15 volunteer athletes, 14 athletes, who were categorized into the criterion of good or excellent fitness level, were pre and post tested during two testing sessions. All subjects were members of the Division II California University of Pennsylvania Men’s/Women’s soccer team. Tests were conducted in the same way and by the same tester to increase internal validity. All demographic data was collected by self report (Table 1).
Hypothesis Testing

Hypothesis testing was performed by using the 14 subjects who met the pre-screening test criteria. All of the hypotheses were tested at the $P < .05$ alpha level.

Hypothesis 1: The LOS overall score will decrease due to functional fatigue. A paired t-test was calculated to compare the mean difference of the LOS overall score during FFP and NFP.

Conclusion: There was a significant difference in LOS overall score due to fatigue ($t(13) = -3.645$, $P = .003$). The mean of the difference of the LOS overall score during FFP was $-4.1429 + 5.07$, and the mean on the difference of LOS overall score during Non-Fatigue Protocol (NFP) was $3.7857 + 6.14$.

Hypothesis 2: The LOS total time to complete test will increase due to functional fatigue. A paired t-test was
calculated to compare the mean difference of LOS total time to complete test during FFP and NFP.

Conclusion: There was no significant difference between LOS time to complete test during FFP and NFP ($t(13) = 2.012, P = .065$). The mean of the difference for LOS total time during FFP was $7.6429 \pm 10.07$, and the mean of the difference for LOS total time during NFP was $0.7143 \pm 6.08$.

Table 2. A paired t-test for the differences between FFP and NFP

<table>
<thead>
<tr>
<th>Test</th>
<th>df</th>
<th>t</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS Score</td>
<td>13</td>
<td>-0.3645</td>
<td>0.003*</td>
</tr>
<tr>
<td>LOS Time</td>
<td>13</td>
<td>2.012</td>
<td>0.065</td>
</tr>
</tbody>
</table>

*P < .01
Figure 1. Mean LOS overall score of pre and post testing during Functional Fatigue Protocol (FFP) and Non-Fatigue Protocol (NFP).
Figure 2. Mean LOS total time to complete testing of pre and post test during Functional Fatigue Protocol (FFP) and Non-Fatigue Protocol (NFP).

Table 3. Means and SD for the LOS overall score and the LOS total time to complete test, and mean difference score and time on both conditions

<table>
<thead>
<tr>
<th></th>
<th>FFP</th>
<th>NFP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>LOS score</td>
<td>29.0714</td>
<td>24.9286</td>
</tr>
<tr>
<td></td>
<td>(10.00)</td>
<td>(9.90)</td>
</tr>
<tr>
<td>Diff =</td>
<td>-4.1249</td>
<td>(5.07)</td>
</tr>
<tr>
<td>LOS time</td>
<td>48.7143</td>
<td>56.3571</td>
</tr>
<tr>
<td></td>
<td>(13.40)</td>
<td>(18.02)</td>
</tr>
<tr>
<td>Diff =</td>
<td>7.6429</td>
<td>(10.07)</td>
</tr>
</tbody>
</table>
Additional findings

Further testing was conducted to determine if there was a relationship among weight, shoe size, and average LOS overall score, as well as average LOS total time to complete test. The average LOS overall score, and average LOS total time to complete test was calculated by dividing the sum of all four LOS overall scores (pre/post FFP, NFP) on each condition by four.

Pearson Product Moment correlation measurements resulted in a significant moderate negative correlation for subjects' weight and average LOS overall scores ($r(12) = -0.641, P = 0.014$), and a significant moderate positive correlation for weight and average LOS total time to complete the test ($r(12) = 0.537, P = 0.048$). Lighter subjects had better balance and tended to finish testing faster. A significant negative correlation was reported for subjects’ shoe size and average LOS overall scores ($r(12) = -0.684, P = 0.007$). Subjects with smaller feet tended to have better balance scores.

Subjects LOS scores were divided into a high, moderate, or low group based on average LOS scores with 5 subjects in the high and moderate groups, and 4 subjects in low group.
Each group was assigned a balance code (1,2,or 3) for analysis (Table 4).

Table 4. Average LOS score among high, moderate, and low groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Range</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (N = 5)</td>
<td>13.75</td>
<td>45.25</td>
<td>31.50</td>
<td>38.75</td>
<td>5.97</td>
</tr>
<tr>
<td>Moderate (N = 5)</td>
<td>7.50</td>
<td>29.75</td>
<td>22.25</td>
<td>26.00</td>
<td>3.07</td>
</tr>
<tr>
<td>Low (N = 4)</td>
<td>4.50</td>
<td>21.75</td>
<td>17.25</td>
<td>19.88</td>
<td>2.25</td>
</tr>
</tbody>
</table>

A one-way ANOVA reported a significant difference in mean difference LOS overall score between the FFP and NFP among the high, moderate, and low group(2, 11) = 5.641, \( P = .021 \). Post-hoc analysis using Tukey’s HSD revealed that there was a significant difference between the “moderate” and “low” groups (mean differences = -8.35, \( P = .021 \)). An additional post-hoc test using LSD also revealed that there was significant difference between the high and moderate groups (mean Difference = -5.80, \( P = .037 \)), and between the moderate and low groups (mean Difference = -8.35, \( P = .008 \)). In general, fatigue affected the moderate group LOS scores more than subjects in the high or low score groups (Table 5).
Table 5. The mean difference LOS overall score among three groups during FFP and NFP

<table>
<thead>
<tr>
<th></th>
<th>FFP (SD)</th>
<th>NFP (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>-2.80 (3.27)</td>
<td>7.80 (8.47)</td>
</tr>
<tr>
<td>Moderate</td>
<td>-8.60 (3.58)</td>
<td>2.60 (2.07)</td>
</tr>
<tr>
<td>Low</td>
<td>-0.25 (4.86)</td>
<td>0.25 (4.03)</td>
</tr>
</tbody>
</table>

Figure 3. The mean difference LOS overall score among three groups during Functional Fatigue Protocol (FFP) and Non-Fatigue Protocol (NFP).
Table 6. The mean LOS overall score among the three groups pre and post test during each protocol

<table>
<thead>
<tr>
<th></th>
<th>FFP Pre</th>
<th>FFP Post</th>
<th>NFP Pre</th>
<th>NFP Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>38.6</td>
<td>35.8</td>
<td>36.4</td>
<td>44.2</td>
</tr>
<tr>
<td></td>
<td>(7.16)</td>
<td>(6.38)</td>
<td>(5.41)</td>
<td>(9.96)</td>
</tr>
<tr>
<td>Moderate</td>
<td>28.6</td>
<td>20.0</td>
<td>26.4</td>
<td>29.0</td>
</tr>
<tr>
<td></td>
<td>(4.28)</td>
<td>(1.22)</td>
<td>(3.78)</td>
<td>(4.18)</td>
</tr>
<tr>
<td>Low</td>
<td>17.8</td>
<td>17.5</td>
<td>22.0</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>(4.19)</td>
<td>(7.55)</td>
<td>(3.56)</td>
<td>(6.02)</td>
</tr>
</tbody>
</table>

Figure 4. The mean LOS overall score among the three groups during Functional Fatigue Protocol (FFP).
Figure 5. The LOS overall score among the three groups during Non-Fatigue Protocol (NFP).

Figure 6. Range of the pre and post LOS total score during Functional Fatigue Protocol (FFP) among the three group.
For the validity of FFP, 12 out of 14 subjects reported values of 15 or above on the RPE scale, which was defined as "fatigue". This result indicated that 20 minutes FFP used in this study was able to induce adequate fatigue (Table 7).

Table 7. RPE after 20 minutes of functional exercise and 20 minutes of rest

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
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DISCUSSION

The following discussion is divided into three sections: Discussion of Results, Conclusions, and Recommendations.

Discussion of Results

The main finding was that 20 minutes of functional exercise adversely affected dynamic balance as measured by the BBS. Dynamic LOS test measured the quality of ability to control their COG as maintaining balance over unstable surface.\textsuperscript{18} The dynamic balance ability was represented by using the LOS overall score and LOS total time to complete the test. The LOS overall score was significantly decreased due to functional fatigue and LOS total time was increased after 20 minutes of functional exercises. The LOS score was calculated to see how effectively the subjects move their COG to “hit” targets on an unstable surface. To have a high LOS total score, the subjects had to control their COG during whole testing period. On the other hand, subjects can reduce their testing time even if they failed to maintain their COG completely, but move their COG faster.
Therefore, the LOS total score maybe a better indicator of dynamic balance.

During the dynamic LOS testing, the subjects have to move their COG effectively with keeping their balance on an unstable surface. During the dynamic stability (DS) test on BBS, subjects would be required to maintain their COG on an unstable surface. Therefore, the LOS test maybe more difficult in which an advanced balance skill would be needed. For dynamic LOS testing, two different abilities will be required. One is to maintain balance, and the other is to move their COG effectively. To maintain balance, sensory organization is very important because sensory organization, which includes the vestibular, visual, and somatosensory inputs, informs the person of the position of the body in relation to gravity and its surroundings.²⁰ To move their COG effectively, muscular coordination is very important because muscle coordination has an important role in maintaining a postural stability and in moving the COG in any desired directions.⁵,²⁰ It is difficult to say which technique contributes more than the other. Blackburn et al¹ found that enhancement of proprioception and muscular strength were equally beneficial to increased dynamic balance ability as measured by BBS and Bass test. Therefore, these two systems need to work effectively each other to
perform dynamic LOS testing better.

Because the LOS total score was significantly decreased after 20 minutes of FFP, fatigue could inhibit one of two systems or both, but it is difficult to distinguish which systems was inhibited more. Rozzi et al\textsuperscript{27} found that muscular fatigue caused decreasing proprioceptive ability and alterations in muscle activity around the knee joint. Isokinetically induced muscular fatigue of the knee extensors resulted in decrease in sense to detect joint motion and an increase in the onset of contraction time\textsuperscript{27}. One system, which was inhibited due to fatigue, might lead to decrease the ability of the other system or vice versa. Or fatigue had a negative influence on both systems directly. As a result, dynamic balance performance was decreased due to fatigue.

A decrease in balance ability due to fatigue has been found in previous studies by using various fatigue protocols\textsuperscript{3-10}. For our study, we used 20 minutes of functional exercise, which is more similar to sport specific movements and could induce similar fatigue symptoms that the player feels during athletic events. Fatigue is associated with the decline in muscle tension or force capacity with repeated stimulation, including perceptual deterioration for achieving desired exercise outcome due to increased
difficulty or discomfort.\textsuperscript{11} Fatigue can be addressed as central and/or muscular.\textsuperscript{14} We tried to induce central fatigue using 20 minutes of functional activities. Based on the RPE scale, this protocol induced adequate fatigue. Some authors used the same protocol and concluded that this functional exercise protocol induced adequate fatigue.\textsuperscript{3,4} However, this functional exercise may lead to localized muscular fatigue as well because the exercises included repetitive movement of the same muscles.\textsuperscript{3} Therefore, it is difficult to say that central fatigue alone due to functional activity caused decreased dynamic balance ability. On the other hand, some authors found that localized muscle fatigue lead to inhibit balance performance using IFP.\textsuperscript{6,7,10} A decrease of below 50% of the peak torque has been commonly used to determine the quality of localized muscular fatigue during the IFP.\textsuperscript{6,7,10} FFP was designed to induce central fatigue, not localized muscle fatigue.\textsuperscript{3} It seemed that this FFP might not able to induce 50% reduction of the peak torque on any one small body area.

In addition, Sterner et al\textsuperscript{28} found that functional fatigue activity including forward sprint, backward sprint, rapid cutting maneuvers, and bilateral side-shuffling movement, decreased maximum voluntary isometric contraction of quadriceps. Subjects completed ten cycles of functional
activities during each trial and three trials caused about 20% reduction of maximum voluntary isometric contraction of the quadriceps.\textsuperscript{28} FFP might induce localized muscular fatigue, but it will not be significant enough. Therefore, central fatigue with minor extent of local muscular fatigue due to FFP will likely affect dynamic balance ability.

While 20 minutes of functional activity had a negative influence on the dynamic balance ability, the amount of influence was different based on the level of balance score. Twenty minutes of functional exercise affected the balance score the most of those who were scored into moderate range. Most practice or competition lasts more than 20 minutes. Therefore, after 20 minutes of practice or competition, those who have moderate balance ability will likely have more chance to lose their balance, which may increase the chance of injury. So for those athletes, adequate amount of rest will be necessary for recovery from fatigue.

There was correlation between balance ability and weight based on our additional finding. The lighter subjects showed better balance performance under both fatigue and non-fatigue conditions. Davlin\textsuperscript{29} reported that there was moderate negative correlation between dynamic balance ability and weight among the high level athletes. LaPierre\textsuperscript{30} also reported that there was high negative
correlation between weight and DS among the Division II football players. During this test, subjects tilted unstable surface to chase targets. Once tilting the surface, the force is going to work to the direction which subjects leaned. This force will increase as the weight of the subject increases. If more dynamic force is applied in one direction, it becomes more difficult to maintain balance upon the unstable surface. Therefore, heavier subjects will likely have more difficulty of maintaining balance on an unstable surface.

There was a negative correlation between shoe size and dynamic balance ability. The smaller the shoe size, the better the balance performance. Usually the balance is maintained better over the bigger base of support. We could not find any reports about shoe size and balance. The possible reason will be the correlation between shoe size and weight. There was a high positive correlation between weight and shoe size in our study. Supposedly heavier people with bigger feet does not control their balance as well as smaller people. Therefore, it looked that shoe size affected dynamic balance ability. To prove this, further testing may be needed by using the subjects who are the same weight.
All subjects were in out of season while they did lifting with team. Even if their scores of fitness level test were above “good” criteria, their anaerobic capacities were less than those during in-season.

Conclusions

Twenty minutes of functional activity will likely have a negative influence on dynamic balance ability in Division II collegiate Men/Women soccer athletes. For LOS testing, athletes who score between 22.25 and 29.75 will be most affected due to 20 minutes of functional activity. As a result, the degree to which dynamic balance is affected by functional fatigue will be different based on balance ability of the athlete. In addition, the weight and shoe size are closely related to dynamic balance ability, in which lighter athletes with a relatively small shoe size tend to have better dynamic balance ability.

Recommendation

Our findings suggest that 20 minutes of sport activities will lead to decreased dynamic balance ability and potentially, performance level, as well as an increased
risk of injury. Therefore, adequate rest intervals at approximately every 20 minutes of intense activity may be necessary to enhance performance and/or prevent injury. Further research using LOS testing on different sport athletes or athletes at different levels of competition may be beneficial to understanding the general nature of LOS and fatigue, as well as exploring adequate recovery time after 20 minutes of functional activity.
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APPENDIX A

Review of the Literature
Balance, especially dynamic balance, is a factor which has the most influence on the athletic performance since maintaining some level of equilibrium is involved in almost all forms of movements.\textsuperscript{1} Balance is defined as the ability to maintain the center of gravity (COG) within the base of support.\textsuperscript{1} This complicated function is achieved by sensory, motor, and biomechanical processes.\textsuperscript{1} In this way, it could be argued that better control of balance may lead to better performance. On the other hand, fatigue may decrease athletic performance. As many injuries seem to occur at the later stage of the game,\textsuperscript{2} fatigue is also related to athletic performance and injury occurrence. Many authors have studied the relationship between fatigue and balance.\textsuperscript{3-10} Therefore, the purpose of this review of the literature is to discuss the relationship between fatigue and balance. The topics that will be discussed include (1) Fatigue and Functional Fatigue, (2) Balance and Limits of Stability (LOS), (3) Effect of Fatigue on Balance, and (4) Summary.

**Fatigue and Functional Fatigue**

While many investigations concerning fatigue and
athletic performance have been conducted, the precise aetiology of muscular fatigue remains unknown.\textsuperscript{11-13} While fatigue is viewed as a complex phenomenon, simply, fatigue is defined as the decline in muscle tension or force capacity with repeated stimulation including perceptual deterioration for achieving desired exercise outcome due to increased difficulty or discomfort.\textsuperscript{14} Fatigue is very closely related to voluntary muscle actions which are controlled by the central nervous system (CNS), peripheral nervous system (PNS), neuromuscular junction, and muscle fiber.\textsuperscript{14} An interruption in the chain of events within these four components may result in fatigue.\textsuperscript{14} Overall fatigue may lead to a loss in strength.\textsuperscript{13}

Fatigue can be addressed as central fatigue, and muscle fatigue.\textsuperscript{15} While the exact mechanism of central fatigue is still unclear, central fatigue occurs when the CNS can no longer stimulate the motor neuron to fire, even though the muscles are still able to contract.\textsuperscript{15} Alternating the levels of CNS neurotransmitters due to the exercise may lead to changed perceptual conditions and cause deterioration in the ability to perform.\textsuperscript{14} Central fatigue is responsible for changing the sense of effort.\textsuperscript{3} Central fatigue has been reported during prolonged running exercises, yet not after lower intensity cycling or skiing because of spinal
inhibition in central fatigue.\textsuperscript{13}

Muscle fatigue, in which the muscle no longer respond to the stimulation, occurs and inhibits muscle contraction when the factors such as the accumulation of lactic acid and/or depletion of energy reserves happen.\textsuperscript{15} Neuromuscular fatigue is a term used to describe the combination of central fatigue and muscle fatigue in the inability of active motor neuron to create action potential from motor neurons to the muscles.\textsuperscript{15}

Fatigue can be induced by the duration of exercise. Metabolic factors such as the lack of oxygen, accumulation of waste products, or lactic acid can induce fatigue even in short duration exercises.\textsuperscript{13,14} With long duration exercise, metabolic factors such as lack of glycogen or accumulation of intercellular Ca\textsuperscript{2+} and CNS factors can induce fatigue.\textsuperscript{13} Depending on the activity pattern such as whole body activity or localized movement, the body responses in different ways.

\section*{Inducing Fatigue}

Various protocols have been used to induce fatigue such as the localized muscle fatigue protocol, isokinetic fatigue protocol (IFP), and functional fatigue protocol (FFP).\textsuperscript{3-10,16} Localized muscle fatigue protocol induced fatigue by
repetitive muscle contraction in uniplanar motions until subjects can no longer complete the full range of motion.\textsuperscript{16} The IFP consists of open kinetic chain exercises and focuses on isolated joint motion and muscle action, which do not mimic athletic movement.\textsuperscript{6} Wikstrom et al\textsuperscript{6} used a IFP in which fatigue was induced by continuous concentric-concentric contraction of the plantar flexors and dorsiflexors at the same velocity (30\textdegree/s and 120\textdegree/s). Then, fatigue was determined to be the point when the torque of plantar-flexors and dorsiflexors decreased below 50\% of their peak torque value. Gribble et al\textsuperscript{7} used a similar IFP on three joints: ankle, knee, and hip at 60\textdegree/s. Fatigue was determined to be the point when the torque decreased below 50\% of their peak torque as well. However, results using IFP are questionable in generalizing to real athletic activity since isokinetic movements are not similar to athletic performance.\textsuperscript{6}

While IFP has been used traditionally, FFP has developed recently.\textsuperscript{6} The concept of a FFP was developed to use close kinetic chain exercises, which are more similar to sport specific movements to induce similar fatigue symptoms that the player feels during the athletic events.\textsuperscript{6} Typical exercises in a FFP include jogging, sprinting, push-ups, sit-ups, and 12-in (30.48cm) step ups, using the 15-point
Borg rating of perceived exertion (RPE) scale to evaluate the subject’s fatigue level.\textsuperscript{3,4} Wilkstrom et al\textsuperscript{6} established a more sophisticated and challenging FFP. This protocol included six stations: Southeast Missouri Agility Drill, Plyometric box jumps, side to side bounds, minitramp jumps, cocontraction arc, and two-legged hop sequence.\textsuperscript{6} Fatigue was determined if the time of completion of all six stations increased by 50\% of initial trial time.\textsuperscript{6} A long distance triathlon has also been used to induce fatigue.\textsuperscript{17} Sterner et al\textsuperscript{18} suggested that the FFP containing high intensity and short duration exercises for extended time period may induce similarly as seen with athletic performance. The disadvantage of using FFP is difficulty of measuring the general level of fatigue.

**Fatigue and Rating of Perceived Exertion**

Due to differences in inducing fatigue, it is difficult to evaluate the general level of fatigue. As mentioned, some studies have used 15-point Borg RPE to determine the level of fatigue.\textsuperscript{3,4} According to Borg\textsuperscript{19}, the 15-point RPE scale is the best indicator of the level of physical strain since various physiological signals coming from all body parts are integrated into perceived exertion. Because of its simplicity, the 15-point Borg’s RPE scale can predict
exercise intensity on the athletic field and during sport rehabilitation.\textsuperscript{19}

In addition to 15-point Borg RPE scale, working heart rate, oxygen consumption, ventilation, and blood lactate can be indicator of exercise intensity.\textsuperscript{14,20} There is a reported correlation between the 15-point Borg RPE scale and working heart rate (WHR), where the RPE value of 13 or 14 (somewhat hard to hard) can concur with 70\% of maximum working heart rate.\textsuperscript{14,19} One study reported the relationship between heart rate and 15-point Borg RPE scale during six minutes treadmill exercises among the active people whose age were from 20 to 30 years old.\textsuperscript{20} The RPE score of 13 was corresponded to the WHR ranging from 160 to 170 BPM and the RPE score of 15 (hard) was corresponded to the working heart rate ranging from 170 to 180 BPM.\textsuperscript{20} Additionally 80\% of maximum heart rate has been correlated with 15-point Borg RPE scale values ranging from 15 to 16 during treadmill exercise.\textsuperscript{21}

A relationship between the 15-point Borg RPE scale and the relative VO\textsubscript{2} max during the dynamic exercise has also been reported.\textsuperscript{22} Reportedly 80\% of maximum VO\textsubscript{2} corresponds to the RPE scale ranging 14 to 16 during treadmill exercise.\textsuperscript{21} Therefore, the RPE value of 15, which was thought as an adequate fatigue,\textsuperscript{4} coincides with 75\% to 90\% of maximum VO\textsubscript{2} consumption and WHR.\textsuperscript{20,21} As the feeling of
the fatigue is different one another, the body will respond to the level of fatigue. Many performance indicators such as balance may be affected by fatigue.

Balance and Limits of Stability

Balance, which is also referred to as postural equilibrium or postural stability, is defined as maintaining the COG within the base of support.\(^1,23,24\) To maintain balance, the feedback sensory control circuit between the CNS and the musculoskeletal system, and feed-forward mechanism compiled from previous motor experience are key factors.\(^1,23\) In addition, balance can be discussed as static or dynamic balance. Dynamic balance can be defined as the ability to maintain the body’s equilibrium under unstable conditions causing the COG to move.\(^24,25\) Static balance is defined as the ability of maintaining the body’s equilibrium under stable conditions without motion.\(^25\) These distinctions are important in determining what factors control dynamic balance overall.

Two components of the CNS, sensory organization and muscle coordination, have very important roles in control of
posture or balance. Sensory organization, which includes the vestibular, visual, and somatosensory inputs, informs the person of the position of the body in relation to gravity and its surroundings. Muscle coordination, which include the motion of ankle, knee, hip, trunk within entire kinetic chain, also has an important role in maintaining a postural stability during standing posture by contraction of the lower extremity or trunk musculatures to move the COG in any desired directions.

**Perception and Motor Control**

The CNS controls the perception and execution of musculoskeletal activity and performance. Perception and sensation of the movement are further controlled by three subsystems, which are somatosensory, visual, and vestibular system. Somatosensation, which is also referred to as proprioception or kinesthesia, includes the recognition of the joint movement and joint position sense. The somatosensory system receives information from mechanoreceptors, which include muscle spindle and Golgi tendon organ, with regard to muscle tension and length. The vestibular system receives information from the ear, and the visual system receives information from the eye system. Input received from all three subsystems is sent
to the three different levels of motor control, which are the spinal level, the brain stem, and higher centers from the cerebellum, basal ganglia to motor cortex. The spinal level is responsible for more immediate dynamic muscular stabilization while the brain stem controls posture and balance. The higher centers work in coordination to control voluntary motor movement. Any disruption among these sophisticated systems may impede balance, and may be caused by several factors such as injury, chronic ankle instability or foot type besides fatigue.

Other Factors Affecting Balance

Injuries to muscle or ligament may have a negative effect on the somatosensory mechanism, which can result in the decreased ability of maintaining balance. Chronic ankle instability also has a negative influence on the dynamic postural control because it will alter the somatosensory sense leading to increased movement of COG. Impairment of one joint due to injury may lead to alter the neural activity and compensation of other structures, which results in the disrupt balance control. Moreover, structural foot type, pronated or supinated, can negatively influence dynamic balance control using the Star Excursion Balance Test (SEBT). The SEBT measures the dynamic balance
control by letting subjects reach or lean without moving the foot and maintain upright posture. Structural abnormality of the midfoot, supinated or pronated, may also alter one’s LOS during the dynamic activity.

Additionally, impairment of one of three sensory inputs affects the control of balance. One study, which measured the control of balance near the LOS under various sensory conditions, showed that balance control was mostly affected by closed eyes and by vibration of the Achilles’ tendon. In this study, vision contributed most among all three sensory inputs for postural control, with proprioception contributing secondary to visual input for postural control. Many factors impede balance ability. Measuring accurate balance is important for studying balance or assessing an improvement of balance during rehabilitation. While there are some devices or technique assessing balance, the Biodex Balance system (BBS) is an effective tool as other balance measurement tools.

**Biodex Balance System**

The BBS (Biodex Medical System, Shirley, NY) utilizes a dynamic circular platform which can tilt up to 20° in all directions. The stability of the platform can be changed by on the touch screen which adjust the resistance of spring
wires located under and at the perimeter of the platform. The length of the wire is 13.97 cm, an outside diameter is 3.11 cm, a diameter of the wire is 0.24 cm, and a rate of spring is 13.81 N/cm. When the wire is compressed to 7.52 cm it creates 88.9 N of force. There are eight levels of stability. Level eight allows the platform to be most stable so that subjects maintain balance easily.

Researchers use the BBS to measure dynamic bilateral and unilateral postural stability on an unfixed surface, as well as dynamic LOS.

LOS is defined as the maximum angle a body is able to lean from vertical to all directions without falling or changing their base of support. Average LOS in normal adults extends 8° anteriorly, 4° posteriorly, and 8° medially and laterally. Dynamic LOS testing on the BBS lets subjects move their center of gravity to eight directions (anterior, posterior, medial, lateral, anterior-medial, anterior-lateral, posterior-medial, and posterior-lateral) by chasing targets on the touch screen. This test measures the quality of ability to control their COG as maintaining balance. According to Hinman, the reliability of dynamic LOS testing ranges from .77 to .89. Dynamic LOS assesses how smoothly and quickly a person is able to lean to one’s LOS. However, dynamic LOS testing
on the BBS does not measure the maximal angle which people is able to lean but this test assess how soon subjects return to original place from the place they lean.\textsuperscript{30} Once fatigued, dynamic motor control and balance control may be negatively affected.

The Effect of Fatigue on Balance

When fatigue occurs, joint proprioception and neuromuscular control of joints can be impaired.\textsuperscript{11} Due to fatigue, increasing the threshold of muscle spindle discharge may result in disruption of the afferent sensory feedback, which alters the joint proprioception.\textsuperscript{11} In addition to muscle spindle desensitization, ligament relaxation and/or Golgi Tendon Organ desensitization may lead to decrease efferent muscle response, which results in decreasing ability of balance.\textsuperscript{10} For example in the knee, Rozzi et al\textsuperscript{32} found that muscular fatigue caused decreasing proprioceptive ability and alterations in muscle activity. Moreover, fatigue may lead to increasing reaction time for muscle contraction.\textsuperscript{11} The time between the stimulus and the electrical response in skeletal muscle, and the time between
the electrical response and force generation by the muscle are delayed.\textsuperscript{11} Throughout these responses, fatigue has effects on the ability of both static and dynamic balance.

**Static Balance and Fatigue**

Static balance ability is reportedly disrupted due to fatigue no matter what fatigue protocol has been used.\textsuperscript{8-10} After ten minutes' IFP on the ankle, knee and hip, the unilateral and bilateral static balance ability significantly decreased.\textsuperscript{10} According to Nardone et al,\textsuperscript{9} fatigue negatively affected postural stability during quiet standing immediately after the fatigue exercises but the effect lasted only for 15 minutes. The sway path, which is distance covered during the quiet standing by the moving of center of foot pressure, significantly increased under both eye-open and eye-closed condition after treadmill fatigue protocols, while the sway path and sway area, which is the surface swept during the quiet standing by shifting the center of foot pressure, significantly increased only under eye-closed condition.\textsuperscript{9} This result showed that the contribution of the visual sensory might be more of a contributing factor than that of fatigue.\textsuperscript{9} Gauchard et al\textsuperscript{8} found the fatigue induced by a cycle ergometer increased postural instability, mainly due to decreased motor control.
efficiency and decreased sensitivity of sensory systems.

Dynamic Balance and Fatigue

Yaggie et al\textsuperscript{5} investigated the effect of lower extremity fatigue on dynamic balance using Kinesthetic Ability Trainer 2000 (KAT-2000) Balance System before, immediately, and 10 minutes after cycle ergometer exercise. The balance test was conducted by unilateral stand with looking the center of pressure on the screen.\textsuperscript{5} Results showed that balance ability has been disrupted due to fatigue, but the effect of fatigue was relatively short, lasting approximately 10 minutes. Eccentric muscle contraction might cause injurious muscle damage which can significantly affect force production. Cycle ergometer exercise containing mostly concentric muscle contraction, which cannot cause injurious muscle damage, might yield a transient fatigue effect.\textsuperscript{5} Moreover, fatigue induced by cycle ergometer exercise is not similar to fatigue induced by athletic activity or FFP because of the uniplanar motions used on the cycle ergometer.
**Functional Fatigue Protocol and Balance**

The total score of Balance Error Scoring System (BESS), a valid and reliable tool, which included double leg stand, single leg stand and tandem stand on both firm and foam surface, has increased due to the 20 minutes FFP, which includes jogging, sprinting, push-ups, sit-ups, and step-ups, but the effect only lasted for 20 minutes. In detail, functional fatigue had a great effect on the complex balance conditions such as tandem and single leg, while it had little effect on easy balance conditions such as double leg stand. The double stand did not result in many errors regardless of fatigue or not, while single leg stand under fatigued condition scored as many errors as under non-fatigue condition.

**Types of Fatigue Protocol and Balance**

No matter what fatigue protocols have been used, balance has been disrupted. Wikstrom et al found that FFP and IFP at the ankle adversely affected dynamic balance measured by time to stabilization test (TTS), which includes complex task of jump landing. However, there was no significant difference between functional fatigue and isokinetic fatigue to dynamic stability balance when landing from jump. One reason was that TTS is much more dynamic
and more difficult because this activity is a combination of strength, coordination, balance, and stability. Because of that, the test may not be sensitive or functional enough to detect the changes caused by fatigue.

**LOS Testing and Fatigue**

Johnston et al\textsuperscript{10} studied similar LOS testing before and after IFP using an instrumented balance assessment system (KAT, Breg INC). The test was performed by which subjects moved their center of gravity to chase the moving target on the screen, similar to the dynamic LOS test on the BBS.\textsuperscript{10} The result of this similar LOS testing showed that motor control performance was decreased, but not significantly. Because the subjects were able to view their COG on the screen during the test, the visual feedback might contribute to enhance their balance.\textsuperscript{10} Moreover, this test was performed after the static tests, which might give the time to recover their fatigue.\textsuperscript{10} Overall, fatigue has an effect on the balance ability no matter how fatigue is induced. On the other hand, balance tests that are too easy or too difficult seem to not be able to detect the exact effect of fatigue.
Summary

Fatigue is associated with the decline in muscle tension or force capacity with repeated stimulation, including perceptual alteration of increased difficulty for achieving desired exercise outcome. Fatigue can be addressed as central fatigue and muscle fatigue. As a result, fatigue may lead to increased reaction and movement time for muscle contraction. Various protocols have been used to induce fatigue such as the localized muscle fatigue protocol, IFP, and FFP. While IFP has been used traditionally, FFP has developed recently. The concept of the FFP was developed to use close kinetic chain exercises, which are more similar to sport specific movements to induce similar fatigue symptoms that the player feels during an athletic event. On the other hand, it is difficult to evaluate the general level of fatigue, due to differences in inducing fatigue. The 15-point Borg RPE scale can be an excellent indicator of the level of physical strain because various physiological signals coming from all body parts are integrated into perceived exertion. Because of its simplicity, the 15-point Borg RPE scale can predict exercise intensity in the athletic field and sport rehabilitation as well as research.
Balance is defined as maintaining the COG within the base of support.\textsuperscript{1,23,24} BBS has been reported as an effective device to measure balance. Researchers have used the BBS to measure dynamic bilateral and unilateral postural stability and dynamic LOS on an unfixed surface.\textsuperscript{30} LOS is defined as the maximum angle a body is able to lean from vertical to all directions without falling or changing their base of support.\textsuperscript{24} Dynamic LOS assesses how smoothly and quickly person is able to lean to one’s LOS while dynamic LOS test on BBS does not measure the maximal angle which people is able to lean.\textsuperscript{30}

Balance is maintained via the feedback sensory control circuit between the CNS and the musculoskeletal system, and feed-forward mechanism compiled from previous motor experience are key factors.\textsuperscript{1,23} Sensory organization, which includes the vestibular, visual, and somatosensory inputs, and muscle coordination, which includes motion of the ankle, knee, hip, and trunk, have a very important roles in control of posture.\textsuperscript{23} Therefore, any disruption in these procedure due to fatigue may affect static and dynamic balance. Many authors found that fatigue negatively affects static and dynamic balance.\textsuperscript{3-10} On the other hand, one study concluded that the contribution of the visual sensory might be more of
a contributing factor than that of fatigue for static balance.\textsuperscript{9}

Recently, authors have used dynamic balance tests or FFP because they want to create conditions similar to those of athletic competition. However, reliability and validity of the FFP is questionable. On the other hand, there are limited studies concerning the LOS or relationship between fatigue and LOS. While we already knew that fatigue affects balance, there still may be many ambiguous aspects between fatigue and balance as results differ based on the types of balance test and fatigue protocol. Further research is needed to determine more detailed factors.
APPENDIX B

The Problem
Statement of the Problem

The purpose of this study was to determine if fatigue induced by functional activity negatively affects dynamic LOS as measured by the BBS. Subjects were asked to move their COG to a target while looking on the screen which displays their COG and targets, and were tested under fatigue and non-fatigue condition during which the overall LOS score and time to complete the test were obtained. Because fatigue decreases the muscle coordination function and proprioception ability, it should have been more difficult to control their COG and meet the targets, resulting in a longer time to complete the test as well.

Definition of Terms

The following definitions of terms were operationally defined for this study:

1) Center of pressure – central point of the pressure that is applied to the foot during standing on the ground.

2) Central Fatigue – decreasing the ability for the central nervous system to stimulate the muscle contraction and changing the sense of effort.
3) Dynamic balance – the body’s maintenance of equilibrium under unstable conditions which causes the center of gravity to move.\textsuperscript{25}

4) Functional Fatigue Protocol – protocol which contains exercises mimicking athletic activity, which may result in the 15-point Borg RPE score of 15 or above.\textsuperscript{6}

5) Limits of stability – maximal angle that person is able to lean from a vertical position to any direction without falling.\textsuperscript{24}

6) Muscle fatigue – when a muscle no longer respond to neural stimulation.\textsuperscript{15}

7) Somatosensation – the recognition of joint movement and of the joint position sense.\textsuperscript{1,23} This term is also referred to as proprioception.\textsuperscript{23}

8) Static balance – the body’s maintenance of equilibrium under stable conditions without motion.\textsuperscript{25}

Basic Assumptions

The followings were basic assumptions of this study:

1) The subjects were adequately fatigued by completing FFP.

2) The equipment was calibrated and work properly during this study.

3) The subjects reported their perceived exertion
honestly and appropriately and test score would indicate adequate fatigue.

4) Testing instruments (Dynamic LOS testing and FFP) were valid and reliable.

5) The prescreening fitness level minimized subjects’ variability for the FFP.

**Limitation of the Study**

Generalizability of test results to the NCAA Division II Collegiate athletes, perhaps soccer only, whose fitness level were good or excellent.

**Significance of the Study**

The scope of this study was to expand the relationship between functional fatigue and LOS in healthy Division II collegiate athletes. During the athletic performance, one’s COG changes as the base of support is constantly changed. Once the COG exceeds the limit, a person will loose balance and fall. The prolonged and repeated intense activity can make athletes get tired, which can happen at the end of game or practice. Fatigue decrease performance and may induce an injury.\(^2\) While many authors found that fatigue negatively affect on the static and dynamic balance ability,\(^3-10\) there
are limited studies to examine the LOS as measured by the BBS under fatigue conditions.

In addition, the LOS test on BBS is unique because the subject tries to move the COG away from the center of the body. In a typical dynamic balance test, subjects are asked to hold their COG in place. Potential findings were that the overall LOS score would decrease and the time to complete test would get longer. These findings may demonstrate that controlling their COG is most difficult when fatigued, which may lead to decrease performance and increase the chance of injury.
APPENDIX C

Additional Methods
APPENDIX C1

Tecumseh Step Test
Tecumseh Step Test

Procedure

Subjects performed the test using 8 in (20.3cm) stair or box. Subjects were asked to perform the stepping cycle to a four-step cadence (up-up-down-down). All subjects completed 24 step-ups per minutes continuously for three minutes. After completing the test, subjects were asked to keep standing while the researcher took their heart rate for 30 seconds into recovery for 30 seconds. The number of the pulse represents the score.

Classification

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<td>52-59</td>
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APPENDIX C2

Push-Up Muscular Endurance Test
Push-Up Muscular Endurance Test

Procedure
This test was performed in full body push-up. Subjects performed as many push-ups as they could without rest.

Initial position
Full body push-up: keeping the hands shoulder width apart with arms fully extended

Movement
Full body push-up:
Pushing down until the elbows reach 90° of flexion and pushing up until the elbows are fully extended. The motion continued without any rest pauses.

Classification

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<td>Average</td>
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<tr>
<td>Fair</td>
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<td>Poor</td>
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</tbody>
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APPENDIX C3

Informed Consent Form
Informed-Consent Form

1. Hideki Matsumoto, ATC has requested my participation in a research study at California University of Pennsylvania. The title of the research is "The Relationship between Functional Fatigue and Limits of Stability in Division II Collegiate Athletes".

2. I have been informed that the purpose of the research is to compare the rate of change in limits of stability between a functional fatigue condition and non-fatigue condition in NCAA Division II collegiate athletes.

3. My participation will involve prescreening test for measuring personal fitness level and testing for limits of stability under functional fatigue and non-fatigue condition for 20 minutes of each conditions. I understand that I may not participate in the study past the prescreening fitness test. The fatigue protocol is 20 minutes exercise including jogging, sprinting, push-ups, sit-ups, and step-ups. The testing under both conditions will be conducted on two different days at the Hamer Hall’s athletic training room.

4. I understand there are foreseeable risks or discomforts to me if I agree to participate in the study. The possible risks include discomforts due to exercise or a fall from the BBS where the risks will be minimized by the spotter. While you can request stretching after testing, discomfort such as muscle soreness might not minimized by stretching and persist over 2 to 3 days, but normal exercises and activity is encouraged. These risks are no more than normal physical activity that collegiate athletes would be exposed during a regular practice.

5. I understand that in case of injury or persisted muscle soreness I can expect to receive treatment or care in Hamer Hall’s Athletic Training Facility which will provided by the student researcher, Hideki Matsumoto, ATC, or another Certified Athletic Trainer, either of whom can administer emergency and rehabilitative care. Additional services needed for prolonged care past 3 days will be referred to the attend in physician at the Downey Garofola Health Services located on campus.
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 that my name or identity will not be revealed. In order to maintain confidentiality of my records, Hideki Matsumoto will maintain all documents in a secure location in which only the student researcher and research advisor can 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 this study will be informed after completion of the study by:
    Hideki Matsumoto, ATC
    524 Second Street Apt#D
    California PA 15419
    724-825-9087
    Mat4216@cup.edu
    Or by the graduate thesis advisor:
    Rebecca Hess, Ph.D
    133 Hamer Hall
    California University of Pennsylvania
    California, PA 15419
    724-938-4359
    Hess_ra@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 any time 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.
Subject’s Signature __________________________ Date ________

Other signature (if appropriate) __________________ Date ________

13. I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research 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 ________

Approved by the California University of Pennsylvania IRB
APPENDIX C4

Demographic Sheet
Demographic Sheet

Subject Name: ______________ Date: __________
Age: ______________
Height: ______________
Weight: ______________
Gender: ______________
Current Sport: __________
Shoe size: __________

Tecumseh Step Test: __________
Push-Up Muscular Endurance Test: __________
APPENDIX C5

Functional Fatigue Protocol
Functional Fatigue Protocol

Station 1: Moderate jogging for 5 minutes

Subjects jogged at their own pace but not at a slow pace. Each subject run approximately 750m for five minutes. If they did not seem to achieve this criterion, they were encouraged to jog faster.

Station 2: Straight-line sprint for 3 minutes

Subjects sprinted down and forth along the length of the court as fast as they could with continued verbal encouragement to maintain speed. They were allowed to take a break between each sprint, but it was no longer than 15 seconds. If they took a break for more than 15 seconds, they were encouraged to re-start sprint.

Station 3: Push-ups for 2 minutes

Subjects were to do as many push-ups as they could in 2 minutes. They were allowed to take a break if they feel exhausted, but this rest was for no more than 10 seconds. If they did not
feel they could do push-ups anymore, they held the push-up position rest of the time.

Station 4: Sit-ups for 2 minutes

Subjects were to do as many sit-ups as they could in 2 minutes. They were allowed to take a break if they felt exhausted, but this rest would be for no more than 10 seconds. If they did not feel they could do sit-ups anymore, they held the sit-up position the rest of the time.

Station 5: 12-in (30.48cm) step-ups for 3 minutes

Subjects were to do step-ups at moderate pace for 3 minutes. The moderate pace was approximately 120 steps per minutes. They were allowed to take a break if they felt exhausted, but this rest would be for no longer than 10 seconds. If they took a break for more than 10 seconds, they re-started step-ups.

Station 6: Straight-line sprint for 3 minutes

Subjects were to sprint down and forth along the length of the court as fast as they could with continued verbal encouragement to maintain
speed. They are allowed to take a break between each sprint, but this rest would be for no longer than 15 seconds. If they took a break for more than 15 seconds, they re-started the sprint.

Station 7: Moderate jogging for 2 minutes

Subjects were to jog at their own pace. This was more like a cool-down, but they were not allowed to stop running.
APPENDIX C6

15-point Borg RPE Scale
15-point Borg’s RPE Scale

APPENDIX C7

Test Score Sheet
Test score

Subject number: ____________ Date: ____________

Condition: Functional fatigue

Pre-test

Overall LOS score: __________

LOS time to complete: __________

RPE score: before test __________; after test __________

Foot position: ________________________________

Knee position: ________________________________

Overall posture: ________________________________

Post-test

Overall LOS score: __________

LOS time to complete: __________

RPE score: before test __________; after test __________

Foot position: ________________________________

Knee position: ________________________________

Overall posture: ________________________________
Date: __________
Condition: non-fatigue

Pre-test
Overall LOS score:__________
LOS time to complete:__________
RPE score: before test__________; after test__________
Foot position:________________________________________
Knee position:________________________________________
Overall posture:______________________________________

Post-test
Overall LOS score:__________
LOS time to complete:__________
RPE score: before test__________; after test__________
Foot position:________________________________________
Knee position:________________________________________
Overall posture:______________________________________
APPENDIX C8

Institutional Review Board
**Project Title**  The Relationship between the Functional Fatigue and Limits of Stability in Division II Collegiate Athletes

**Researcher/Project Director**  Hideki Matsumoto

**Phone #**  724-825-9087

**E-mail Address**  mat4216@cup.edu

**Faculty Sponsor (if required)**  Dr. Rebecca Hess

**Department**  Health Science and Sport Studies

**Project Dates**  September 2005 to May 2006

**Sponsoring Agent (if applicable)**

**Project to be Conducted at**  Hamer Athletic Training Room at California University of PA

**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/](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**
Please attach a typed, detailed summary of your project AND complete items 2 through 6.

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 relationship between functional fatigue and limits of stability (LOS). Twenty (N = 20) healthy National Collegiate Athletic Association (NCAA) Division II collegiate athletes from California University of Pennsylvania are expected to participate in this study. Volunteer subjects who sign the informed consent form will go through prescreening tests (Appendices C1 and C2). Based on their results, subjects whose scores are in the top 20 will perform dynamic LOS test using Biodex Balance System (BBS) before and after 20 minutes of functional fatigue exercise and 20 minutes of rest. Any athletes who are in NCAA official regular season during this study will not be included in this study. Any athletes who suffer from any visual, vestibular, balance disorder, serious lower extremity injury and/or a concussion within the last six months will not be included in the study. The testing will be administered two times under both fatigue and non-fatigue conditions. The functional fatigue protocol includes jogging, sprinting, sit-ups, push-ups, and step-ups (Appendix C5). The researcher will obtain the LOS overall score and LOS time to complete test. For a data analysis, difference scores will be calculated for pre/post test (post-pre) for both conditions. A paired t-test will be used to determine the difference between condition (fatigue/non-fatigue) for the dependent variables, LOS overall score and LOS total time to complete test. SPSS 12.0 will be used for data analysis. The followings are the research hypotheses: (1) The LOS overall score will decrease due to functional fatigue; (2) The LOS time to complete test will increase due to functional fatigue.

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 insure 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 BBS during testing where the risks will be minimized by a spotter. While subjects can request stretching after the testing, discomfort such as muscle soreness might not be minimized by stretching and persist over 2 to 3 days. This activity is no more than an athlete would endure in a regular competition or practice. In that case, I will take care of the subjects next 3 days in the Hamer Hall’s Athletic Training Room. Additional services needed for prolonged care past 3 days will be referred to the attending physician at the Downey Garofola Health Services located on campus.

   b. How will you insure 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.*

All subjects will be volunteers and are NCAA Division II collegiate athletes at California University of Pennsylvania. Any athletes who are in NCAA official regular season during the study will be not included. Any athletes who suffer from any visual, vestibular, balance disorder, serious lower extremity injury and/or a concussion within the last six months will not be included in the study. They have adequate fitness level measured by prescreening test to minimize subjects’ variability for the FFP.

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 completed and signed by all subjects before participating in this study at the informational meeting. A copy of the form is attached to this form. Each signed form will be kept by the researcher.

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.*

Data will be collected during spring semester but no later than spring break. All subjects are supposed to come in 2 different occasions for testing under fatigue and non-fatigue condition. All collected data which will be identified by subject number will be maintained by the researcher in a secure location in which the researcher and research advisor can access.

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

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<td>Economically Disadvantaged People</td>
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<td>Children Under 18</td>
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<tr>
<td>☐ Physically Handicapped People</td>
<td>Neonates</td>
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</table>

4. *Is remuneration involved in your project? ☐ Yes or ☒ No. If yes, Explain here.*

5. *Is this project part of a grant? ☐ Yes or ☒ No*  
**If yes, provide the following information:**

Title of the Grant Proposal

Name of the Funding Agency
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

[Signatures]

Student or Class Research

[Signatures]

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:
Dates of the Project Period

6. Does your project involve the debriefing of those who participated?  ☐ Yes or  ☑ 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.
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

9 February 2006
Date
REFERENCES


10. Johnston III RB, Howard ME, Cawley PW, Losse GM. Effect of lower extremity muscular fatigue on motor


31. Brouwer B, Culham EG, Liston RA, Grant T. Normal variability of postural measures: implications for the

ABSTRACT

TITILE: The Relationship between Functional Fatigue and Limits of Stability in Division II Collegiate Athletes

RESEARCHER: Hideki Matsumoto

ADVISOR: Dr. Rebecca Hess

DATE: May 2006

RESEARCH PROBLEM: Master Thesis

PURPOSE: The purpose of our study was to examine how 20 minutes of functional fatigue affected dynamic balance ability (LOS) as measured by the Biodex Balance System (BBS) in collegiate athletes.

PROBLEM: Dynamic balance ability, which has the most influence on the athletic performance, will be most difficult when fatigued, which might lead to decreased performance and increase the chance of injury.

METHODS: This study used a within-subject design. Fourteen Division II collegiate soccer athletes participated in this study. Testing was administered two times under fatigued and non-fatigued condition.

FINDINGS: There was a significant difference in LOS overall score due to fatigue (t(13) = -3.645, P = .003).

CONCLUSIONS: Twenty minutes of functional activity will likely have a negative influence on dynamic balance ability in Division II collegiate athletes. Our findings suggest that 20 minutes of sport activities will lead to decreased dynamic balance ability and potentially, performance level, as well as an increased risk of injury.