RECOVERY TIME ON LIMITS OF STABILITY FROM FUNCTIONAL FATIGUE 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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THESIS APPROVAL

Athletic Training

We hereby approve the Thesis of

Toshimitsu Ishizuka
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ACKNOWLEDGEMENTS

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 thank my advisor Dr. Rebecca Hess and the members of my committee: Dr. Marc Federico and Dr. Ben Reuter. Their knowledge, input, and experience were invaluable to maintain my motivation to think deeper and work consistently, which lead the success of this product.

I also thank all my classmates, faculty, coaches, and students at California University of Pennsylvania for their support and a fun year. To the members of the California University of Pennsylvania soccer team, I really appreciate your time and effort to participate in my study.

Finally, I thank my family for always supporting me and understanding my desire to complete my Master of Science Degree. I appreciate all the help. I love you all: Dad, Mom, and my brothers, Toshihiro and Toshiyuki.
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INTRODUCTION

Most athletic participation requires dynamic balance, or maintaining equilibrium during motion or regaining equilibrium through changing position. During athletic activity, one’s center of gravity (COG) shifts continuously and the base of support (BOS) changes spontaneously. Therefore, better control of the COG may lead to better performance. In fact, higher level athletes are reportedly superior in dynamic balance performance. On the other hand, fatigue decreases dynamic balance ability and subsequently may negatively affect physical performance. As athletic performance declines, the risk of injury may also increase due to fall or collision. Previous research has found that dynamic balance and limits of stability (LOS) is negatively affected by functional fatigue. However, there is limited literature reported for recovery time on balance after fatigue is induced. It is critical for athletes to retrieve dynamic balance ability in order to maintain optimal performance level and decrease the risk of injury.

High-intensity repeated, or low-intensity prolonged exercises may induce fatigue, which is a natural physiological response. While the exact mechanism of neuromuscular fatigue is not totally understood, fatigue is
categorized into central and peripheral depending on type, duration, and intensity of activities.\textsuperscript{15-17} Central fatigue is a reduction in the neural drive from the central nervous system (CNS) to muscles that cause a decline in the force output.\textsuperscript{15,17} On the other hand, peripheral fatigue is described as an inability for the body to supply sufficient energy to the contracting muscles to meet the increased energy demand.\textsuperscript{15-17} Fatigue in short-term exercise may be explained by peripheral fatigue, but, during prolonged exercise, the combination of central fatigue and peripheral fatigue may develop.\textsuperscript{15,16}

The functional fatigue protocol (FFP) designed by Wilkins et al\textsuperscript{14} is intended to induce similar fatigue athletes would encounter during the course of sports participation such as soccer, football, and basketball. Therefore, the FFP should consist of closed kinetic chain exercises occurring through multi planes to simulate sports specific movements when applied to athletes.\textsuperscript{7,12,14} To quantify the amount of fatigue, some researchers have measured ratings of perceived exertion (RPE) on the Borg 15-point RPE scale.\textsuperscript{12-14} RPE indicates the level of physical strain perceived by the individual during exercise.\textsuperscript{18,19} RPE has been shown to positively relate to heart rate and oxygen uptake.\textsuperscript{20,21} A score of 15 or above of RPE with FFP has been
considered as adequate fatigue for healthy subjects, as well as athletic population.\textsuperscript{12-14}

Static and dynamic balance require the CNS to integrate afferent information from the visual, vestibular, and proprioceptive systems.\textsuperscript{1,2,22-24} The visual, vestibular, and proprioceptive systems work together as well as compensate for each other.\textsuperscript{2,22,24} Depending on available sensory information and athletic levels, relative contribution of sensory inputs might vary.\textsuperscript{2,24} Better dynamic balance may be achieved with a greater sensitivity of sensory receptors and/or better integration of information.\textsuperscript{1-3} The dynamic LOS test is unique for assessing athletic performance because it invokes a great amount of neuromuscular control, as well as visual and vestibular components.\textsuperscript{25,26}

The LOS is defined as the maximum angle that a person can incline from the upright position in any direction without falling or altering his or her BOS.\textsuperscript{25} The Biodex Balance System (BBS) allows a dynamic balance assessment by inquiring subjects to intentionally move their center of mass (COM) within their LOS.\textsuperscript{25} In other words, dynamic LOS testing on the BBS assesses how accurately and quickly subjects move their COM and regain their balance.\textsuperscript{26} The CNS needs to integrate afferent information from the visual, vestibular, and proprioceptive systems to complete the
complex balance task providing accurate neuromuscular control.\textsuperscript{1,2,22-24} Fatigue, both central and peripheral, may cause the decline in balance performance altering the functions of the three sensory systems and/or integration of information.\textsuperscript{27} Twenty minutes of functional fatigue negatively influences tandem and single leg balance conditions, while no difference was observed on the double leg condition during dynamic balance testing in healthy subjects.\textsuperscript{14} Matsumoto\textsuperscript{12} also found that 20 minutes of functional fatigue deteriorated the dynamic LOS score as measured by the BBS in Division II collegiate athletes.

Balance deficits in healthy subjects have been reported at immediately, 5, 10 and 15 minutes after functional fatigue, with deficits improving by 15 minutes and recovering by 20 minutes when static and dynamic balance was assessed using the Balance Error Scoring System (BESS).\textsuperscript{13} The single leg balance ability on a moveable platform resolved within 10 minutes after exertion induced by an anaerobic ergocycle.\textsuperscript{4} Increased body sway was also reported up to 15 minutes after 25 minutes of treadmill running.\textsuperscript{10} However, research investigating the time needed to recover dynamic LOS from exertion has not been reported. Therefore, the purpose of this study was to determine recovery timeline on LOS from functional fatigue in collegiate athletes. It
was expected that the overall LOS score would decrease immediately after functional fatigue, recover with rest, and return to baseline by 20 minutes after functional fatigue.
METHODS

Research Design

This study was a quasi-experimental, within-subject design. The independent variables were condition (fatigue/non-fatigue) and time (repeated measure). Functional fatigue was determined by using the Borg 15-point RPE scale. The dependent variable was overall LOS score as measured by the Biodex Balance System (BBS). Measurements were administered under two conditions (fatigue/non-fatigue) on different days, and conditions were randomized to control test effect. Under the fatigue condition, subjects were tested for LOS on the BBS before a fatigue procedure, immediately after the fatigue procedure, and 10, 15, and 20 minutes after the fatigue procedure. The use of the within-subjects design was an advantage of this study as subjects served as their own control. The unique use of the dynamic LOS test after the FFP made this study valuable in addressing the effect of functional fatigue on dynamic balance recovery. Findings may be generalized to the Division II collegiate athletes, perhaps only soccer players.
Subjects

Healthy National Collegiate Athletic Association (NCAA) Division II collegiate athletes from California University of Pennsylvania men’s and women’s soccer teams participated in this study. Twenty three athletes (14 males, 9 females) volunteered to participate in this study after the researcher explained the concept of the study by oral and written document. Fitness levels of subjects were screened by the Tecumseh Step Test (Appendix C1) and the Push-Up Muscular Endurance Test (Appendix C2). Subjects who scored into or above the “good” level for both tests were included in this study. Any subjects who had suffered from visual, vestibular, balance disorder, lower extremity injury, and/or a concussion within the last six months were excluded from this study as these conditions might interfere with accurate balance assessment. All subjects read and signed the informed consent form (Appendix C3) prior to the fitness screening and further participation of this study.
Preliminary Investigation

Preliminary investigation was designed to obtain the information about learning effects on the LOS test. Four healthy subjects (two male, two female) were tested under both fatigue and non-fatigue conditions using the same methods for the study. Learning effects on dynamic and static balance have been reported in non-fatigued subjects.\textsuperscript{12-14,28} However, after a fatigue protocol, no such effects have been present.\textsuperscript{12-14,28} A lack of a learning effect after fatigue compared with the non-fatigue procedure suggests that fatigue may interfere with or impair the learning of a task.\textsuperscript{14,13,28} The pilot research helped to determine adequate practice times, as well as effects of multiple dynamic LOS tests. It was determined that two practices of dynamic LOS testing were enough for subjects to become familiar with the dynamic LOS test and sufficiently minimize learning effects.

Instruments

A demographic sheet (Appendix C4), the Biodex Balance System (BBS), the functional fatigue protocol (FFP)
(Appendix C5), the 15-point Borg RPE scale (Appendix C6), and test score sheet (Appendix C7) were used in this study.

**Testing Instrument**

Overall LOS score and time to complete the test were obtained by the BBS. LOS is defined as the maximum angle that a person can incline from the upright position in any direction without falling or altering their BOS. The dynamic LOS is measured by requiring subjects to move their COG to eight targets indicated on the screen in any direction under their own control. The subjects should hit each target with a cursor and hold the cursor inside the flashing box for .25 seconds. The dynamic LOS testing on the BBS assesses how accurately and quickly subjects control their COG. The LOS test score is represented by the following formula was utilized to calculate the overall LOS score and total time to complete test.

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

Overall LOS score = (LOS scores)/8
Subjects with higher scores in a shorter time to complete the test have better control of their COG within their LOS. Reliability of the LOS test on the BBS has been reported from .77 to .89. NeuroCom’s protocol for testing LOS has reported reliability range form .73 to .91.\textsuperscript{26}

**Protocol and Instruments**

Fatigue was induced by using an established FFP (Appendix C5) to simulate exertion during athletic activity.\textsuperscript{12-14} The FFP was divided into seven stations: Station one was a five-minute moderate jog at the subject’s self-selected pace, station two was sprints up and down the length of a basketball court for three minutes, station three was two minutes of push-ups, station four was two minutes of sit-ups, station five was three minutes of 12-in (30.48cm) step-ups, station six was another set of sprints for three minutes, and station seven was again moderate jogging for two minutes. Subjects were given specific instructions for the FFP by the researcher and were encouraged to maintain a high level of exertion through station two to station six.

The Borg 15-point RPE scale (Appendix C6) was used to measure the level of physical strain, or perceived exertion.\textsuperscript{18,19} On the scale, RPE is rated between six and 20,
where six is minimum and 20 is maximum exertion. RPE has been positively related to heart rate and oxygen consumption during exercise \((r = .95 \text{ to } 1.00)\).\textsuperscript{20,21} A score of 15 or above has been considered as adequate fatigue,\textsuperscript{12-14} and has been shown to correspond with 75% to 90% of maximum oxygen consumption and maximum heart rate.\textsuperscript{20,21} For subjects in the fatigue condition, RPE scores were monitored immediately before the FFP and before each post dynamic LOS test.

Procedures

The study was approved by the California University of Pennsylvania Institutional Review Board (IRB) (Appendix C8). Athletes at California University of Pennsylvania men’s and women’s soccer teams volunteered to participate in this study during a brief meeting with each team in the absence of the coach. The concept of the study was explained to the athletes and the informed consent form (Appendix C3) was reviewed for them to understand the need for and risks of involvement in the study. Qualifications for the subjects were also announced. The pre-screening tests were set up before the testing date was scheduled for each subject. After athletes understood and signed the informed consent form, their height and weight were measured by the
researcher, and fitness levels were assessed using the Tecumseh step test (Appendix C1) and Push-up muscular endurance test (Appendix C2) to complete the demographic sheet (Appendix C4).

Qualified subjects, those scoring into the “good” or above level for the fitness tests, were scheduled for two test sessions on different days. To determine which test condition the subjects would take part in, subjects chose one of two sheets (fatigue/non-fatigue) the first day of testing to allow for random administration of the condition. The test procedure and method were explained again prior to beginning of the test session. The subjects prepared themselves as needed before testing. The researcher instructed each subject to stand on both legs on the BBS platform and to maintain their balance on the unstable platform while they were chasing a blinking target appearing in random sequence in any directions of the eight target boxes. The platform firmness was set at level eight, the most stable. The subjects were asked to keep their arms crossed in front of their chest. Two practice testing sessions were given for each subject before testing in order to become familiar with LOS testing on the BBS, and then to minimize the learning effects.
Under the non-fatigue condition (NON-FATIGUE), subjects performed the dynamic LOS test (PRE) on the BBS and then rest for 20 minutes. The subjects sat down on a chair during the 20-minute rest. Then, the non-fatigue subjects performed the dynamic LOS tests immediately (TEST1) after the rest, and 10 (TEST2), 15 (TEST3), and 20 (TEST4) minutes after the rest. Under the fatigue condition (FATIGUE), subjects performed the dynamic LOS test (PRE) and then begin the FFP (Appendix C5). The functional fatigue subjects performed the dynamic LOS tests immediately (TEST1) after the FFP, and 10 (TEST2), 15 (TEST3), and 20 (TEST4) minutes after the FFP. The subjects were allowed to sit down or walk around between the dynamic LOS tests after the FFP. The functional fatigue subjects were asked to report their RPE on the Borg 15-point RPE scale (Appendix C6) immediately before the FFP and before each post dynamic LOS test. Every test score and RPE score were recorded on the test score sheet (Appendix C7) by the researcher. The subjects were asked to come back in one week from the first day to complete the second session using the other condition.
Hypothesis

The following hypothesis was tested in this study:

The overall LOS score will decrease immediately after functional fatigue, recover with rest, and return to baseline by 20 minutes after functional fatigue.

Data Analysis

A 5 × 2 mixed-design ANOVA was used to determine the difference within subjects (PRE, TEST1, TEST2, TEST3, and TEST4) and between conditions (FATIGUE or NON-FATIGUE) for the overall LOS score. The data analysis was performed using the SPSS 14.0 statistical software package at an alpha level of ≤ .05.
RESULT

Demographic Data

Twenty three athletes (14 males, 9 females) from the Division II California University of Pennsylvania men’s/women’s soccer team volunteered to participate in the study. Two volunteer athletes did not meet the criterion level of “good” or above on the Tecumseh step test and Push-up muscular endurance test. Three volunteer athletes dropped out of the study after the fitness tests due to injury or illness. Eighteen athletes (11 males, 7 females) completed two testing sessions (the fatigue and non-fatigue conditions). All demographic data (Table 1) were collected by the researcher at the time of fitness testing. All tests were conducted in the same way by the researcher to increase internal validity.
Table 1. Demographic Data

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Hypothesis Testing

Hypothesis testing was performed by using data from the eighteen subjects who completed two testing sessions. The hypothesis was tested at an alpha level of ≤ .05.

Hypothesis: The overall LOS score will decrease immediately after functional fatigue, recover with rest, and return to baseline by 20 minutes after functional fatigue. A 5 × 2 mixed-design ANOVA was calculated to examine the effect of the time (PRE, TEST1, TEST2, TEST3, and TEST4) and conditions (FATIGUE, NON-FATIGUE) on the overall LOS scores.

Conclusion: A significant time × condition interaction was present (F(4, 136) = 4.1777, P = .003). In addition, the
main effect for time was significant \((F(4,136) = 6.574, P < .001)\). The main effect for condition was not significant \((F(1,34) = .001, P > .05)\).

A follow-up one-way ANOVA was performed to examine the time \(\times\) condition interaction and indicated that overall LOS scores were significantly different between FATIGUE and NON-FATIGUE at TEST1 \((F(1,34) = 4.364, P = .044)\). Upon examination of the data, the mean score for NON-FATIGUE \((37.111 \pm 11.09)\) was higher than the mean score for FATIGUE \((30.444 \pm 7.76)\) at TEST1, indicating that overall LOS score was significantly decreased immediately after the FFP.

Follow-up paired t-tests were calculated for the effect of time comparing PRE to TEST1, TEST1 to TEST2, TEST2 to TEST3, and TEST3 to TEST4 regardless of condition. A significant increase from TEST1 to TEST2 was found \((t(35) = -2.148, P = 0.39)\). The mean score difference from TEST1 to TEST2 regardless of condition was \(3.083 \pm 8.61\). The figure 1 indicates that the FATIGUE group considerably increased overall LOS score, but the Non-FATIGUE group decreased overall LOS score.
Figure 1. Mean overall LOS score at prior to (PRE), immediately (TEST1), 10 (TEST2), 15 (TEST3), and 20 minutes (TEST4) following 20 minutes of the FFP (FATIGUE) and 20 minutes of rest (NON-FATIGUE).

Table 2. Means and standard deviations for the overall LOS score of prior to (PRE), immediately (TEST1), 10 (TEST2), 15 (TEST3), and 20 minutes (TEST4) following 20 minutes of the FFP (FATIGUE) and 20 minutes of rest (NON-FATIGUE).

<table>
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<tr>
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<th>NON-FATIGUE</th>
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<tr>
<td>PRE</td>
<td>34.389 (10.39)</td>
<td>31.833 (8.49)</td>
</tr>
<tr>
<td>TEST1</td>
<td>30.444 (7.76)</td>
<td>37.111 (11.09)</td>
</tr>
<tr>
<td>TEST2</td>
<td>37.167 (8.33)</td>
<td>36.556 (6.98)</td>
</tr>
<tr>
<td>TEST3</td>
<td>38.389 (11.40)</td>
<td>37.833 (9.82)</td>
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<tr>
<td>TEST4</td>
<td>40.278 (10.64)</td>
<td>36.833 (11.00)</td>
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Additional Findings

Paired t-tests for the effect of time during the fatigue condition revealed that there was no significant difference from PRE (prior to the FFP) to TEST1 (immediately after the FFP) \((t(17) = 1.678, P > .05)\), even though the mean overall score decreased from 34.389 ± 10.38 to 30.444 ± 7.76. A significant increase from TEST1 to TEST2 (10 minutes after the FFP) was found \((t(17) = -4.148, P = .001)\). The mean score difference from TEST1 to TEST2 on the fatigue condition was 6.722 ± 6.86. This indicates that dynamic LOS recovered within 10 minutes and continued to improve 10 minutes after the FFP.

Paired t-tests for the effect of time during the non-fatigue condition revealed that there was a significant increase from PRE (prior to 20 minutes of rest) to TEST1 (immediately after 20 minutes of rest) \((t(17) = -2.782, P = .013)\). The mean score difference from PRE to TEST1 on NON-FATIGUE condition was 5.278 ± 8.05. This indicates the subjects significantly improved overall LOS score at the forth trial (two practices and one pretest had been given) when no activity was involved between trials.

Subjects were asked to report their RPE on the Borg 15-point RPE scale immediately before the FFP and before each
post LOS test. Sixteen subjects out of eighteen reported a score of 15 or above of RPE immediately after the FFP, indicating that the FFP induced adequate fatigue. Mean RPE significantly increased after the FFP and gradually decreased with rest (Figure 2). Mean LOS score dropped off as mean RPE increased.

Figure 2. Mean RPE reported by subjects before the functional fatigue protocol (FFP) and before each post LOS test.
A one-way ANOVA at every test (PRE, TEST1, TEST2, TEST3, and TEST4) was computed comparing gender differences on overall LOS score. A significant difference for every test was found between male and female: PRE \( (F(1,34) = 16.030, P < .001) \), TEST1 \( (F(1,34) = 8.376, P = .007) \), TEST2 \( (F(1,34) = 9.353, P = .004) \), TEST3 \( (F(1,34) = 13.362, P = .001) \), and TEST4 \( (F(1,34) = 6.991, P = .012) \). Female subjects scored higher than male subjects for every dynamic LOS test (Figure 3). A follow-up one-way MANCOVA was calculated examining the effect of weight on overall LOS score, co-varying the effect of gender since the female subjects were lighter in weight. A significant effect of weight was found \( (F(75,76) = 1.544, P = .030) \), with no significant effect for gender \( (F(5,15) = .981, P > .05) \). Follow-up univariate ANOVAs indicated that overall LOS scores were significantly influenced by weight at PRE \( (F(16,19) = 5.531, P < .001) \), TEST2 \( (F(16,19) = 3.547, P = .005) \), TEST3 \( (F(16,19) = 2.393, P = .036) \), and TEST4 \( (F(16,19) = 8.697, P < .001) \), but not at TEST1 \( (F(16,19) = 2.051, P > .05) \). These data combined, indicate that weight had a greater effect on overall LOS score than gender as the females were not only lighter, but also scored higher on the dynamic LOS test than the males.
Figure 3. Mean overall LOS score of male and female at prior to (PRE), immediately (TEST1), 10 (TEST2), 15 (TEST3), and 20 minutes (TEST4) following 20 minutes of the FFP (FATIGUE) and 20 minutes of rest (NON-FATIGUE).

Figure 4. Mean weight of male and female.
Figure 5. Relationship between weight (kg) and overall LOS score at the pretest.
DISCUSSION

Discussion of Results

The main finding was that exertion induced by 20 minutes of functional exercise negatively affected dynamic balance as measured by the dynamic LOS test, with recovery of dynamic balance occurring within 10-minute rest period. The finding of decreased dynamic balance after exertion is consistent with findings of previous studies.\textsuperscript{12-14} Interestingly, dynamic balance was recovered within 10 minutes after exertion, which support finding of Yaggie and Armstrong.\textsuperscript{4} Yaggie and Armstrong\textsuperscript{4} found that dynamic balance on a moveable platform recovered within 10 minutes after exertion induced by two maximal effort cycling for 30 seconds with a 2-minute test between. However, the balance recovery time was faster than previous findings.\textsuperscript{10,13} Susco et al\textsuperscript{13} found that balance deficits lasted up to 15 minutes after exertion induced by the FFP and that balance recovered at the 20 minutes of rest, as measured by the Balance Error Scoring System (BESS). Nardone et al\textsuperscript{10} also reported that increased body sway while standing feet together lasted about 15 minutes after exertion induced by 25 minutes of treadmill running.
The different recovery time may be due to different types of balance test. Balance was tested on an unstable platform in our study as well as Yoggie and Armstrong's study, while Scott et al and Nardone et al tested balance on a flat or more stable surface. Dynamic balance on a moveable platform would be a novel task. Therefore, subjects might be more trainable on the unique task than on a stable surface. In fact, there was a significant increase of LOS score immediately following 20 minutes of rest, indicating significant learning effect occurred after three trials (two practices and one pretest). The learning effects might interact with the effect of fatigue, contributing to the result of no significant difference in LOS score between pretest and the test immediately after the FFP. Furthermore, the learning effect of repeated testing might have exaggerated the recovery time of dynamic balance measured by the BBS.

Dynamic LOS test on the BBS measures accuracy of control motion of COM within LOS. This task requires higher integration of afferent information from visual, vestibular, and proprioceptive systems in the CNS since stimulation of the sensory systems are constantly changing. Sensorimotor integration allows one to execute desired movement. The visual, vestibular, and proprioceptive systems
work together and compensate for each other.\textsuperscript{2,22,24} Vision, auditory, and proprioceptive information reportedly contribute maximum 37\%, maximum 44\%, and minimum 26\%, respectively, to balance control in healthy subjects.\textsuperscript{24} When they cannot compensate for each other, dynamic balance is disturbed.\textsuperscript{13} It is difficult to distinguish which sensory systems were influenced more by the FFP in our study.

Sensory inputs from visual, vestibular, and proprioceptive systems might be highly stimulated during the FFP.\textsuperscript{27} There is constant stimulation of muscle spindles, Golgi tendon organs, joint receptors, and cutaneous afferents on the sole of the foot. Vestibular system senses head acceleration and deceleration, and the eyes are constantly stimulated by the motion of the visual fields. An adaptation of the CNS to the hyper-stimulation of sensory inputs might alter sensorimotor integration, which leads to altered dynamic balance.\textsuperscript{27} As well, vestibular function might be altered due to dehydration or perturbed vestibular vascularization caused by peripheral blood pooling after sudden stop in exercise.\textsuperscript{8,27}

The FFP in our study produced adequate fatigue indicated by the reported levels of perceived exertion in the same way as previous studies.\textsuperscript{12-14} We considered a score of 15 or above on the RPE scale as adequate fatigue, which
reportedly corresponds to approximately more than 80% VO₂max and maximum heart rate.\textsuperscript{21} In our study, RPE significantly decreased 10 minutes after exertion and continued to gradually decrease with rest, as LOS score significantly increased with 10-minute rest and continued to gradually increase. In other words, recovery of physical strain after exertion appeared to coincide with the recovery of dynamic balance. Susco et al\textsuperscript{13} found a significant positive correlation between the posttest BESS score and the corresponding RPE score, suggesting that “level of exertion may be a factor that affects balance deficits and recovery, and an RPE score might be a better indication of recovery than a specified time interval.”\textsuperscript{13(pp245)} Since heart rate and oxygen uptake are positively correlated with RPE scores,\textsuperscript{20,21} heart rate or other physiologic measures may also be utilized as better indicators of recovery than a specified time interval, or in conjunction with an approximate time.

The FFP was designed to induce similar fatigue athletes would encounter during the course of sports participation such as soccer, football, and basketball.\textsuperscript{7,12-14} Although RPE indicates central fatigue rather than peripheral fatigue, the FFP possibly induced both the peripheral and central fatigue. It is difficult to quantify the two type of fatigue without the electromyography (EMG).\textsuperscript{17} Neuromuscular fatigue,
or decreased tension output in muscle, is the result of either central or peripheral fatigue, or both. Since 50% or more decreased maximum voluntary contraction resulted in balance deterioration in previous studies, decreased strength due to fatigue might adversely affect dynamic balance after the FFP.

Female subjects had better dynamic balance measured by dynamic LOS test than male subjects. However, weight difference between genders would be the explanation of the gender difference on LOS score since the females were not only lighter, but also scored higher on the dynamic LOS test than the males. Matsumoto found a moderate negative correlation between weight and LOS score among Division II soccer players. LaPierre also reported high negative correlation between weight and dynamic stability, as measured by the “Dynamic Balance” test that requires subjects to stand on the moveable platform as stable as possible, among the Division II football players. These findings indicate that a heavier person tends to have less dynamic balance than a lighter person. During the dynamic LOS test on the BBS, subjects need to move their COM toward targets while standing on a moveable platform. In a heavier person, higher momentum is applied to the direction of movement making the change in direction of movement much
harder. Therefore, it is more difficult for a heavier person to regain balance on an unstable surface.

Conclusions

Twenty minutes of functional activity will likely have a negative influence on dynamic balance, with balance recovery occurring within 10 minutes after the cease of exercise in Division II collegiate soccer athletes. For the dynamic LOS test, at least four trials before testing will minimize the learning effect of repeated testing. Moreover, the level of exertion measured by RPE will correspond to dynamic balance. In addition, gender differences in favor of college-aged females may be expected on the LOS test due to their relatively lighter weight as opposed to a true difference in dynamic balance control.

Recommendations

Our findings suggest that functional activities will lead to decreased dynamic balance ability as athletes are fatigued, and that dynamic balance ability will recover as recovery of physical exertion occurs. Decreased dynamic balance ability may lead decreased performance as well as
increased risk of injury due to fall or collision during sport activities. Therefore, rest intervals between physically challenging activities during practice or training may help to enhance performance and prevent injury. Moreover, athletic trainers may be able to identify those athletes who are at high risk for injury due to fall or collision, using a similar protocol applied in our study. After identifying high risk athletes, athletic trainers and conditioning coaches may be able to design exercise programs for them with adequate resting time. Furthermore, athletes might be able to improve their control of COG during strenuous functional activities if they incorporate LOS training after exertion.
REFERENCES


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APPENDICES
APPENDIX A

Review of the Literature
Balance is an important element of motor skills.\textsuperscript{1} Loosing balance negatively affects athletic performance.\textsuperscript{2} Athletes would struggle or fail to complete their task if they lose their balance. Poor balance, as well as fatigue, may also increase the risk of injury due to fall or collision. While the relationship between fatigue, recovery time, and dynamic balance have been reviewed,\textsuperscript{3-10} only one study has addressed the effect of fatigue on limits of stability (LOS), or regaining balance.\textsuperscript{11} Moreover, the recovery time from fatigue on LOS has not been studied. Therefore, the purpose of this review of the literature is to discuss fatigue and functional fatigue, balance and limits of stability, and the effects of fatigue on balance and recovery.

Fatigue and Functional Fatigue

Fatigue may be a natural physiological response induced by high-intensity repeated exercise or low-intensity prolonged exercise.\textsuperscript{12} One cannot sustain the level of normal ability when fatigued.\textsuperscript{12} The neuromuscular system that consists of the central nervous system (CNS), peripheral nervous system (PNS), neuromuscular junction, and muscle fiber can all be affected by fatigue.\textsuperscript{13} While the exact
mechanism of neuromuscular fatigue is not totally understood, two main types of fatigue are accepted, central and peripheral fatigue.\textsuperscript{12,14}

Central fatigue is a reduction in the neural drive from the CNS to muscles that cause a decline in the force output.\textsuperscript{12,15} The reduced neural drive is considered to be a mechanism for normal function of vital organs.\textsuperscript{12,15} On the other hand, peripheral fatigue is described as an inability for the body to supply sufficient energy to the contracting muscles to meet the increased energy demand.\textsuperscript{12,14,15} The deficiency of energy, then, leads to the accumulation of lactic acid and other acidic anaerobic metabolic by-products in the muscle, causing burning sensation of local muscle.\textsuperscript{12,14,15} Fatigue in short-term exercise may be explained by peripheral fatigue, but, during prolonged exercise, the combination of central fatigue and peripheral fatigue may develop.\textsuperscript{12,14} However, fatigue level is task dependent.\textsuperscript{12}

**Fatigue Protocols**

Researchers have used various protocols to induce fatigue. In the localized muscle fatigue protocol, subjects simply repeat muscle contraction until they can no longer complete the given task.\textsuperscript{10,16-18} Lyons et al\textsuperscript{19} quantified
fatigue levels by calculating 70% and 90% of the maximum number of alternate split squats performed by each subject within one minute. An isokinetic protocol also has been used to induce fatigue and quantify levels of fatigue.4,6,8,20-23 The isokinetic dynamometer allows researchers to identify peak-torque values of an isolated joint motion. In the isokinetic protocol, an indicator of fatigue is decreased force output.6,20-22 Most researchers have defined muscle fatigue when peak-torque values fell below 50% of maximum voluntary contraction.4,6,20-22 Harkins et al20 questioned whether 50% decrease in strength represented fatigue, and compared two ankle fatigue models, 70% and 50% decrease in strength to postural stability using healthy subjects. They found longer impairment of postural stability when a 70% decrease in strength was used as the indicator of fatigue, and thus concluded that 70% decrease in strength was useful for the indicator of fatigue.20

Aerobic types of exercises such as triathlon, cycling, and running have been selected to induce fatigue that is more central in nature.5,7,9,24 In a previous study, fatigue was induced to healthy subjects by 45-minute cycling at a power corresponding to about 60% of individual maximal oxygen uptake.7 Nardone et al9 determined fatigue for healthy subjects when the heart rate was 60% or higher of
the individual maximum heart rate. However, higher intensity of aerobic exercise may be necessary to induce fatigue to a high-level athlete.

Researchers have also developed the functional fatigue protocol (FFP) to induce similar fatigue athletes would encounter during the course of sports participation such as soccer, football, and basketball.\(^6,25,26\) The FFP should consist of closed kinetic chain exercises occurring through multi planes to simulate sports specific movements when applied to athletes.\(^6,11,26\) Wikstrom et al\(^6\) determined that healthy subjects were fatigued when time to completion of a FFP increased by 50% of initial trial time. When a FFP has been utilized, exertion levels have also been quantified by measuring ratings of perceived exertion (RPE).\(^11,25,26\) A score of 15 or above of RPE with FFP has been considered as adequate fatigue for healthy subjects, as well as athletic population.\(^11,25,26\)

**Ratings of Perceived Exertion**

RPE is a useful indicator for monitoring an individual’s exercise tolerance.\(^27\) RPE indicates the level of physical strain perceived by the individual during exercise.\(^28,29\) In addition to local signals from working muscle, central signals of perceived exertion during
exercise may be triggered by altered blood circulation, ventilation, and aerobic metabolism.\textsuperscript{28} The Borg 15-point RPE scale has been used to measure RPE, allowing subjects to rate their feelings during exercise.\textsuperscript{27} On the Borg 15-point RPE scale, exercise intensity is rated between 6 and 20, where 6 is minimum and 20 is maximum exertion.\textsuperscript{27-33} Most healthy individuals report RPE of 18 to 19 on the scale when they reach their subjective limit of fatigue.\textsuperscript{27,29,31,33} To minimize misinterpretation of RPE, the American College of Sports Medicine (ACSM) recommends the use of the following standardized instructions:\textsuperscript{27}

"During the exercise test we want you to pay close attention to how hard you feel the exercise work rate is. This feeling should reflect your total amount of exertion and fatigue, combining all sensations and feelings of physical stress, effort, and fatigue. Don’t concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try to concentrate on your total, inner feeling of exertion. Try not to underestimate or overestimate your feelings of exertion; be as accurate as you can." \textsuperscript{27(pp76-77)}

RPE has been shown to positively relate to heart rate (HR) and oxygen uptake.\textsuperscript{30,31} Moyna et al\textsuperscript{30} found differences in oxygen uptake (ml/kg/min or L/min), and therefore energy expenditure among different types of exercise at a given RPE in young healthy men and women. However, energy expenditure was consistent in same exercises at given RPE.\textsuperscript{30} Moreover,
energy expenditure at a given RPE was higher in men than women due to men’s greater maximal oxygen uptake.30 According to Robertson et al,31 females had higher RPE than males when comparisons were made at absolute oxygen uptake and HR, but RPE was not different between genders when comparisons were made at relative oxygen uptake and HR at exercise intensities between 70 and 90% of mode specific maximal/peak values. Reported RPE values in physical active subjects ranged from 12.9 to 14.2 at 70% VO2max, 15.2 to 16 at 80% VO2max, 18 to 18.4 at 90% VO2max, 12.9 to 14.3 at 70% HR, 15.2 to 16.2 at 80% HR, and 18 to 18.6 at 90% HR across the exercise mode.31

Psychological and environmental factors may alter individual perception.32,33 Dispositional and situational psychological factors have been shown to negatively correlate with RPE at low intensities, but the relationship becomes weaker at higher exercise intensities.32

Garcin et al33 reported that reliability of RPE was between 0.95 and 1 when progressive and constant load exercises till exhaustion were done on a track with trained males. Therefore, it is reasonably thought that the reliability of RPE in the FFP would be high. Static or dynamic balance has been disturbed when one scored 15 or
above of RPE with FFP.11,25,26 As various factors influence balance, it is important to understand these factors.

Balance and Limits of Stability

Factors Affecting Balance

Balance, or postural regulation, is a key component to most athletic activities.1,2,34,35 Static balance refers to maintaining equilibrium over a stationary base of support (BOS). However, most athletic participation requires dynamic balance, or maintaining equilibrium during motion or regaining equilibrium through changing position.35 Both static and dynamic balance requires the CNS to integrate afferent information from the visual, vestibular, and proprioceptive systems.1,2,34-36 As the CNS consists of the spinal cord, brain stem, and cerebral cortex, spinal reflex can be induced by a sudden change of direction or position in the body.34 The brain stem is responsible for controlling balance and posture, and receiving afferent inputs from the all three subsystems.34 The cerebral cortex, or the highest level of the brain, is vital for voluntary motor movement and learning, where complex thoughts and motor response can be initiated.34
The visual, vestibular, and proprioceptive systems work together and compensate each other.\textsuperscript{1,2,36} Vision, auditory, and proprioceptive information reportedly contribute maximum 37\%, maximum 44\%, and minimum 26\%, respectively, to balance control in healthy subjects.\textsuperscript{36} Depending on available sensory information and athletic levels, relative contribution of sensory inputs might vary.\textsuperscript{2,36} Sighted individuals performed better in dynamic balance than individual with visual impairment.\textsuperscript{37} High level athletes in gymnastics and soccer appeared to be superior in dynamic balance performance.\textsuperscript{2,35,38} Paillard et al\textsuperscript{2} found that, in the static and dynamic balance conditions, national soccer players in France produced better balance performances than regional soccer players and showed a different postural strategy. Higher level athletes may possess a greater sensitivity of sensory receptors or better integration of information than lower level athletes.\textsuperscript{2,35,38}

Proprioception refers to the body’s ability to recognize joint position sense and sensation of joint movement, or kinesthesia, through sensory information from muscle spindles, Golgi tendon organs, joint capsules, ligaments, and cutaneous receptors.\textsuperscript{1,34} Proprioception and muscle strength may contribute to dynamic balance in similar manners since strength training, proprioception training,
and combination of both strength and proprioception training have been effective in promoting dynamic balance.¹

Age has not been determined as a factor affecting dynamic balance performance.³⁵,³⁸ When there are significant differences in dynamic balance across different age groups, it has been reported the result is explained by experience of the specific skills as opposed to age.³⁸ Height of center of gravity may be a factor.³⁹ In a previous study, elite male basketball players demonstrated lower scores on dynamic balance than non-basketball players.³⁹ Weight may also affect dynamic balance performance. A moderate negative correlation between weight and dynamic balance has been reported, which indicates that a heavier person has a difficult time recovering balance.¹¹,⁴⁰

Athletes with lower extremity injury may experience decreased balance performance. Ankle injury may result in disruption of sensory receptors in the muscles, ligaments, joint capsule around the joint, leading to an impairment of dynamic balance.⁴¹ Researchers agree that ankle instability decreases dynamic balance performance.⁴²,⁴³ Moreover, structural foot types (neutral, pronated, and spined) appears to be a factor affecting dynamic balance when dynamic balance has been tested by using the Star Excursion Balance Test.⁴⁴
The anterior cruciate ligament (ACL) rupture and/or reconstruction were also reported to negatively affect dynamic balance.\textsuperscript{45,46} Hoffman et al\textsuperscript{46} found decreased dynamic balance performance in both injured and uninjured legs of ACL patients when compared with non-injured subjects. A decrease in the general control of posture after ACL rupture may be explained by “a central postural control mechanism,” in which the body tries to reestablish symmetry by reducing the function of the uninvolved leg.\textsuperscript{46}

Most researches measured dynamic balance using some types of balance devices.\textsuperscript{35-37,42-44,46} A valid and reliable devise is necessary for accurately assessing dynamic balance ability.

\textbf{Biodex Balance System}

The Biodex Balance System (BBS) (Biodex Medical System, Shirley, NY) is a balance devise with a circular balance platform that tilts up to 20° in any direction.\textsuperscript{37,47-50} The freely moveable platform makes the maximum stimulation of the ankle joint mechanoreceptors possible.\textsuperscript{51} The stability of the platform is mechanically changeable, adjusting eight springs located at the perimeter of the balance platform.\textsuperscript{37,47-50} Stability level 8 is the most stable setting, and stability level 1 is the least stable setting.\textsuperscript{37,47-50}
The “Dynamic Balance” test on the BBS requires a subject to stand on the moveable platform as stable as possible. For the “Dynamic Balance” test, the overall stability index (OSI), the anterior-posterior stability index (APSI), and the medial-lateral stability index (MLSI) are calculated by the BBS computer. These indexes represent fluctuations of the balance platform from a level position. The APSI and the MLSI represent fluctuations occurring in the sagittal and frontal planes, respectively. The OSI is a combined index of the APSI and the MLSI.

Either bilateral or unilateral stance can be used for the “Dynamic Balance” training and testing. Test time ranges are from 10 seconds up to 10 minutes, adjusted in 10-second increments. The BBS allows a more dynamic balance assessment by inquiring subjects to intentionally move their center of mass (COM) within their LOS. LOS is defined as the maximum angle that a person can incline from the upright position in any direction without falling or altering his or her BOS.

Previous researchers reported acceptable reliability of the BBS. Schmitz and Arnold reported that intertester intraclass correlation coefficients (ICCs) were 0.70, 0.68, and 0.42 for OSI, APSI, and MLSI, respectively, and that
intraterror ICCs were 0.82, 0.80, and 0.43, respectively, using a 30-second, unilateral stance, gradually decreasing platform stability test. Although the OSI provided the most reliable data, the use of APSI and MLSI have been suggested to be more useful in assessing ankle stability.\(^{50}\) ICCs for LOS tests were reported as the range from 0.77 to 0.89.\(^{48}\) Hinman\(^{48}\) found better reliable measures with more challenging test conditions. Dynamic LOS assesses the smoothness and/or the quickness a person can lean to one’s LOS.\(^{51}\) However, dynamic LOS testing on the BBS does not measure the maximal angle one can lean, but rather how quickly and accurately subjects return to original place from the leaning position.\(^{51}\) The ability to regain balance after functional fatigue has been examined for LOS.\(^{11}\)

The Effect of Fatigue on Balance

Peripheral Fatigue and Proprioception

It has been speculated that peripheral fatigue would negatively affect both joint position sense and kinesthesia, the sense of limb movement.\(^{21-23,52}\) Joint position sense and kinesthesia are considered elements of proprioception.\(^{21,52}\) Muscle receptors such as muscle spindles and Golgi tendon organs primarily contribute to proprioception.\(^{21,52}\) Therefore,
deterioration of joint position sense and kinesthesia would result from the altered function of the muscle receptors due to peripheral fatigue.\textsuperscript{21,52} The ability to detect joint position and motion of the knee decreased when muscle fatigue was induced to primary knee flexors/extensors.\textsuperscript{22,23,52} However, in a recent study, the ability to centrally process somatosensory information at the ankle was not altered after peripheral fatigue was induced by isometric exercise.\textsuperscript{21} In the study, the time to detect passive ankle motion with the index finger was not different before and after isometric dorsiflexion.

\textbf{Peripheral Fatigue and Balance}

In spite of different methods for inducing peripheral fatigue and different way to assess balance, disrupted balance ability has been observed due to peripheral fatigue.\textsuperscript{3,4,6,8,16-18,20} Deterioration of balance ability was reported when peripheral fatigue was induced on dorsiflexor and planterflexor using an isokinetic machine.\textsuperscript{4,6,20} According to Adlerton and Moritz,\textsuperscript{18} when one leg stance was performed repeatedly on the non-fatigue leg, body sway decreased over time, indicating learning effect, but when fatigue was induced on calf-muscles, body sway was consistent over time, indicating interference of the learning effect by muscle
fatigue. Peripheral fatigue induced by closed kinetic exercises such as squats and lunges appeared to adversely affect balance.\(^3,4,8,10,16,17\) Rozzi et al.\(^22\) induced fatigue in knee flexors and extensors isokinetically and assessed kinesthesia and balance on a device similar to BBS before and after fatigue was induced. Although Rozzi et al.\(^22\) found a decrease in the ability to detect joint motion, they failed to find significant differences on single leg balance between pre-fatigue and post-fatigue. It is speculated that ankle proprioception may be more important on single leg balance than knee proprioception.

Central Fatigue and Balance

Prolonged exercises may induce both central and peripheral fatigue.\(^3,5,9\) It was reported that upright double leg stance with eyes closed was deteriorated after a triathlon race, which composed of swimming (3.8 km), cycling (180 km), and running (42.195 km).\(^5\) The horizontal motions of the centre of gravity increased 83% for mean amplitudes, while the difference between the center of foot pressure and the center of gravity, indication of postural control, increased 44% after triathlon.\(^5\) Similarly, Nardone et al.\(^9\) found significant increase in center of foot pressure displacements after exhaustive treadmill. However, there
were no significant differences in balance performance for ergocycle exercises performed with the same intensity and over the same duration as the treadmill exercise. The two types of exercise are different in both the active muscles and the type of contraction. There may be more muscle damage and then peripheral fatigue with treadmill running since eccentric contraction of the lower extremity muscles occurs during running while cycling involves mostly concentric contraction. According to Nardone et al, exercise performed below the estimated anaerobic threshold had little influence on static balance.

Sensory inputs form visual, vestibular, and proprioceptive systems are highly stimulated during a run. There is stimulation of muscle spindles, tendon organs, joint receptors and cutaneous afferents on the sole of the foot at each stride. Vestibular system senses head acceleration. The eyes are constantly stimulated by the motion of the visual fields. It is hypothesized that an adaptation of the CNS to the hyper-stimulation of sensory inputs would occur during prolonged exercise, and then ability to maintain balance would alter. It is also thought that vestibular vascularization would be perturbed after exercise since the sudden stop in exercise could cause peripheral blood pooling. These hypotheses have been
remained to be investigated. Hydration during exercise has helped healthy subjects keep function of the balance control.\textsuperscript{7} Vestibular function may be altered by dehydration since loss of endolymphatic liquid may decrease the vestibular afferent sensitivity.\textsuperscript{7}

The FFP probably induce both the peripheral and central fatigue.\textsuperscript{25,26} The FFP has negatively affected on static balance\textsuperscript{25,26} ability as well as LOS.\textsuperscript{11} Twenty minutes of functional fatigue had a great influence on the tandem and single leg conditions, while no difference was observed on the double leg condition during dynamic balance testing.\textsuperscript{26} However, 20 minutes of functional fatigue also deteriorated LOS as measured by BBS in collegiate athletes.\textsuperscript{11}

**Recovery Time on Balance**

There is limited literature reported for recovery time on balance after fatigue is induced.\textsuperscript{3,9,25} Balance deficits in healthy college students remained at 0, 5, 10 and 15 minutes after functional fatigue, with deficits improving by 15 minutes and recovering by 20 minutes when static and dynamic balance was assessed by using Balance Error Scoring System (BESS).\textsuperscript{25} OSI of the single leg balance on a moveable platform in college-age men resolved 10 minutes after exertion induced by an anaerobic ergocycle.\textsuperscript{3} Increased body
sway in healthy subjects was also reported up to 15 minutes after 25 minutes of treadmill running. Therefore, it is speculated that regaining balance ability would occur between 10 and 20 minutes after fatigue, depending on the task inducing fatigue.

Summary

Fatigue is categorized into central and peripheral depending on type, duration, and intensity of activities. Repeated maximal or sub-maximal contraction of muscle groups causes peripheral fatigue, while central fatigue results from prolonged cardiovascular exercises such as running and cycling. Fatigue induced by FFP probably explained by central and peripheral fatigue. RPE, or exertion levels need to be measure subjectively during FFP using the Borg 15-point RPE scale since fatigue cannot be assessed objectively during FFP. RPE represents the level of physical strain perceived by the individual during exercise. RPE is highly correlated with heart rate, oxygen uptake, and energy expenditure. Most healthy subjects and athletes feel fatigue when they score 15 or above on the Borg 15-point RPE scale.
Static balance refers to maintaining equilibrium over stationary BOS, while dynamic balance refers to maintaining equilibrium during motion or regaining equilibrium through changing position. The visual, vestibular, and proprioceptive systems work together and compensate each other for static or dynamic balance. Proprioception refers to the body’s ability to recognize joint position sense and sensation of joint movement, or kinesthesia, through sensory information from muscle spindles, Golgi tendon organs, joint capsules, ligaments, and cutaneous receptors. It is reported that proprioception in the ankle has significant influence on balance ability.

The BBS, a reliable device for balance assessment, allows a dynamic balance assessment by inquiring subjects to intentionally move their COM within their LOS. LOS is defined as the maximum angle that a person can incline from the upright position in any direction without falling or altering his or her BOS. Dynamic LOS assesses smoothness and/or quickness a person can lean to one’s LOS. The test on the BBS measures how quickly and accurately subjects return to original place from the leaning position. The CNS needs to integrate afferent information from the visual, vestibular, and proprioceptive systems to complete the task of LOS test, or regaining balance. Fatigue, both
central and peripheral fatigue, may alter the function of
the three sensory systems. Therefore, ability to regain
balance can be disturbed. Although static or dynamic balance
ability has recovered within 20 minutes, recovery time
of LOS is not known. It is speculated that recovery on LOS
would occur between 10 and 20 minutes after functional
fatigue protocol.
APPENDIX B

The Problem
Statement of the Problem

Maintaining balance is a fundamental skill of most activities. Athletes need to control their balance while they are performing sport specific movements to maintain dynamic balance. Athletes’ ability to maintain their dynamic balance is critical for correct performance in their athletic events. However, fatigue decreases dynamic balance ability and subsequently may negatively affect physical performance.3-10 As athletic performance declines, the risk of injury may also increase due to fall or collision. Previous research has found that dynamic balance and limits of stability (LOS) is negatively affected by functional fatigue.11,25,26 It is critical for athletes to retrieve dynamic balance ability in order to maintain optimal performance level and decrease the risk of injury. Therefore, the purpose of this study was to determine recovery timeline on LOS from functional fatigue in collegiate athletes.

Definition of Terms

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

1) Balance Error Scoring System – a clinical field test for objective evaluations of an athlete’s postural
stability after mild head injury, which consists of six testing conditions that use three stances (double leg, single leg, and tandem) on two surfaces (firm and foam).

2) Biodex Balance System - a devise with a circular balance platform that quantifies the ability to maintain dynamic bilateral and unilateral balance, as well as dynamic LOS.

3) Borg 15-point RPE scale - a scale that allows subjects to rate their feelings about exertion levels during exercise. It ranges from 6 to 20, where 6 is minimum and 20 is maximum exertion.

4) Center of gravity - the point in the body or object around which its weight is equilibrate. This term is also referred as center of mass.

5) Central fatigue - fatigue caused by a reduction in the neural drive from the CNS to muscles that cause a decline in the force output.

6) Dynamic balance - maintaining equilibrium during motion or regaining equilibrium through changing position.

7) Functional fatigue protocol - a protocol to induce similar fatigue a subject would encounter during the course of sports participation such as soccer,
football, and basketball.  

8) **Isokinetic protocol** – a protocol to induce fatigue by using the isokinetic dynamometer that quantifies peak-torque values of an isolated joint motion.  

9) **Kinesthesia** – sensation of joint movement.  

10) **Limits of stability** – the maximum angle that a person can incline from the upright position in any direction without falling or altering his or her base of support (BOS).  

11) **Localized muscle fatigue protocol** – a protocol to induce fatigue by letting subjects simply repeat muscle contraction until they can no longer complete the given task.  

12) **Peripheral fatigue** – fatigue due to an inability for the body to supply sufficient energy to the contracting muscles to meet the increased energy demand.  

13) **Proprioception** – the body’s ability to recognize joint position sense and sensation of joint movement through sensory information from muscle spindles, Golgi tendon organs, joint capsules, ligaments, and cutaneous receptors.  

14) **Rating of perceived exertion** – an indicator to monitor the level of physical strain perceive by the
individual during exercise.\textsuperscript{27-29} This is typically measured by the Borg 15-point RPE scale.

15) Somatosensory – relating to sensation from muscle spindles, Golgi tendon organs, joint capsules, ligaments, and cutaneous receptors.\textsuperscript{1,34}

16) Star Excursion Balance Test – a dynamic balance test that challenges the subject to maintain a single-leg stance of one leg while reaching as far as possible in eight directions with the opposing leg.\textsuperscript{4,44}

17) Static balance – maintaining equilibrium over stationary base of support.\textsuperscript{35}

Basic Assumptions

The followings were basic assumptions for this study:

1) The subjects were adequately fatigued by completing the FFP.

2) The BBS was calibrated and worked properly during this study.

3) The subjects reported their RPE honestly and appropriately, and the score indicated adequate fatigue.

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

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

6) The learning effects on the dynamic LOS test were minimal when subjects are adequately fatigued.25

Limitation of Study

Test results are generalized to only the NCAA Division II collegiate athletes; perhaps soccer players only, whose fitness level are good or excellent.

Significance of the Study

During athletic activity, one’s COG shifts continuously and the BOS changes spontaneously. Athletes need to control their COG precisely when performing dynamic movements. When athletes lose the control of their COG, they fail to perform their tasks, and are also vulnerable due to risk of falling and collision. As a result, athletic performance declines and most injuries occur at the end of competition when athletes are exhausted.52,54 Therefore, it is speculated that athletes would experience some difficulties in controlling their COG when fatigued. While researchers have found that static and dynamic balance ability is negatively affected by fatigue,3-10,25,26 only one study has addressed that 20 minutes of sports activity deteriorates the ability to control COG for LOS in collegiate athletes.11
Although the effect of exertion on LOS is evident, the time needed to recover from exertion and regain LOS has not been examined. When the ability to control COG drops after exertion, decreased performance is a potential consequence, as well as, increased risk of injury due to fall or collision. This may be related to high incidence of injuries toward the end of a match or a training session. For that reason, athletes should be able to maintain optimum levels of dynamic balance even when fatigued in order to decrease risk of injury. Athletic trainers may be able to identify those athletes who are at high risk for injury due to fall or collision, using a similar protocol applied in our study. Moreover, if a recovery timeline after exertion is established; athletic trainers and conditioning coaches may be able to design training programs with adequate resting time. Furthermore, considering specific adaptation to training, athletes who play a sport that requires prolonged strenuous activities may have benefits from LOS training after exertion, so that they can improve controlling their COG when fatigued.
APPENDIX C

Additional Methods
APPENDIX C1

The Tecumseh Step Test
The Tecumseh Step Test

Procedure

Subjects performed the stepping cycle to a four-step cadence (up-up-down-down) on a stair or stool eight inch (20.3 centimeter) high. Subjects completed 24 step-ups per minute (two step-ups within a five second span) for exactly three continuous minutes. A metronome was set at 96 beats per minute to give subjects the appropriate one footstep per beat cadence. After completion of the three minutes, subjects remained standing, and the researcher took their heart rate (radial pulse) exactly 30 seconds into recovery for 30 seconds. The number of pulse beats in 30 seconds represented the score. Scores were classified as follows:
## Classification

<table>
<thead>
<tr>
<th>Age 20-29</th>
<th>Number of Beats*</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outstanding</strong></td>
<td>34-36</td>
<td>39-42</td>
<td></td>
</tr>
<tr>
<td><strong>Very good</strong></td>
<td>37-40</td>
<td>43-44</td>
<td></td>
</tr>
<tr>
<td><strong>Good</strong></td>
<td>41-42</td>
<td>45-46</td>
<td></td>
</tr>
<tr>
<td><strong>Fair</strong></td>
<td>43-47</td>
<td>47-52</td>
<td></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>48-51</td>
<td>53-56</td>
<td></td>
</tr>
<tr>
<td><strong>Poor</strong></td>
<td>52-59</td>
<td>57-66</td>
<td></td>
</tr>
</tbody>
</table>

*Thirty-second heart rate beginning 30s after exercise stops.*

APPENDIX C2

Push-Up Muscular Endurance Test
Push-Up Muscular Endurance Test\textsuperscript{56}

Procedure
Male subjects performed full body push-ups. Because females possess less relative strength, female subjects performed modified push-ups. All subjects performed as many push-ups as they could without rest.

Initial position
Full Body Push-Up: Subjects assumed a straight prone position from head to ankles, keeping the hands shoulder width apart and directly under the shoulder, and arms fully extended.

Modified Push-Up: Subjects assumed the bent-knee position, in which the knees and toes contact with floor, keeping the hands shoulder width apart and directly over the shoulder, and arms fully extended.

Movement
Subjects lowered their body until the elbows reached 90° of flexion and push up until the arms fully extended. The motion continued without any rest or pauses. Scores were classified as follows:
### Classification

**Age 20-29**

<table>
<thead>
<tr>
<th>Number of Push-ups Completed</th>
<th>Full body push-up</th>
<th>Modified Push-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt;54</td>
<td>&gt;48</td>
</tr>
<tr>
<td>Good</td>
<td>45-54</td>
<td>34-48</td>
</tr>
<tr>
<td>Average</td>
<td>35-44</td>
<td>17-33</td>
</tr>
<tr>
<td>Fair</td>
<td>20-34</td>
<td>6-16</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;20</td>
<td>&lt;6</td>
</tr>
</tbody>
</table>


---

### Notes

- The classification system evaluates push-up performance by age group and type of push-up.
- The table categorizes push-ups into levels of performance based on the number completed.
- The distinction between full body and modified push-ups is made for accuracy.

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### References

APPENDIX C3

Informed Consent Form
Informed Consent Form

1. Toshimitsu Ishizuka, ATC has requested my participation in a research study at California University of Pennsylvania. The title of the research is "Recovery Time on Limits of Stability from Functional Fatigue in Division II Collegiate Athletes".

2. I have been informed that the purpose of the research is to determine recovery timeline on limits of stability from functional fatigue in NCAA Division II collegiate athletes.

3. My participation will involve prescreening tests for measuring personal fitness levels. If I qualify for participation based on the screening tests, I will be balance tested for limits of stability, which requires standing on an unstable platform, moving body weight to desired directions, and regaining balance, under a functional fatigue and non-fatigue condition. I understand that I may not participate in the study after the prescreening fitness test. The fatigue protocol is 20 minutes exercise, which includes jogging, sprinting, push-ups, and step-ups. The testing under both conditions will be conducted on two different days at the athletic training room in the Hamer Hall.

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 researcher as a spotter. I may experience muscle soreness over 2 to 3 days after the functional fatigue protocol. These risks are no more than normal physical
activity that a collegiate athlete would be exposed to during a regular practice.

5. I understand that, in case of injury or prolonged muscle soreness, I can expect to receive treatment or care in Hamer Hall’s Athletic Training Facility which will be provided by the researcher, Toshimitsu Ishizuka, ATC, or another Certified Athletic Trainer, either of whom can administer emergency and rehabilitative care. Additional services needed for prolonged care past three days will be referred to the attending 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, Toshimitsu Ishizuka will maintain all documents in secure location in which only the researcher and research advisor can access them.

9. I have been informed that I will not be compensated for my participation.

10. I have been informed that any questions or concerns I may have about the research or my participation in it will be answered any time, and that my individual scores or the abstract of this study will be informed after completion of the study by:
    Toshimitsu Ishizuka, ATC
    947 Cross Street Apt#2
    California PA 15419
    402-850-3875
    ish6748@cup.edu
    Or by the graduate thesis advisor:
    Rebecca Hess, Ph.D
    133 Hamer Hall
    California University of Pennsylvania
    California, PA 15419
    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 waiving 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 #:_________________    Date:__________
Age:______________
Gender:__________
Shoe Size:__________
Height:__________
Weight:__________

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

Functional Fatigue Protocol
Functional Fatigue Protocol

Station 1: Moderate jogging for 5 minutes

Subjects jog at their own pace but not at a slow pace. Subjects are encouraged to jog approximately 750m for five minutes.

Station 2: Straight-line sprint for 3 minutes

Subjects sprint down and forth along the length of the basketball court as fast as they can. Subjects are allowed to take a break for no longer than 15 seconds between each sprint. Subjects have to re-start sprint when they take a break for longer than 15 seconds.

Station 3: Push-ups for 2 minutes

Subjects perform as many push-ups as they can in two minutes. Subjects are allowed to take a break for no longer than 10 seconds if they feel exhausted. Subjects hold the push-up position for the rest of the time if they are not able to continue push-ups.

Station 4: Sit-ups for 2 minutes

Subjects perform as many sit-ups as they can in 2 minutes. Subjects are allowed to take a break for no longer than 10 seconds if they feel exhausted.
Subjects hold the sit-up position for the rest of the time if they are not able to continue sit-ups.

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

Subjects perform step-ups at moderate pace for 3 minutes. The moderate pace is approximately 120 steps per minutes. Subjects are allowed to take a break for no longer than 10 seconds if they feel exhausted. Subjects have to re-start step-ups when they took a break for longer than 10 seconds.

Station 6: Straight-line sprint for 3 minutes

Subjects sprint down and forth along the length of the basketball court as fast as they can. Subjects are allowed to take a break for no longer than 15 seconds between each sprint. Subjects have to re-start sprint when they take a break for longer than 15 seconds.

Station 7: Moderate jogging for 2 minutes

Subjects jog at their own paces. This is considered as a cool-down, but subjects are not allowed to stop running.
APPENDIX C6

The Borg 15-Point Ratings of Perceived Exertion Scale
The Borg 15-point RPE scale\textsuperscript{27}

To minimize misinterpretation of RPE, following instructions were given to subjects by the researcher:
“During the exercise test we want you to pay close attention to how hard you feel the exercise work rate is. This feeling should reflect your total amount of exertion and fatigue, combining all sensations and feelings of physical stress, effort, and fatigue. Don’t concern yourself with any one factor such as leg pain, shortness of breath or exercise intensity, but try to concentrate on your total, inner feeling of exertion. Try not to underestimate or overestimate your feelings of exertion; be as accurate as you can.”27(pp76-77)
APPENDIX C7

Test Score Sheet
Test Score Sheet

Subject number:_____ Date:__________
Condition: Functional fatigue

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Before FFP</th>
<th>0 min post-test</th>
<th>10 min post-test</th>
<th>15 min post-test</th>
<th>20 min post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Date:__________
Condition: Non-fatigue

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>0 min post-rest</th>
<th>10 min post-rest</th>
<th>15 min post-rest</th>
<th>20 min post-rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C8

Institutional Review Board
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**  Recovery Time on Limits of Stability from Functional Fatigue in Division II Collegiate Athletes

**Researcher/Project Director**  Toshimitsu Ishizuka

**Phone #** 402-850-3875  
**E-mail Address**  ish6748@cupedu

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

**Department**  Health Science and Sport Studies

**Project Dates**  September 2006 to May 2007

**Sponsoring Agent (if applicable)**

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

**Project Purpose:**  
- [x] 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(es) 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.

The purpose of this study will be to determine the recovery timeline on limits of stability (LOS) after functional fatigue. Twenty (N = 20) healthy National Collegiate Athletic Association (NCAA) Division II collegiate athletes from California University of Pennsylvania Men’s and Women’s soccer teams are expected to participate in this study. Volunteers who sign the informed consent will go through fitness screening tests (Appendices C1 and C2). 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. Subjects who meet the criteria will be tested under two conditions (fatigue/non-fatigue). Under fatigue condition, subjects will perform dynamic LOS tests on the Biodex Balance System (BBS) before the functional fatigue protocol (FFP), immediately after the FFP, and 10, 15, and 20 minutes after the FFP. Under non-fatigue condition, subjects will have a 20-minutes rest instead of the FFP and perform dynamic LOS tests. The FFP includes jogging, sprinting, sit-ups, push-ups, and step-ups (Appendix C5). Difference overall LOS scores in both within-subjects and between-conditions will be calculated using a 5 × 2 mixed-design ANOVA (p ≤ 0.05). SPSS 13.0 will be used for data analysis. It is hypothesized that the overall LOS score will decrease immediately after functional fatigue, recover with rest, and return to baseline by 20 minutes after 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 the FFP and/or a fall from the BBS. The risks of falling 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. These risks are no more than normal physical activity that collegiate athletes would be exposed during a regular competition or practice. Incase of injury or prolonged muscle soreness, 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 Service 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 Men’s and Women’s soccer team. 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 as these conditions may interfere with accurate balance assessment. 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 (Appendix C3) will be completed and signed by all subjects before participating in this study at the informational meeting. 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 two different days 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.

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

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 ________________________________
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.

I will release results of the tests to the athletes after the study is completed by way of a poster presentation paper in the spring semester.

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  
Chairperson, Institutional Review Board

Disapproved  

Date: 01-18-07
REFERENCES


11. Matsumoto H. *The relationship between functional fatigue and limits of stability in Division II*


21. Shields RK, Madhavan S, Cole K. Sustained muscle activity minimally influences dynamic position sense of


41. Bernier JN, Perrin DH. Effect of coordination training


ABSTRACT

TITLE: Recovery Time on Limits of Stability from Functional Fatigue in Division II Collegiate Athletes

RESEARCHER: Toshimitsu Ishizuka

ADVISOR: Dr. Rebecca Hess

DATE: May 2007

RESEARCH PROBLEM: Master Thesis

PURPOSE: The purpose of this study was to determine recovery timeline on limits of stability (LOS), as measured by the Biodex Balance System (BBS), from functional fatigue in collegiate athletes.

PROBLEM: It is critical for athletes to retrieve dynamic balance ability in order to maintain optimal performance level and decrease the risk of injury due to fall or collision.

METHODS: This study was a quasi-experimental, within-subject design. Eighteen Division II collegiate soccer athletes completed two testing sessions (fatigue and non-fatigue conditions).

FINDINGS: A significant time × condition interaction was present (F(4, 136) = 4.1777, P = .003). In addition, the main effect for time was significant (F(4,136) = 6.574, P < .001).

CONCLUSIONS: Twenty minutes of functional activities will likely have a negative influence on dynamic balance, with balance recovery occurring within 10 minutes after the cease of exercise in Division II collegiate athletes.