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Effects of Exercise Induced Fatigue on Postural Balance: A Comparison of Treadmill Versus Cycle Fatiguing Protocols

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**EFFECTS OF EXERCISE INDUCED FATIGUE ON POSTURAL BALANCE: A
COMPARISON OF TREADMILL VERSUS CYCLE FATIGUING PROTOCOLS**

A Thesis
Presented to
The Faculty of the Department of Physical Education and Recreation
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Physical Education

By
Katherine E. Wright

May 2008

**EFFECTS OF EXERCISE INDUCED FATIGUE ON POSTURAL BALANCE: A
COMPARISON OF TREADMILL VERSUS CYCLE FATIGUING PROTOCOLS**

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The purpose of this study was to examine the effects of muscle fatigue after a treadmill versus cycle ergometer incremental test on postural balance indices and recovery time recreationally trained individuals. The Bruce Treadmill Test and the Incremental Cycle Ergometer test were used to induce fatigue. Each subject (N=16) performed both exercises, but the order of the exercises was randomized. The subjects performed balance measures on a Biodex Balance System via the Dynamic Balance Test at level 5 and indices were recorded as given. Balance was measured a total of nine times (pre-exercise, immediately post, and at 3, 6, 9, 12, 15, 18, and 21 minutes post). Immediately following the fatiguing treadmill test, balance increased significantly in the overall stability index (SI) and the anterior/posterior index (API). Immediately following the fatiguing cycle test, balance was not increased or decreased significantly in SI or API. Balance was not increased or decreased significantly for the medial/lateral index (MLI) for either exercise test at any time point. Post-hoc analysis found that the only significant difference ($p = 0.05$) between treadmill and cycle ergometer test was seen immediately following exercise for only SI and API indices. Additionally, there were no significant differences in the time to recovery, although subjects did tend to recovery quicker following the treadmill test (treadmill = 9 minutes, cycle = 12 minutes, $p = 0.731$). At 12-minutes post-exercise, all indices were below pre values, indicating fatiguing exercise has

a positive effect on balance overtime. The results of this study indicate a general consistency with previous research, suggesting that any effects of fatigue on balance are seen immediately post-exercise and are diminished as time after exercise increases.

CHAPTER I

INTRODUCTION

Many researchers have identified that the maintenance of balance in sport is important in the prevention of injuries (Hrysomallis, 2007; Salavati, Modhadam, Ebrahimi, & Arab, 2007). Balance is controlled by the central nervous system (CNS) and is achieved by integrating sensory information from the vestibular, somatosensory, and visual systems. When the muscles that control balance are fatigued, these systems could be affected, thus inhibiting proper balance control. Many researchers have examined the effects of fatigue on both types of balance, static and dynamic, and have explained that fatigue to the stabilizing muscles may also be the cause of balance problems (Yaggie & Armstrong, 2004; Reimann & Guskiewicz, 2000). Thus, active individuals may be susceptible to injuries during activity due to fatigue from sensory integration or motor coordination.

Fatigue can be defined as the inability to maintain a particular force or power output during or following a repeated muscular contraction (Rozzi, Yuktanandana, Pincivero, & Lephart, 2000). Fatigue following various types of exercises has been found to alter balance and postural stability (Johnston, Howard, Cawley, & Losse, 1998; Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004; Surenkok, Isler, Aytar, Gultekin, & Akman, 2006).

Common methods to induce muscular fatigue and associated balance include protocols on various ergometers. Isokinetic dynamometers impose closed kinetic chain antagonistic exercise on multiple joints. This type of machine forces concentric and eccentric exercise on the hip, knee, and ankle muscle groups. Research has found that

inducing hip, knee, or ankle fatigue affects balance in a detrimental way (Surenkok et al., 2006; Johnston et al., 1998; Yaggie & McGregor, 2002). Another common fatiguing protocol is exercise specific fatigue protocols, which has also been found to induce a detrimental effect on balance. Some researchers use a circuit type design to induce whole body fatigue, while others use a localized muscle design, such as performing calf raises until exhaustion (Wilson, Madigan, Davidson, & Nussbaum, 2006; Vuillerme, Burdet, Isableu, & Demetz, 2006; Wilkins et al., 2004). A third way to induce fatigue is to use a bicycle or treadmill, which may be more applicable to exercise prescription. Only two studies have included both a bicycle and treadmill as modes for inducing fatigue, and only one has compared the results from the same subjects between the two very different exercises (Lepers, Bigard, Diard, Gouteyran, & Guezennec, 1997; Nardone, Tarantola, Giordano, & Schieppatti, 1997). Lepers et al. (1997) found that fatigue affected balance greater following the treadmill test when compared to the bicycle test. However, both treadmill and cycling tests used in these studies incorporated trained individuals who had experience running and/or cycling.

Lepers et al. (1997) also did not assess recovery time and any differences seen between the two different fatiguing protocols. Yaggie et al. (2004) found that following two Wingate tests, all effects were diminished and pre-fatigue levels were restored within 10 minutes. Nardone et al. (1997) found that for both fatiguing treadmill and fatiguing cycling tests, all effects were diminished and pre-fatigue levels were restored within 15 minutes. The researchers in this study failed to identify any differences in recovery time between the two tests, which may or may not have been present.

Statement of Problem

Most studies in the past have used trained individuals, if not highly trained individuals, who were experienced with running or cycling (Lepers et al., 1997; Nardone et al., 1997). These studies found that any effects of fatigue on postural balance were generally restored within 15-20 minutes. These studies failed to compare differences between recovery time within the two protocol modes which will be examined, cycling and treadmill running/walking.

Statement of Purpose

The purpose of this study was to examine the effects of fatigue on postural balance and how quickly balance is restored to pre-fatigue levels in recreationally trained individuals. Any differences between an incremental treadmill test and an incremental cycle ergometer test on balance and recovery time will be explored. Recovery time for the two different fatiguing protocols will also be examined and compared.

Statement of Hypothesis

Postural Balance will be unaffected following either incremental fatiguing exercise (H_{O1}). Postural balance will be affected following incremental fatiguing exercise, with a higher detrimental effect following the treadmill protocol (H_{A1}).

Recovery time following incremental fatiguing exercise will be the same for both fatiguing protocols (H_{O2}). Recovery time following incremental fatiguing exercise will differ between fatiguing protocols (H_{A2}).

Limitations

The study was limited to

Subject compliance before the test

Performance on balancing task individual to skill level

Amount of sleep the subject has that could contribute to balance measures

Any sickness that could contribute to balance measures

Delimitations

The study was delimited to

Recreationally active college aged subjects (18-24)

Method of assessing balance

Condition of balance test (Two-legged dynamic stance)

Fatiguing protocol (Treadmill and Cycle Test- See Appendix C)

Definition of Terms

- Static balance- ability to maintain postural stability on a stable surface
- Dynamic balance- the ability to maintain postural stability while walking or on a perturbed surface
- Fatigue- the inability to maintain a particular force or power output during or following a repeated muscular contraction
- Stability Index- the variance of foot platform displacement in degrees in all motions during the test
- Anterior/Posterior Stability Index (API)- the variance of foot platform displacement in degrees for motion in the sagittal plane
- Medial/Lateral Stability Index (MLI)- the variance of foot platform displacement in degrees for motion in the frontal plane

CHAPTER II

REVIEW OF LITERATURE

During sporting competitions athletes strive for optimal performance, which comes with practice and the acquisition of effective and efficient movement strategies. Proper maintenance of balance could, therefore, be a vital component in performing at optimal level. It is thought that fatigue can affect the maintenance of postural balance, which could lead to injuries during sporting competitions or during activity (Hrysomallis, 2007; Salavati et al., 2007). Many injuries that occur during sport occur toward the end of a game or practice and are sometimes due to unstable hip, knee, or ankle joints. The underlying cause may be due to fatigue of the stabilizing muscles (Yaggie & Armstrong, 2004; Reimann & Guskiewicz, 2000).

Postural balance is known as the process of maintaining the center of gravity (COG) within the body's base of support. Balance is controlled by the central nervous system (CNS) and can be labeled as either static or dynamic balance. Static balance is the ability to maintain postural stability on a stable surface, whereas dynamic balance is the ability to maintain postural stability while walking or on a perturbed surface. Most researchers examine the effects of fatigue on both types of balance, since various sports require different stances throughout the competition.

Postural balance is achieved by integrating sensory information from three sensory systems (Reimann and Guskiewicz, 2000). The first sensory system is the somatosensory system. This system receives input from peripheral articular and musculotendinous receptors concerning changes in muscle length and tension. The most important information supplied by this system in the maintenance of balance is

information regarding joint position and motion. Most healthy individuals primarily rely on this sensory system in normal conditions. The second sensory system that provides information to maintain balance is the visual system. This system measures the orientation of the eyes and head in relation to surrounding objects. It also provides visual cues to the body, which contribute to any adjustments made when maintaining postural balance. The last sensory system to contribute to maintenance of balance is the vestibular system. This system receives information from vestibules and semicircular canals in the ear. It plays a minor role in maintaining balance when the other systems are accurately providing information. Impairment of these systems is likely caused by a pathological condition, such as recurrent injuries or fatigue.

Once the body provides sensory information, the stabilizing muscles make adjustments as needed. There are three ways that the body strategically maintains balance by bringing the COG back to a balanced position. The ankle strategy is the most commonly selected strategy, which shifts the COG by rotating the body at the ankle joint. The hip strategy is used by subjects with somatosensory loss, such as the elderly. This strategy shifts the COG by rotating at the hip joint, in a forward and backward motion. Wilson et al. (2006) found that after fatigue, eight out of twelve subjects choose the hip strategy. The other four subjects used a mixed strategy, rotating at the hip and ankle. This may indicate a possible disturbance in the sensory systems due to fatigue of the stabilizing muscles. The last strategy, the stepping strategy, occurs when the COG is displaced beyond the limit of stability (LOS). LOS is the maximum anterior-posterior and medial-lateral angles that keep the COG within the base of support. When a subject's

COG sway angle surpasses the LOS, the subject will use the strategies stated above or will fall.

Fatigue is defined as the inability to maintain a particular force or power output during or following a repeated muscular contraction (Rozzi et al., 2000). The source of fatigue can be peripherally, in the muscle, or centrally, in the CNS. Peripheral fatigue following various types of exercises has been found to alter balance and postural stability (Johnston et al., 1998; Wilkins et al., 2004; Surenkok et al., 2006). The effects of three fatiguing exercise protocols on postural stability are reviewed: isokinetic fatigue protocol, exercise specific fatigue protocol, and cycle/treadmill fatigue protocol.

Isokinetic Fatigue Protocol

Muscle fatigue can be induced through several types of protocols to study effects on balance. Some researchers choose to use isokinetic dynamometers, which imposes a closed kinetic chain antagonistic exercise on multiple joints while maintaining a constant velocity. This type of machine forces concentric and eccentric exercise on the hip, knee, and ankle muscle groups.

Johnston et al. (1998) designed an investigation to determine if lower extremity fatigue affects performance on a balancing test. Subjects (N = 12 men, N = 8 women) were between the ages of 20 and 39 years old and had no history of vestibular or CNS balancing disorders. They performed exercises on an isokinetic dynamometer until fatigued followed by a balance assessment (on KAT 2000) before and after the fatiguing exercise. There were four conditions to the balance assessment: 1) Unilateral static test, 2) Bilateral static test, 3) Bilateral dynamic test, and 4) Visual feedback (which involved subjects chasing a moving object to aid in maintenance of balance). Balance was

significantly decreased after lower extremity muscle fatigue when performing the first two balance conditions. Balance measures were also decreased in the bilateral dynamic test but not as significantly. One possible cause for the lack of significant decrease in the fourth condition could be due to the visual system feedback. In conclusion, the researchers found that fatigue of the lower extremities can affect balance performance.

Yaggie and McGregor (2002) investigated the effects of isokinetic ankle fatigue on balance. The subjects ($N = 24$ males, mean age = 24.9 years old) performed the fatiguing protocol on an isokinetic dynamometer and performed the balance test on a force platform before and after the fatiguing test at 0 minutes post (immediately), 10 minutes post, 20 minutes post, and 30 minutes post. The researchers were measuring sway and displacement in the directions of mediolateral and fore-aft. Significant increases in mediolateral displacement were observed immediately and significant decreases in fore-aft displacement were observed immediately. Sway was greater for mediolateral immediately post-test and fore-aft sway was also increased immediately. In conclusion, isokinetic ankle fatigue significantly affected postural balance while all parameters were returned to pre-fatigue levels within 20 minutes.

In the study completed by Surenkok et al. (2006), the authors investigated how balance, specifically static balance, was affected by knee muscle fatigue and lactate. The subjects ($N = 16$ males, mean age = 22.75 years) performed fatiguing exercise on an isokinetic dynamometer followed by balance assessment on the KAT 3000. Following knee muscle fatigue, subjects showed a significant increase in static balance scores. However, the researchers could not determine a significant correlation between lactate

and balance scores. It was concluded that muscle fatigue has a detrimental effect on balance but lactate cannot be correlated to this effect.

One study examined the effects of ankle, knee, and hip isokinetic fatigue. Gribble, Hertel, Denegar, & Buckley (2004) evaluated the effects fatigue and chronic ankle instability (CAI) when performing the Star Excursion Balance Test (SEBT). The subjects consisted of 15 males and 15 females (mean age = 22.3 years; 7 males and 7 females with CAI) and were required to perform 5 testing sessions: isokinetic ankle fatigue, isokinetic knee fatigue, isokinetic hip fatigue, lunging task, and control (5 minutes of quiet sitting). The subjects performed the SEBT test before and after the fatiguing protocols, which consists of an anterior, medial, and posterior reaching direction. With the injured limb, the CAI group demonstrated less knee flexion, hip flexion, and reach distance as a percentage of leg length (MAXD) in all 3 directions. A decrease in performance was also demonstrated due to fatigue in both groups, which could be correlated to CAI. This study demonstrated the insufficiency of postural control created by chronic ankle instability and fatigue, which could be linked to changes in the kinematic changes at the knee and hip.

Exercise Specific Fatigue Protocols

In addition to isokinetic fatiguing protocols, researchers also used exercise specific fatiguing protocols. For example, the researcher could induce localized muscle fatigue by the subject performing back extension exercises. Pline, Madigan, & Nussbaum (2006) explored the effects of varying fatigue time and level on postural sway. Subjects (N = 12 physically active males; age = 20-22 years) performed four experimental sessions of varying level of maximum voluntary back extension contractions (MVC) on a Roman Chair. Postural sway values were collected every three minutes for thirty minutes

post-fatigue. Fatigue level was found to significantly increase peak sway velocity immediately. There were no significant differences caused by fatigue immediately following the protocol. Both fatigue level and time affected postural sway velocity and area throughout 30 minutes following the fatigue protocol. This result on recovery time is not consistent with previous research (Yaggie and McGregor, 2002). In conclusion, the higher fatigue levels induced a larger increase in sway velocity and longer durations in sway velocity and area.

Wilson et al (2006) explored the effect fatigue to the lumbar extensor muscles has on postural strategy. The twelve male subjects (age = 20-22 years) had no history of low back pain or injury. Subjects completed three experimental sessions, each consisting of four stages. Stage one was warm up, stage two was unfatigued balance perturbations, stage three was fatiguing protocol, and stage four was fatigued balance perturbation. The fatiguing protocol was varied at each session: 86, 73, or 60% of unfatigued maximum voluntary contraction (MVC) by the subjects performing back extension exercises on a Roman Chair. The perturbation applied when conducting analysis involved an anteriorly-directed force, which was a padded pendulum to mimic a bump to the upper back. The subjects exhibited an increase in low back and ankle joint angle and an increase in low back and hip joint torque. In addition, they exhibited a decrease in ankle torque. There were no significant changes in hip and knee joint angles and knee joint torque. The researchers found that eight of twelve subjects maintained postural stability at the hip, while the others maintained postural stability at the hip and ankle (commonly called a mixed strategy). The researchers concluded that fatigued lumbar extensor muscles affect postural strategy.

Vuillerme et al. (2006) explored the effects of calf muscle fatigue on postural control. They also explored how vision may factor into these effects. The subjects (N = 12, age = 21.9 years, gender unidentified) performed calf raises until exhaustion for three trials. The subjects also participated in a control group. In each trial, the visual feedback distance was varied with conditions including no vision, vision at 1 meter, and vision at 4 meters. The researchers measured center of pressure (COP) displacements along the medial-lateral and anterior-posterior axis. The researchers found at 4 meters and with no vision the subject's displacement was increased in comparison to the 1 meter condition. This suggests vision and target distance does have an effect on postural balance following calf muscle fatigue.

Another common exercise specific fatiguing exercise is a circuit type design, which could be said to induce whole body fatigue in comparison to localized fatigue. The purpose of one study was to determine if performance on the Balance Error Scoring System (BESS) was immediately affected by a circuit fatigue protocol (Wilkins et al., 2004). The BESS is a test measuring postural stability after a mild head injury and is commonly used as a clinical field test by athletic trainers. The subjects were Division I college male athletes (N = 27, mean age = 20.3 years) and were randomly assigned to one of two test groups, fatigue or control. Participants performed the balance test before and after the fatigue protocol or before and after 20 minutes of rest (control). The athletes assigned to the fatigue group completed a circuit type design which consisted of seven stations. Athletes assigned to the fatigue group made significantly more errors at post-test in comparison to pre-test conditions as well as in comparison to the control group at post-test. Additionally, the control group decreased the amount of errors on the BESS, which

demonstrated improvement and possibly a learning effect. In conclusion, fatigue following a circuit type design significantly decreases performance on the BESS.

Cycle/Treadmill Fatigue Protocols

Some studies combined both treadmill and cycle fatiguing protocols to compare the effects on balance. For example, Yaggie & Armstrong (2004) explored the effects of lower extremity fatigue induced by the Wingate test. The college-age subjects ($N = 16$ men, mean age = 24 years) were either required to rest (control) or complete two Wingate tests with two minutes of rest between tests. Balance was then measured on a KAT 2000 pre-fatigue, immediately after fatigue, and following a 10-minute recovery. There was a significant increase in balance index immediately but a decrease after the 10-minute recovery. The control group improved in balance indices, which is consistent with results from Wilkins et al. (2004). The researchers concluded that any changes in the balance index due to fatigue were returned to baseline following a 10 minute recovery.

Nardone et al. (1997) assessed treadmill performance and cycle performance both below and above the fatigue threshold and how these exercises affect body sway. Thirteen healthy trained subjects (males $N = 6$, females $N = 7$; age = 18-39 years) were randomly assigned to either treadmill or cycle exercises and performed both a fatiguing and non-fatiguing conditions of the exercise protocol (three subjects performed both cycle and treadmill exercises). Body sway was assessed both prior to and following the exercise (5 minutes and 25 minutes) and was assessed by the subjects performing 10 trials of the balance assessment on a dynamometric platform (5 with eyes open and 5 with eyes closed). It was found that body sway was significantly increased when the fatiguing treadmill test was performed in comparison to the non-fatiguing treadmill test.

For the cycling test, however, the eyes open condition was the only condition which showed a significant increase in body sway following the fatiguing exercise when compared to the non-fatiguing exercise. The fatiguing treadmill test showed greater effects of fatigue in comparison to fatiguing cycle test. The researchers also examined and found that all effects on balance were shown immediately and lasted no longer than 15 minutes following the end of exercise. In conclusion, body sway is affected by fatigue, which is strongly affected following treadmill exercise.

Lepers et al. (1997) investigated the effect of long-distance running on balance, as well as the importance visual stimulus has on body balance. Nine well trained male subjects (4 of which were runners and 5 of which were triathletes; mean age = 34 years old) performed a long-distance run followed by the sensory organization test (SOT). The triathletes also performed a cycle test one week after the run. The SOT is a test which provides information about the integration of multiple components of balance. The test consists of six conditions, five of which are considered “dynamic environment” conditions. The subjects demonstrated a decrease in postural stability during the dynamic environment following exercise on both the treadmill and cycle ergometer. In conclusion, prolonged running and cycling affected the subjects’ ability to maintain balance.

Conclusion

It is well supported that fatigue does affect postural stability following various types of fatiguing protocols. Balance has been found to be altered following isokinetic fatigue to the hip, knee and ankle joints (Johnson et al., 1998; Yaggie & McGregor, 2002; Surenkok et al., 2006; Gribble et al., 2004). Back extension exercises and calf raises have also been found to have a detrimental effect on balance, and may cause alterations in

balance strategies (Pline et al., 2006; Wilson et al., 2006). Treadmill and cycling fatiguing protocols have been found to alter balance, while alterations are generally restored within 20 minutes (Yaggie & Armstrong, 2004; Nardone et al., 1997; Lepers et al., 1997). Many researchers have demonstrated and concluded that effects of fatigue on balance could therefore be caused by disturbance in the body's equilibrium and sensory systems while the stabilizing muscles become fatigued (Yaggie & Armstrong, 2004; Reimann & Guskiewicz, 2000). In conclusion, fatigue does have a detrimental effect on postural stability.

CHAPTER III

METHODOLOGY

Subjects

Sixteen recreationally active volunteers (Male N=11, Female N=5) between the ages of 19 and 24 (average age = 21.2 ± 2.04) who had no history of balance problems were chosen to participate in the study. The subjects' average weight was $77.76 \text{ kg} \pm 14.36 \text{ kg}$; average height was $172.593 \text{ cm} \pm 10.135 \text{ cm}$; average percent of body fat was $16.58\% \pm 7.95\%$. All subjects completed the Modified AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire to determine exclusionary conditions (see Appendix A). Subjects stated that they participated in physical activity at least 3-4 days a week for 1-2 hours per session, which was recorded on the Preparticipation Screening Questionnaire. Any subjects who did not meet this criterion were excluded from the investigation. Subjects were chosen from Physical Education classes at Western Kentucky University. All subjects read and signed an informed consent form (see Appendix B) that was approved by Human Subjects Institutional Review Board (HS08-122).

Instruments

Balance Assessment

A Biodex Balance System (#945-300, Biodex Medical Systems, Shirley, New York, USA) was used to measure balance via the Dynamic Balance Test. This test allows the researcher to assess the subject's neuromuscular control in a closed-chain multi-plane test. The ability of the subject to maintain dynamic bilateral postural stability on an unstable surface is quantified using this test. The degree of surface instability was

controlled and set at level five (eight being the most stable surface and one being the least stable surface). Additionally, the screen was turned around to prevent visual feedback, but subjects were allowed to keep eyes open during testing.

At the beginning of each session, subjects were given a “practice” trial to determine foot stance and to get acquainted with the platform. The platform was then locked and foot stance was recorded and outlined with chalk for reference. The subject used this same foot stance for all balance testing during that session. Testing began after recording of foot stance as platform was released for a 20-second test. The subjects were instructed to not touch side-rails unless absolutely necessary and to keep arms at side unless needed to help maintain balance. Subjects could look at the wall or down at the moving platform while testing occurred. Subjects were instructed to keep the moving platform as level as possible.

An Overall Stability Index, Anterior/Posterior Index, and Medial/Lateral Index was recorded and used for analysis. Overall Stability Index (SI) is the variance of foot platform displacement in degrees in all motions during the test. Anterior/Posterior Stability Index (API) is the variance of foot platform displacement in degrees for motion in the sagittal plane. Medial/Lateral Stability Index (MLI) is the variance of foot platform displacement in degrees for motion in the frontal plane.

Assessment of Fatigue.

Several tools were used to determine fatigue and thereby to justify ending exercise prior to completion of protocol. Subjects wore a heart-rate monitor during the entire duration of exercise. If heart rate reached above 85% of HR_{max} , the test could be terminated according to ACSM guidelines. Rating of Perceived Exertion (RPE) was also

taken every other minute during exercise on a scale of 6-20, and was recorded immediately upon ending of exercise (Borg, 1970). Oxygen Consumption (VO_2) was also taken to aid in determining if exercise could be terminated. VO_2 in ml/kg/min was recorded. If VO_2 reached a plateau ($<.05$ L/min during last 30 seconds), the researchers could terminate exercise. Additionally, if the subject expressed fatigue and was unable to continue protocol, exercise was terminated.

Design

The subjects first came into the Human Performance laboratory for a preliminary session where they reviewed an orientation protocol which consisted of an example of the balance test and demonstrated stages of cycle and treadmill exercise. Additionally, subjects reviewed and signed informed consent and medical screening documents during this session.

After being oriented with protocol and signing the appropriate documents, the subjects returned to the laboratory for the first session. Each session consisted of a balance measure before exercise (as described below), an incremental fatiguing exercise, and balance measures after exercise for up to 21 minutes. Balance was measured a total of 9 times: pre-exercise (PRE), immediately after exercise (IMMED-POST), three minutes after exercise (3-POST), six minutes after exercise (6-POST), nine minutes after exercise (9-POST), twelve minutes after exercise (12-POST), fifteen minutes after exercise (15-POST), eighteen minutes after exercise (18-POST), and twenty-one minutes after exercise (21-POST). Between the post-exercise balance measures, subjects were allowed to rest, either seated or standing depending on personal preference.

The incremental fatiguing exercise consisted of either an incremental cycle ergometer test or incremental treadmill test (Bruce protocol; see Appendix C). The order of the test was randomized, with 8 subjects completing the treadmill protocol first while 8 subjects completed the cycling protocol first (see Appendix C). The subjects had at least 4 days to return to laboratory to complete second session, with some subjects not returning for up to 14 days (on average they returned 8 days after initial session).

Data Analysis

A paired-samples t-test was used to determine correlation and significance between recovery times for the two modes. Significance was accepted at the $p < 0.05$ level. Recovery time was determined and defined when two consecutive SI scores (measured every three minutes) were at or below pre-exercise levels.

To ensure pre-exercise balance values were similar to first and second exercise bout, correlations between the values was used on all SI, MLI, and API values. Significance was accepted at $p < 0.01$ level (2-tailed).

To determine differences in PRE values and IMMEDIATE-POST exercise values, a two-tailed t-test was run to determine significant increases or decreases, if any, after the exercise bout. Significance was accepted at the $p < 0.01$ level.

To determine differences between cycling and treadmill protocols, SI, MLI and API was assessed using three 2 x 6 ANOVA with Repeated Measures on both variables. The first two factors of the ANOVA were mode of exercise (cycle versus treadmill), and the second six factors were the times at which balance was measured. Linear Trends were assessed for Within-Subjects Contrasts. Significance was accepted at the $p < 0.05$ level.

If ANOVA identified a significant mode*time interaction, further analysis was completed using the Tukey post-hoc test. This test was used to identify the time points at which stability indices were significantly ($p < 0.05$) different between modes of exercise. Time points included all six factors at which balance was measured and analyzed (PRE, IMMED, 3-, 6-, 9-, and 12-POST) between the two modes (cycle versus treadmill).

CHAPTER IV

RESULTS

Recovery Time

Although subjects tended to exercise longer on the cycle test (14.94 ± 3.30 minutes), there were no significant differences compared to the length of exercise to fatigue on the Bruce treadmill test (12.20 ± 1.64 minutes, $p = 0.06$). See Appendix D.

While recovery time tended to be longer following the fatiguing cycle protocol (12 ± 6 minutes), there was no significant difference compared to the fatiguing treadmill protocol (9 ± 6 minutes, $p = 0.858$). See Appendix E.

Stability Index

For the cycling test, SI scores increased 0.106 (from 4.42 ± 3.01 to 4.53 ± 2.37). This was an average increase of 2.4% in scores. A t-test showed that the increase was not significant ($t = 0.164$, $p < 0.01$).

For the treadmill test, SI scores increased 1.713 (from 4.38 ± 2.48 to 6.09 ± 1.80) (See Appendix F, Figure 4.1). This was an average increase of 39% in scores. A t-test showed that the increase was significant ($t = 3.025$, $p < 0.01$).

Please note that only the first six time points (PRE, IMMED, 3-, 6-, 9-, and 12-POST) were analyzed after recovery time analysis indicated all effects were diminished and restored after 12 minutes of rest for both protocols. The means for all stability indices are presented in Appendix F. Figure 4.1. Stability index scores were similar before exercise in both modes (cycle = 4.42 ± 3.01 ; treadmill = 4.38 ± 2.48 ; $p = 0.01$). See ANOVA table (Appendix G, Table 4.1) for full results. There was a significant mode*time interaction ($p = 0.02$). There was also a significant finding for time ($p =$

0.001), but not for mode ($p = 0.55$). See Appendix F, Figure 4.1 for Trend Analysis Graph. SI was significantly affected negatively immediately post exercise following the treadmill bout.

Post-hoc analysis found that there was a significant difference ($p = 0.05$) in stability indices immediately following exercise (IMMED) between the two modes, but no other significant difference was found at any other time point.

Anterior/Posterior Index

For the cycling test, API scores increased 0.313 (from 3.54 ± 2.71 to 3.85 ± 2.22). This was an average increase of 8.8% in scores. A t-test showed that the increase was not significant ($t = 0.523$, $p < 0.01$).

For the treadmill test, stability index scores increased 1.788 (from 3.49 ± 2.18 to 5.28 ± 1.81) (See Appendix H, Figure 4.2). This was an average increase of 51.3% in scores. A t-test showed that the increase was significant ($t = 3.505$, $p < 0.01$).

Please note that only the first six time points (PRE, IMMED, 3-, 6-, 9-, and 12-POST) were analyzed after recovery time analysis indicated all effects were diminished and restored after 12 minutes of rest for both protocols. The means for all AP indices are presented in Appendix H, Figure 4.2. API scores were similar before exercise in both modes (cycle = 3.54 ± 2.71 ; treadmill = 3.49 ± 2.18 ; $p = 0.01$). See ANOVA table (Appendix I, Table 4.2) for full results. There was a significant mode*time interaction ($p = 0.04$). There was a significant finding for time as well ($p = 0.00$), but not for mode ($p = 0.55$). See Appendix H, Figure 4.2 for Trend Analysis Graph. API was significantly affected negatively immediately post exercise following the treadmill bout.

Post-hoc analysis found that there was a significant difference ($p = 0.05$) in API stability indices immediately following exercise (IMMED) between the two modes, but no other significant difference was found at any other time point.

Medial/Lateral Index

For the cycling test, MLI scores decreased 0.319 (from 2.74 ± 1.58 to 2.43 ± 1.22) (See Appendix J, Figure 4.3). This was an average decrease of 13% in scores. A t-test showed that the decrease was not significant ($t = -0.888$, $p < 0.01$).

For the treadmill test, stability index scores increased 0.425 (from 2.76 ± 1.50 to 3.18 ± 1.11). This was an average increase of 15.4% in scores. A t-test showed that the increase was not significant ($t = 1.443$, $p < 0.01$).

Please note that only the first six time points (PRE, IMMED, 3-, 6-, 9-, and 12-POST) were analyzed after recovery time analysis indicated all effects were diminished and restored after 12 minutes of rest for both protocols. The means for all ML indices are presented in Appendix J, Figure 4.3. MLI scores were similar before exercise in both modes (cycle = 2.74 ± 1.58 ; treadmill = 2.76 ± 1.50 ; $p = 0.01$). Please see ANOVA table (Appendix K, Table 4.3) for full results. There was a significant mode*time interaction ($p = 0.04$). There was also a significant finding for time ($p = 0.02$), but not for mode ($p = 0.68$). See Appendix J, Figure 4.3 for Trend Analysis Graph.

Post-hoc analysis found that there was no significant difference ($p = 0.05$) in MLI stability indices at any time point between modes.

CHAPTER V

DISCUSSION

In this study, no significant differences were found in recovery time between the two modes, treadmill versus cycle. Subjects' SI scores were generally restored within 12 minutes for the cycle test and within 9 minutes for the treadmill test. This finding is consistent with previous research done by Nardone et al. (1997) who found that all effects following the fatiguing treadmill and fatiguing cycle test were diminished within 15 minutes. This indicates that individuals participating in physical activity should rest when feeling fatigued. For all stability indices at 21-POST, all values were below PRE values. This indicates an improvement in postural stability following fatiguing exercise. For the treadmill test, at 9-POST SI values were 3.19, which was lower than the cycle SI value of 3.82. Although this difference was found not to be statistically significant, this difference could be significant in the prevention of injuries. Recently, many researchers have identified the importance of maintaining balance in relation to the prevention of injuries (Hyrosomallis, 2007; Salavati, et al., 2007). It is thought that when balance is altered due to fatigue, the sensory systems may be affected thus decreasing ability to alter perturbations and prevent injury. Further research is needed to identify the specific causes and effects in an altered ability to naturally prevent injury.

The improvement in all stability indices seen also indicates the possibility of a learning effect. Wilkins et al. (2004) explained that the improvement in amount of errors on the BESS was due to a learning effect. However, the present study tried to control for learning effects by removing visual feedback screen and maintaining same foot stance for each trial. In addition, on the second testing day, foot angle was compared to first day

testing foot angle. This was used so the researchers could control for differences in angling of foot.

The results of this study indicate that fatigue induced by the Bruce treadmill test significantly reduces postural stability performance for SI and API indices IMMEDIATE POST when resistance is set at level 5 using a Biodex Balance System. These findings are consistent with other research which has found a detrimental effect following treadmill exercise (Nardone et al., 1997; Lepers et al., 1997). Nardone et al. (1997) found that body sway was significantly increased when a fatiguing treadmill test was performed in comparison to the non-fatiguing treadmill test. Lepers et al. (1997) found that subjects experienced a decrease in postural stability under dynamic environments following a fatiguing treadmill test.

This study found the treadmill fatiguing test was the only test to have significant increases immediately after exercise in comparison to the cycling ergometer fatiguing exercise in recreationally trained individuals. The cycle ergometer fatiguing test indicated no significant increases or decreases in stability indices immediately following a fatiguing bout. In addition to these significant findings among the modes, comparison between modes found the only significant differences were found immediately following exercise bout. After the fatiguing treadmill bout, SI and API was significantly increased in comparison to the fatiguing cycle test. This indicates that the treadmill fatiguing exercise had a more detrimental effect on performance in comparison to the cycle ergometer fatiguing exercise. This could be due to the type of fatigue that was induced, since a treadmill fatiguing test is thought to induce whole-body fatigue while the cycle ergometer fatiguing test is thought to induce lower-body fatigue.

The results of the MLI analysis indicated that there were no significant differences found for any tests. This indicates that MLI was not significantly effected in either mode of fatiguing exercise. However, research has shown that MLI accounts for a very small portion of the SI variance (Arnold & Schmitz, 1998). The MLI scores should still be considered important when assessing balance but noted that API is more closely related to overall stability in comparison to MLI. This could be due to the fact that both the cycle and treadmill test were completed in the sagittal plane and little movement during exercise is completed in the frontal plane if no deformity is present. More research needs to be done in examining why MLI accounts for such a small portion of SI variance.

The lack of significant changes in balance following the cycle ergometer test is inconsistent with the Nardone et al. (1997) study. Nardone et al. (1997) found that following a fatiguing cycle ergometer test, significant effects were observed when subjects kept eyes open to perform balance measures. But the present study found that there were no significant effects and therefore does not support the previous finding. However, this could be explained due to the different study design, including the type of cycling exercise and type of balance measure. Nardone et al. (1997) used trained individuals who completed either a treadmill or cycle test. The balance assessment was completed on a dynamometric platform with a total of 10 conditions (5 with eyes open and 5 with eyes closed). The researchers examined body sway before and at 5 and 25 minutes post. The difference in study design may skew any comparisons, especially in relation to type of balance equipment (dynamometric platform versus Biodex Balance System) and outcome variable examined in the studies (body sway versus stability indices).

The Biodex Balance System is a multi-axial device that allows the subject to move in the anterior-posterior and medial-lateral axes simultaneously. This is a contrast to force platforms and dynamometric platforms that are generally used to measure balance via center of pressure (COP) or body sway (respectively). Cacheu, Shifflett, Kahanov, & Wughalter (2001) found that under dynamic conditions, the Biodex Balance System provides accurate information about stability at the level of the ankle, but research has yet to find if knee and hip motions affect measures. Additionally, Arnold & Schmitz (1998) stated that balance measures from Biodex Balance Systems may or may not be related to COP fluctuations. Therefore, it is unclear if the results from this test can be compared to results from other tests using force-plate technology as the balance measure. More research needs to be completed that compare the technology that measures balance and indicate any discrepancies.

Conclusions

In conclusion, the additional knowledge that this study noted was that when recreationally active subjects completed both treadmill and cycle ergometer fatiguing exercise (repeated measures), the treadmill fatiguing test was the only test to have significant increases immediately after exercise in comparison to the cycling ergometer fatiguing exercise, which had no significant increases or decreases in stability indices. The only significant differences in balance between cycle and treadmill protocols were immediately post-exercise. The results of this study indicate that fatigue induced by the treadmill test does have a higher detrimental effect on postural balance when compared to the cycle ergometer test, thus supporting the first hypothesis. All detrimental effects were seen immediately after exercise and were diminished as time after exercise increased.

In opposition to the second hypothesis, it was found that there are no differences between the tests regarding recovery time. Balance indices for the treadmill and cycle tests were returned at or below baseline values at 9 and 12 minutes post (respectively). It appears that this study has confirmed previous studies that suggest any effects on postural balance are diminished shortly after fatiguing exercise (Nardone et al., 1997; Yaggie et al., 2004). This consistent finding can be applied to exercise prescription research. This suggests that individuals need to remain cautious after becoming fatigued but are able to continue with activity after rest.

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APPENDIX A

Modified AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire
Assess your health status by marking all *true* statements

History

You have had:

- ☐ a heart attack
- ☐ heart surgery
- ☐ cardiac catheterization
- ☐ coronary angioplasty (PTCA)
- ☐ pacemaker/implantable cardiac
- ☐ defibrillator/rhythm disturbance
- ☐ heart valve disease
- ☐ heart failure
- ☐ heart transplantation
- ☐ congenital heart disease

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise.

You may need to use a facility with a **medically qualified staff**.

Symptoms

- ☐ You experience chest discomfort with exertion.
- ☐ You experience unreasonable breathlessness.
- ☐ You experience dizziness, fainting, or blackouts.
- ☐ You take heart medications.

Other health issues

- ☐ You have diabetes.
 - ☐ You have asthma or other lung disease.
 - ☐ You have burning or cramping sensation in your lower legs when walking short distances.
 - ☐ You have musculoskeletal problems that limit your physical activity.
 - ☐ You have concerns about the safety of exercise.
 - ☐ You take prescription medication(s).
 - ☐ You are pregnant.
 - ☐ You have a history of balance or neuromuscular disorders
-

Cardiovascular risk factors

- ☐ You are a man older than 45 years.
 - ☐ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
 - ☐ You smoke, or quit smoking within the previous 6 months.
 - ☐ Your blood pressure is >140/90 mm Hg.
 - ☐ You do not know your blood pressure.
 - ☐ You take blood pressure medication.
 - ☐ Your blood cholesterol level is >200 mg/DL.
 - ☐ You do not know your cholesterol level.
 - ☐ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
 - ☐ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week)
 - ☐ You are > 20 pounds overweight.
-

If you marked two or more of the statements in this section consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a **professionally qualified exercise staff[†]** to guide your exercise program

- ☐ You participate in aerobic exercise 1-2h per session, at least 3-4 days per week
-

- ☐ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

APPENDIX B

INFORMED CONSENT DOCUMENT

Project Title: Effects of Exercise Induced Fatigue on Postural Balance: A Comparison of Treadmill vs. Cycle Fatiguing Protocols

Investigator: Kate Wright, Physical Education, 270-745-2992 or 205-454-8991
(include name, department and phone of contact person)

You are being asked to participate in a project conducted through Western Kentucky University (and -- if applicable -- any other cooperating institution). The University requires that you give your signed agreement to participate in this project.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask him/her any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have.

If you then decide to participate in the project, please sign on the last page of this form in the presence of the person who explained the project to you. You should be given a copy of this form to keep.

1. Nature and Purpose of the Project:

The purpose of this study is to compare the results of balance following a fatiguing incremental treadmill test versus a fatiguing incremental cycle test in recreationally trained individuals. Recovery time for the two different fatiguing protocols will also be examined and compared. This test is fatiguing in nature, so you may experience discomfort during or following the test. You may terminate the test at any point.

2. Explanation of Procedures:

You will first come into the lab for a preliminary session where you will be orientated with the protocol and complete a medical screening. You will return to the lab where you will first perform a balance assessment to determine a pre-fatigue balance measure level. Then you will perform either an incremental cycle or treadmill test while oxygen uptake (VO_2) is measured. The exercise intensity will begin at a low level and will be increased according to the protocol. After you complete the incremental test, you will immediately step onto the balance system and perform the balance conditions. You will perform balance tests every 3 minutes for 21 minutes with seated rest between trials. You will return 1 week after to complete the other incremental test following similar protocol. You or the researcher may choose to terminate exercise at anytime. The researcher may chose to terminate the exercise according to ACSM guidelines, including reaching 85% of age predicted maximal heart rate or if VO_2 seems to reach a plateau (<0.05 L/min during the last 30 seconds).

3. Discomfort and Risks:

Due to the nature of the test, you will experience fatigue during or following completion of the test. You may also experience discomfort when performing these tests. This is normal due to the nature of the test you are completing. In every fatiguing exercise, there is risk for abnormal blood pressure, fainting, irregular, fast or slow heart rhythm and shortness of breath. There also is a small and rare chance that a heart attack, stroke, or death could occur. All safeguards will be in place to decrease the chance of risk. There will be a CPR certified individual in the laboratory when all tests are being completed along with an automated external defibrillator (AED).

4. **Benefits:**

The results from this study may be used in application for exercise prescription for individuals, and potentially prevent falls and/or injuries following fatigue in recreationally trained individuals. The results may also be useful in future research in this area of interest.

5. **Confidentiality:**

You will be assigned a random number which will be used for all data. Names will not be used on any data presented. The data will be kept in locked filing cabinet under the supervision of the faculty research sponsor.

6. **Refusal/Withdrawal:**

Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

Signature of Participant

Date

Witness

Date

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT
THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY HUMAN SUBJECTS REVIEW BOARD
Sean Rubino, Compliance Manger
TELEPHONE: (270) 745-4652

APPENDIX C

Bruce Treadmill Test

Minute	MPH	% Grade
0	1.7	10
3	2.5	12
6	3.4	14
9	4.2	16
12	5.0	18
15	5.5	20

ACSM Cycle Ergometer Test

Minute	Kp	Watts
0	150	24
2	300	49
4	450	74
6	600	98
8	750	123
10	900	148
12	1050	172
14	1200	197
16	1350	221
18	1500	246

Note: Subjects were instructed to maintain 50 RPM during Cycle Ergometer Testing

APPENDIX D

Time to Exhaustion Graph

APPENDIX E

Recovery Time Graph

APPENDIX F

Figure 4.1

Stability Index Scores & Graph

Note:

* indicates significant increase in comparison to PRE balance indices ($p < 0.05$)

† indicates significant difference in comparison to Cycle indices at given time point ($p = 0.05$)

APPENDIX G

Table 4.1

ANOVA for Stability Index Scores

Source	<i>df</i>	<i>F</i>	<i>Significance</i>
Within Subjects			
Mode	1	0.380	0.547
Time	1	17.891**	0.001
Mode*Time	1	7.505	0.015
Mode*Time Error	15	(0.903)	

Note: Values enclosed in parentheses represent mean square errors.

*p < .05. **p < .01.

APPENDIX H

Figure 4.2

Anterior/Posterior Stability Index Scores & Graph

Note:

* indicates significant increase in comparison to PRE balance indices ($p < 0.05$)

† indicates significant difference in comparison to Cycle indices at given time point ($p = 0.05$)

APPENDIX I

Table 4.2

ANOVA for Anterior/Posterior Stability Index Scores

Source	<i>df</i>	<i>F</i>	<i>P</i>
Within Subjects			
Mode	1	0.366	0.554
Time	1	25.637**	0.000
Mode*Time	1	4.730*	0.046
Mode*Time Error	15	(0.940)	

Note: Values enclosed in parentheses represent mean square errors.

*p < .05. **p < .01.

APPENDIX J

Figure 4.3

Medial/Lateral Stability Index Scores & Graph

APPENDIX K

Table 4.3
ANOVA for Medial/Lateral Stability Index Scores

Source	<i>df</i>	<i>F</i>	<i>P</i>
Within Subjects			
Mode	1	0.179	0.679
Time	1	12.430*	0.017
Mode*Time	1	5.165*	0.038
Mode*Time Error	15	(0.396)	

Note: Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.