The Effect of Aerobic and Anaerobic Exercise Protocols on Postural Control

Zachary G. Fox ATC, LAT

A thesis submitted to the faculty of The University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Arts in the Department of Exercise and Sport Science (Athletic Training)

Chapel Hill
2007

Approved by:

Advisor: Dr. Kevin M. Guskiewicz

Reader: Dr. Troy Blackburn

Reader: Dr. Claudio Battaglini

Reader: Jason P. Mihalik

ABSTRACT

ZACHARY G. FOX

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"(Under the direction of Kevin M. Guskiewicz, PhD, ATC)"

Sideline management of a suspected mild head injury includes postural control assessments typically performed shortly after exercise. The purpose of this study was to evaluate the effects of fatigue on postural control in healthy college-aged athletes using forceplate measures and the Balance Errors Scoring System (BESS). Post exercise recovery of postural control measures were also observed following each exercise protocol at specific time intervals. Thirty-six Division I collegiate athletes participated in this study. Statistical analysis revealed a significant decrease in postural control assessed immediately after an anaerobic and aerobic exercise protocol performed to fatigue ($p < 0.001$). Postural control deficits from fatigue returned to baseline between eight and thirteen minutes following each exercise protocol. Administering the BESS immediately following exercise may yield false-positive findings due to the effect from fatigue. Athletic trainers and clinicians should be aware of the impact of fatigue on postural control and the fatigue recovery time course when determining an appropriate time to administer sideline assessments of postural control following a suspected mild head injury.

DEDICATION

My mom and dad have been most influential in my life up to this point. They have guided me down a successful path and driven me to achieve my goals. Without their love and support, I would not be the person who I am today.

But over the last two years, and for the rest of my life, my fiancé Terri has been right by my side, day after day, giving me the love and direction I need to continue to excel. Many nights she was unwillingly left alone while I was tucked away in the office studying or working hard on numerous projects. But every night, she always took the time to drop in, say hello, and remind me how much she loved me and how proud she was of me. I know I didn't say it enough, but you deserve a giant thank you for being so understanding, so caring, and for sticking through the tough days with me when school got busy. You helped me mature and become who I am today, and I deeply appreciate it. You will never know just how much you mean to me. I love you always, and cannot wait to spend the rest of my life with you.

ACKNOWLEDGEMENTS

Many outstanding people were involved in making this thesis project possible. First, I would like to express my gratitude to my advisor, Dr. Kevin Guskiewicz for his leadership and effort toward the completion of this project. You always made time for me in your ridiculously busy schedule, and I thank you. I also must give special thanks to Dr. Troy Blackburn and Dr. Claudio Battaglini for all of their analysis and insight into this thesis. Troy, your return to UNC could not have come at better time (for me), and I thank you for the direction you lead me. And Claudio, I now know why every undergrad I speak to says you are their favorite professor. Your assistance has been very much appreciated.

I can honestly say this thesis would not have been what it is without one exceptionally smart and extremely hard working doctoral student, Jason Mihalik. I cannot express how much your guidance and dedication was appreciated. I called on you far too many times, and every single time you responded with nothing but help and support. Never once did you lose your cool, let me down, or shy me away. I could not have asked for a better committee member. Cheers!!! And a huge thank you to you!

Finally to my classmates. Thank you all for helping me out when I needed it the most. We stuck by one another over the last two years, and got it done. I'll never forget the countless 80's nights, quarter darts, and enjoyable J-Bus rides. I sincerely wish you all the best in your future endeavors. Never a doubt.

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CHAPTER I

INTRODUCTION

Proper recognition and management of sport-related mild head injuries (MHI) has gained a great deal of interest within the sports medicine community in recent years. Assessment of MHI has relied heavily on subjective symptoms self-reported by the athlete (Cantu, 1998). This can become dangerously problematic because athletes may withhold information in order to return to competition, leaving the clinician without a clear picture of the athlete's true mental status (Cantu, 1998; Crowell, 2000). Premature return to contact activity following a MHI has the potential for fatal consequences such as Second Impact Syndrome (Cantu, 1998; Saunders & Harbaugh, 1984).

Proper management of MHI requires a comprehensive assessment by athletic trainers and other clinicians. Though an abundance of general guidelines exist regarding return-to-play decisions, the majority of these guidelines are not empirically supported. The lack of objective and quantifiable information on which to make return to play decisions poses a quandary for sports medicine clinicians (Cantu, 1992; Guskiewicz, 2001).

Recent trends in the clinical management of MHI have resorted to alternative means of identifying deficits following a suspected head injury. Postural control and neuropsychological testing have been the catalyst in this regard (Guskiewicz, 2001, , 2003; McCrea et al., 1998; Notebaert & Guskiewicz, 2005). With these measures, it is believed that clinicians will have a more objective, quantifiable notion of the extent of injury an athlete may have sustained. This can lead to better return-to-play decisions and, hence, better management of the condition.

Forceplate technology has enabled the sports medicine community to objectively measure postural control. Research has reported forceplate testing to be a valid and reliable measure to assess postural control in determining MHI severity (Guskiewicz & Perrin, 1996; Guskiewicz, Riemann, Perrin, & Nashner, 1997; Ingersoll & Armstrong, 1992). Clinical balance protocols, such as the Balance Error Scoring System (BESS), have been developed based upon forceplate postural control measures (Guskiewicz et al., 1997).

Traditional sideline evaluations following a MHI have typically included basic mental status tests, such as questions regarding orientation, memory recall, and concentration. The standing Romberg test has also been incorporated in sideline evaluations to test for postural stability. However, research has shown that these tests may not be sensitive to subtle deficits in mental status and postural control. For this reason, sideline evaluations have evolved to include more sensitive tests, including the Balance Error Scoring System (BESS). This test has been demonstrated to be a reliable and valid measure of postural control (B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999).

Postural control assessments are taken at rest before the athlete’s season begins in order to obtain baseline measures for each individual athlete. Following a suspected MHI, another measure of postural control is taken on the sideline, and this post-injury score is compared to the athlete’s baseline score. However, sideline evaluations of MHI are most often taken during practice or competition, not at rest. Therefore, numerous extraneous factors, aside from the MHI, may play a role in affecting postural control (Derave, De Clercq, Bouckaert,

& Pannier, 1998; Gauchard, Gangloff, Vouriot, Mallie, & Perrin, 2002; Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004).

Fatigue has been shown to negatively affect postural control (Adlerton, Moritz, & Moe-Nilssen, 2003; Caron, 2003; Crowell, 2000; Harkins, Mattacola, Uhl, Malone, & McCrory, 2005; Lepers, Bigard, Diard, Gouteyron, & Guezennec, 1997). However, few studies have measured the effect of fatigue on the performance of the BESS. Crowell et al. (2000) demonstrated decreased postural stability after an exercise protocol consisting of squat jumps, sprints, and treadmill running. Similarly, Wilkins et al. (2004) found a decrease in postural stability as a result of a seven-station, twenty-minute exercise protocol as measured by the BESS total error score. Both studies used lengthened exercise protocols to elicit fatigue that included both anaerobic and aerobic characteristics. Neither study examined independently the effects of fatigue from an anaerobic or aerobic exercise protocol.

There are also few studies that have investigated the immediate recovery time following fatigue for postural control measures to return to baseline. The limited research available shows decreased postural stability immediately post-exercise, but no deficits as early as twenty minutes post exercise (Nardone, Tarantola, Galante, & Schieppati, 1998; Nardone, Tarantola, Giordano, & Schieppati, 1997; Susco, Valovich McLeod, Gansneder, & Shultz, 2004; Yaggie & McGregor, 2002). More importantly, these studies examined aerobic exercise protocols that lasted twenty minutes or longer. The recovery timeline may differ when compared to a shorter, anaerobic exercise protocol.

The aforementioned studies examined exercise protocols that were aerobic in nature. It is well known that different sports require athletes to perform at varying speeds and for varying lengths of time. Based on current literature, the immediate effects of an anaerobic exercise protocol on postural control have yet to be established. Furthermore, the effects of fatigue induced by an anaerobic exercise protocol have not been compared to those induced by an aerobic exercise protocol. In addition, the immediate recovery time for an anaerobic exercise protocol may differ from that of an aerobic exercise protocol. There remains a need to further examine this important relationship between fatigue and postural control.

Statement of the Problem

The primary purpose of this study was to evaluate the effects of fatigue on postural control in healthy college-aged athletes. Fatigue was introduced by means of two different exercise protocols: aerobic exercise and anaerobic exercise. A secondary purpose of this study was to establish an immediate recovery time course from each exercise protocol over which the effects of fatigue lessen, and postural control measures returned to baseline status. Forceplate measures and total BESS score were used to assess postural control differences pre and post exercise. Specific research questions included:

1. Is there a difference between baseline and post-fatigue measures of postural control following an anaerobic exercise protocol as measured by a forceplate and scored by the BESS?
2. Is there a difference between baseline and post-fatigue measures of postural control following an aerobic exercise protocol as measured by a forceplate and scored by the BESS?
3. Is there an interaction effect between each exercise protocol and immediate recovery time?

Null Hypotheses

1. There will be no difference in postural control with an anaerobic exercise protocol between baseline and post-fatigue measures as recorded on the forceplate and scored by the BESS.

2. There will be no difference in postural control with an aerobic exercise protocol between baseline and post-fatigue measures as recorded on the forceplate and scored by the BESS.

3. There will be no exercise protocol by immediate recovery time interaction effect.

Research Hypotheses

1. There will be a decrease in postural control following both an anaerobic and aerobic exercise protocol as measured by elliptical sway area and sway velocity on a forceplate.

2. There will be an increase in errors from baseline to post-fatigue following both anaerobic and aerobic exercise protocols as scored by the BESS.

3. There will be a quicker return to baseline following the anaerobic exercise protocol when compared to the aerobic exercise protocol.

Definition of Terms

Aerobic fatigue: the general sensation of tiredness with accompanying decrements in muscle performance due to prolonged exercise (15-20 minutes).

Anaerobic fatigue: the general sensation of tiredness with accompanying decrements in muscle performance due to a high intensity, short bout exercise (2 minutes).

Balance: the ability to maintain the center of body mass over the base of support without falling; alignment of joint segments in an effort to maintain the center of gravity within an optimal range of the body's maximum limits of stability (i.e., postural control).

Base of Support: area contained within the perimeter of contact between the surface and two feet.

Balance Error Scoring System (BESS): clinical measure used to assess static postural control involving three different stances (double leg, single leg, tandem) assessed on two different surfaces (firm, foam) with the participants eyes closed.

Center of Pressure (COP): the point around which all the forces exerted by a person can be centralized. The COP is often referred to as the center of the gravitational force.

Elliptical Sway area: the area defined by the minor and major axes of an ellipse that statistically encompasses an area containing 95% of the data points.

Fatigue: general sensations of tiredness and accompanying decrements in muscle performance.

Forceplate: mechanical device used to measure ground reaction forces along three orthogonal axes aligned in the platform.

Ground Reaction Forces (GRF): the reaction force of the ground upon the foot which is equal in magnitude and opposite in direction to the force imposed on the ground by the foot. Fluctuations in ground reaction forces correspond with the movement of the center of mass and pressure.

Immediate Recovery Time: on the sideline, immediate recovery time refers to the first twenty minutes following a sustained head injury. This is the proposed time in which effects from fatigue will lessen, and balance will remain disturbed due to the head injury itself. In the laboratory, and for each testing session, immediate recovery time refers to the first 18 minutes following each exercise protocol in which subjects will be balance tested.

Limits of Stability (LOS): the maximal excursion that the center of gravity can sway while vertically remaining over the base of support.

Postural Control: the ability to maintain postural stability and orientation in the presence of gravity; bodily systems acting to maintain balance and achieve equilibrium.

Postural Sway: with quiet stance, it can be defined as the very slight adjustments in weight distribution and in location of the COP due to the constantly changing tension in muscles. With dynamic tasks, or pathological populations, movement of the COP (postural sway) can become a determinant for whole body balance performance.

Romberg test: a test of static postural stability specific to sensory modality function.

Delimitations

1. Participants that had a lower extremity musculoskeletal injury within 3 months before testing were excluded from participation

2. Participants that had a mild head injury within 3 months before testing were excluded from participation

3. Only participants who had no known history of disease or condition that would affect postural control (balance) were included in this study.

4. Distractions were minimized by conducting data in a laboratory setting rather than a clinical or more practical setting (sideline during practice).

5. Any inherent difference between participants in cognitive abilities and postural control were negated since comparisons were made to baseline measures.

6. Each participant was given a practice period during the baseline testing to familiarize themselves with the BESS in effort to negate any learning effects associated with a repeated measures design.

7. Each participant was read the same test instructions in the same manner.

Limitations

1. During the extent of involvement, subjects were likely to participate in other activities between test days that may have affected their ability to balance or give an honest performance in the fatigue protocol.

2. Data was collected in a laboratory setting rather than the outdoors on the sideline where the actual BESS test would be performed clinically.

Assumptions

1. Participants were honest about medical history and answered all questionnaires truthfully.

2. Participants provided an honest effort in performing the postural control tests.

3. Participants provided an honest effort in performing the fatigue protocols.

4. The data collection was consistent throughout the research process and the researcher remained neutral in reporting the results.

Dependent Variables

1. Errors (for total BESS score)
2. Elliptical Sway Area
3. Sway Velocity

Independent Variables

1. Exercise protocols (Aerobic, Anaerobic)
2. Recovery time (3min, 8min, 13min, 18min post fatigue)

Significance of the Study

Athletes who sustain a MHI typically exhibit deficits in postural control. In the past, clinicians were limited to mainly subjective reports from the athlete in determining the severity of injury. While subjective reporting of symptoms remains an important aspect in the evaluation process, the development of the BESS has made sideline assessments of mild head injury more objective and quantifiable. However, baseline measures on the BESS are taken under normal resting conditions, not while the athlete is in a fatigued state, as would be the case during a practice or a game.

While studies have shown that athletes with mild head injuries have deficits in postural control, fatigue may contribute significantly to these deficits, thus making it difficult to determine if the lack of postural control is due to a MHI or the effects of fatigue. Research has shown that aerobic fatigue affects postural control, and these deficits last up to twenty minutes. It is not known whether anaerobic fatigue has differential effects on postural control compared to aerobic fatigue. Furthermore, the immediate recovery time from anaerobic fatigue has yet to be established using the BESS. Since different sports have different metabolic demands, and athletes from different sports experience varying levels of fatigue, this remains an important research question. It is possible that an anaerobic exercise protocol may differ in its effects on postural control and recovery time when compared with an aerobic exercise. This study investigated the effects of an anaerobic exercise protocol and an aerobic exercise protocol on postural control, and attempted to establish an immediate recovery timeline from both exercises in an effort to improve the efficiency of sideline assessment of MHI

CHAPTER II

LITERATURE REVIEW

Introduction

Mild head injuries are not uncommon in athletic participation. The sideline assessment of mild head injuries has relied heavily on subjective symptoms self-reported by the athlete, which have the potential to be skewed due to the athlete's desire to return to competition. Having to depend on the athlete's word often makes return to play decisions a daunting task for the athletic trainer. Therefore, objective measures, such as neuropsychological tests and postural control tests, are important tools for athletic trainers to use in order to have quantifiable evidence relating to the state of the athlete.

A dilemma exists in obtaining valid sideline postural control measures due to possible extraneous factors an athlete may possess or be exposed to at the time of testing. The extraneous factor of interest for this literature review is fatigue. Fatigue has been demonstrated to have an adverse effect on postural control. This makes it difficult for the athletic trainer to decipher whether deficits in postural control result from the sustained injury or from the athlete's physical condition. To understand fatigue's involvement on the disturbance of postural control, it is necessary to examine the facets of both fatigue and postural control as they relate to the sideline evaluation of the mild head injured athlete. Understanding the effects fatigue has on postural control and how long those effects remain present will help athletic trainers and clinicians alike be more accurate in the sideline assessment of mild head injuries, assuring themselves that deficits are from injury, not fatigue.

The purpose of this literature review is to present an overview of fatigue and the corresponding deficits fatigue can impose on postural control. Current methods of assessing postural control will be discussed along with an explanation of the postural control system. Mild head injury and its effects on postural control will also be detailed.

Postural Control System

Postural control is a complex process that involves the coordinated activities of several sensory, motor, and biomechanical components. The more commonly used term is balance, which can be defined as the process of maintaining the center of gravity (COG) within the body's base of support (Guskiewicz, 1999). The postural control system is thereby the mechanism by which a person maintains their COG within the limits of stability (LOS). It acts as a feedback control circuit between the brain and the musculoskeletal system (Guskiewicz & Perrin, 1996). When the postural control system becomes disturbed, and an individuals COG is shifted outside their LOS, disequilibrium occurs causing the individual to step to regain balance, stumble in an attempt to restore postural control, or fall (L. Nashner, 1993). The sensory and motor components of the postural control system work synchronously to achieve sensorimotor integration, which is expressed by the central nervous system. The coordinated products of these systems provide the information needed to maintain normal balance.

Sensory Component

The sensory component of the postural control system uses information from the visual, vestibular, and somatosensory systems to accurately sense the COG in relation to the base of support. No system alone can determine the COG directly, rather the inputs from these systems are joined to sense the body's position relative to the support surface, gravity, and surrounding objects (L. Nashner, 1993).

Visual Input

Vision measures the orientation of the eyes and head in relation to surrounding objects (Guskiewicz, 1999). The visual system depends on vestibular support through the vestibulo-ocular reflex, activated upon sudden head movements or perturbations to the body. This reflex is a mechanism by which rotation of the head automatically results in opposite movement of the eyes to stabilize the field of vision, allowing the eyes to remain fixed on an object when the head moves. If this does not occur, disequilibrium is the result (Guskiewicz & Perrin, 1996). The vestibulo-ocular reflex is accomplished by neural signals sent by the semicircular canals and otolith organs as the head begins to move (Martini, 1998).

Along with somatosensation, vision plays an important role in the maintenance of balance and equilibrium. When somatosensory input is disrupted, as is the case of standing on an unstable surface, and vision is eliminated by closing the eyes, postural sway is significantly increased when compared to an eyes open condition (Horak, Nashner, & Diener, 1990; L. Nashner, 1993). COG alignment is shown to be dependent upon visual inputs; as an individual's visual field moves in a specific direction, their COG will shift over the base of support in that same direction (L. Nashner, 1993).

Vestibular Input

The vestibular complex is contained within the temporal bone and is the part of the inner ear that provides equilibrium sensations by detecting rotation, orientation relative to the field of gravitational force, and acceleration. Anatomically, it consists of the semicircular canals, the utricle, and the saccule. Receptors in the semicircular canals respond to rotational movements of the head. The utricle and saccule, known together as the otolith organs, sense changes in orientation due to gravity and linear acceleration of the head. The utricles sense motion in the horizontal plane where the saccules sense motion in the sagittal plane. The hair cells of the vestibular complex, which are the critical component of the sensory mechanism, are innervated by the eighth cranial nerve (Fitzpatrick & Day, 2004; Martini, 1998; Yates, 1996).

When the visual and somatosensory inputs are providing accurate information, the vestibular input plays a relatively small role in maintaining postural stability due to the fact that it does not provide orientation information in relation to external objects (L. Nashner, 1993). It does supply information that measures gravitational, linear, and angular accelerations of the head in relation to inertial space (Guskiewicz, 1999). In a healthy athlete, vestibular input will primarily play a role in providing precise eye position relative to head movement, a motor control task necessary for the complex activities inherent in sports.

Somatosensory Input

Somatosensation is a variation of the sensory modality of touch that encompasses the sensation of kinesthesia and joint position sense. Somatosensation and balance work closely together, as the postural control system utilizes sensory information related to movement and posture from peripheral sensory receptors (Guskiewicz, 1999). Somatosensory input is received from tenomuscular, articular, and cutaneous, mechanoreceptors which send afferent signals to the brain, helping direct the postural control mechanism in regulating balance (B. L. Riemann & Lephart, 2002). Tactile sense organs include Ruffini's endings, free nerve endings, pacinian corpuscles, and Meissner's corpuscles, the combination of which provide sense of touch, pressure, and vibrations. The tactile sense organs located in the soles of the feet convey information to the brain as to whether weight is distributed equally upon the base of support, as well as sensing any changes in the support surface. Conscious appreciation of somatosensory information leads to the sensations of pain, temperature, tactile (ie, touch, pressure, etc), and proprioception sensations (B. L. Riemann & Lephart, 2002).

Muscle spindles and GTOs are special types of somatosensory organs located throughout muscles and tendons that play a vital role in postural control. Together, they relay information to the central nervous system regarding muscle tension, length, and the rate of changes in tension or length. During posture, these sensory organs provide continuous feedback to the central nervous system (CNS) about the status of each muscle as well as an indirect indication of joint position.

The muscle spindle consists of afferent nerve fiber endings that encircle modified muscle fibers, several of which are enclosed in a connective tissue capsule (Martini, 1998). Muscle spindles are responsible for sending messages concerning muscle length and its rate of lengthening. When a spindle is stretched, an impulse is sent along its afferent fibers to the spinal cord. The information is processed and transferred to alpha and gamma motor neurons that carry information back to the muscle fibers and muscle spindle causing the muscle to contract. This completes what is referred to as the myotatic or stretch reflex. The stretch reflex comes into play when perturbations of posture automatically evoke functionally directed responses in the leg muscles to compensate for imbalance or increased postural sway (Dietz, Horstmann, & Berger, 1989).

Golgi tendon organs consist of a mass of nerve endings that are enclosed within a connective tissue capsule and embedded into a muscle tendon near the musculotendinous junction. GTOs are responsible for relaying information to the brain concerning muscle tension and the rate of tension by providing the central nervous system with an indication of the contractile status of muscle. Information about how much or how little additional activity is needed to achieve a certain task is controlled by the GTOs. If tension becomes dangerously high, these receptors will trigger a reflexive relaxation of the contracting muscle. GTOs have an inhibitory effect to protect the muscle from developing too much tension.

Sensorimotor Component (Integration)

As mentioned earlier, the sensory and motor components of the postural control system communicate and work together through a process called sensorimotor integration. For your body to respond to sensory stimuli, the sensory and motor components of your nervous system must function together in a specific sequence of events. First, a sensory stimulus is received by sensory receptors. The impulse travels through sensory neurons to the CNS. The CNS interprets the incoming sensory information and determines which response is most appropriate. Based upon this interaction, the CNS generates an appropriate motor response. The motor impulse travels away from the CNS out along motor neurons. The motor impulse reaches the muscle fibers, and the terminal response occurs (Wilmore, 1999).

Sensory impulses are transmitted via sensory nerves to the spinal cord. These impulses can trigger a local reflex at the level of the spinal cord or they can travel to the upper regions of the spinal cord to the brain. Sensory pathways to the brain can terminate in sensory areas of the brain stem, cerebellum, thalamus, or cerebral cortex. The area in which sensory impulse terminates is referred to as the integration center. Here, the sensory input is interpreted and linked to the motor system.

Depending on where the sensory input terminates, and which integration center is activated, different motor responses will be elicited. Sensory inputs that terminate in the spinal cord result in a simple motor reflex. Sensory signals that terminate in the lower brain stem result in subconscious motor reactions such as postural control when sitting, standing, or moving. Impulses that terminate in the cerebellum also result in subconscious movement control. The cerebellum has been referred to as the center of coordination, smoothing out movements by coordinating the actions of the various contracting muscle groups to perform the desired movement. Fine and gross motor movements appear to be coordinated by the cerebellum along with the basal ganglia. Without the control at this level, all movement would be uncontrolled and uncoordinated. Sensory signals that terminate at the thalamus begin to enter the level of consciousness, and various sensations begin to be distinguished. Signals that terminate at the cerebral cortex can be localized. The primary somatosensory cortex receives general sensory input from receptors in the skin and from proprioceptors in the muscles, tendons, and joints. Stimulation in a specific part of the body is recognized and its exact location is known instantly. Therefore, the cerebral cortex allows constant awareness of surroundings and the relationship to them.

The motor component of the postural control system responds with automatic movements to bring the COG back to a stable position in reaction to perturbations of the COG. Upon reception of a sensory impulse, a response is typically evoked through a motor (efferent) neuron, regardless of the level at which the sensory input stops. Skeletal muscles are controlled by motor neuron impulses that originate from any of three levels: spinal cord, lower regions of the brain, or the motor area of the cerebral cortex. As the level of control moves from the spinal cord to the motor area of the cerebral cortex, the degree of movement complexity increases from simple reflex control to complicated movements that require basic thought processes. Motor responses from more complex movements typically originate in the motor cortex of the brain (Wilmore, 1999).

In a normally functioning human, removal of one and possibly two of the sensory inputs does not necessarily result in postural instability. The brain will always receive an input, but may choose which input to utilize if conflicting and inaccurate information is being transferred. The brain generally relies on only one sense at a time for orientation information (L. Nashner, 1993; Shumway-Cook & Horak, 1986). The integration of sensory inputs may also depend upon the environmental conditions that are present. The visual and somatosensory are the most sensitive, and they rely on external cues and references for their information (Guskiewicz, 1999). In contrast, the vestibular system receives its information from angulations of the head in relation to the field of gravity, thereby leaving it unaffected by changes in the surroundings (L. M. Nashner, Black, & Wall, 1982). Thus, under normal conditions, the vestibular system plays a minor role in postural control and the brain depends more on the somatosensory and visual systems (L. Nashner, 1993).

Each sensory input has the potential to provide incorrect information to the brain. If the surface upon which a person is standing is moving or unstable, the somatosensory input will be inaccurate. Likewise, if objects within the visual field are moving, they may affect the accuracy of information from the visual input. The brain must resolve this conflicting situation by relying on the accurate inputs and ignoring the inaccurate ones, otherwise disequilibrium will occur.

Biomechanical Component – Strategies for Maintaining Postural Control

The biomechanical component of the sensorimotor system provides coordinated muscle movements that elicit postural strategies to maintain balance. Once the brain achieves the task of sensory organization, having determined the correct input, it then processes that information and controls balance through selection and execution of proper musculoskeletal movement strategies. The closed kinetic chain of the lower extremity determines the position of the COG depending upon the relative position of the hip, knee, and ankle joints. The muscular coordination aspect of postural control is a function of the actions of these joints.

When a person's balance is disrupted by an external perturbation, movement strategies involving joints of the lower extremity coordinate movement of the COG back to a balanced position. Three strategies, ankle, hip, and stepping have been identified along a continuum (Horak et al., 1990). The strategy employed is dependent upon the configuration of the base of support, the COG alignment in relation to the LOS, and the speed of the postural movement (Horak et al., 1990). In general, when the COG remains within the LOS, then either an ankle or hip strategy, or some combination of the two, are used to adjust COG without altering initial foot placement with the support surface. In cases where the COG is moved outside the LOS, only a step or stumble can prevent a fall from occurring (L. Nashner, 1993).

The ankle strategy adjusts the COG while maintaining the placement of the feet by rotating the body as a rigid mass about the ankle joints. This strategy is achieved by contracting either the gastroc-soleus complex or the anterior tibialis muscles to generate torque about the ankle joints in the sagittal plane. Anterior sway is counteracted by posterior muscle activity, and posterior sway is counteracted by the anterior musculature. The ankle strategy is most effective in executing relatively slow COG movements when the base of support is firm and the COG is well within the LOS perimeter. The ankle strategy is also believed to be effective in maintaining a static posture with the COG offset from the center (L. Nashner, 1993).

The hip strategy is made accessible when the ankle strategy is not capable of controlling excessive sway. The hip strategy controls motion through the initiation of large and rapid motions at the hip joints with smaller opposing rotations at the ankle joints. It is most effective when the COG is located near the LOS perimeter, and when the base of support is narrowed (Horak et al., 1990). When COG is displaced beyond the LOS, a stepping strategy must be used to prevent a fall. As its name suggests, a step or stumble is used to bring the base of support back into alignment under the COG to help regain postural control (L. Nashner, 1993)

Postural Control Assessment

Several methods of postural control assessment have been proposed for clinical use. These methods can be divided into static and dynamic tests. During static tests, the individual's feet remain in the same position with minimal movement of COG, opposed to dynamic tests in which the individual is required to move outside his or her normal base of support. Static tests include the classic Romberg test, single leg, and tandem stance tests performed with and without the eyes closed. Dynamic tests include agility tasks such as the figure eight, functional reach tests, and balance beam walking.

Traditionally, balance was assessed in a subjective manner, causing clinicians to rely heavily on the qualitative aspects of balance and observation of gross movements in order to make judgments regarding postural deficits (Guskiewicz & Perrin, 1996). Measures of static balance have been performed through the use of the standing Romberg. For this test, the subject stands with feet together, arms at side, and eyes closed. Normally, a person can stand motionless in this position, but a tendency to sway or fall to one side is considered to indicate a loss of control (Black, Wall, Rockette, & Kitch, 1982) The Romberg test has been criticized for its lack of sensitivity and objectivity. In a study by Jansen et al., the Romberg test was concluded to be a rather qualitative assessment of static balance because a considerable amount of stress is required to make the subject sway enough for an observer to characterize the sway (Jansen, Larsen, & Olesen, 1982). In contrast to static tests, the purpose of most dynamic tests is to decrease the size of the base of support in an attempt to determine a person's ability to control upright posture while moving. Due to the lack of objectivity, tests of this nature have been criticized for failing to quantify balance adequately, as they merely report the length of time a particular stance is maintained, angular displacement, or the distance covered after walking (Black et al., 1982; Flores, 1992; L. Nashner, 1993).

More recently, advancements in technology have allowed the sports medicine community to use commercially available balance systems for quantitatively (objectively) assessing both static and dynamic balance. Force platforms and computerized dynamic posturography are examples of these systems. These developments have enabled researchers to analyze postural stability and postural control in a more objective manner, creating much growth in the area of balance research. However, due to the high costs and impracticality of these methods in the sideline examination of a mild head injury, researchers have developed inexpensive, practical evaluative tools that assess objective measures of postural control and are based on scientific evidence. The Balance Error Scoring System (BESS) was developed with the purpose of providing an inexpensive and practical method of assessing postural stability (B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999). While there has been development of many subjective and objective tests to assess postural control, only the BESS and forceplate methods will be discussed in this review.

Forceplate Measures

Computerized forceplate systems allow for quantitative analysis and understanding of postural stability. A basic forceplate consists of a flat, rigid surface supported on three or more points by independent force-measuring devices (Guskiewicz & Perrin, 1996). As the subject stands on the forceplate, the position of the center of vertical force exerted on the forceplate over time is calculated. The movement of the point of application of the vertical force provides an indirect measure of postural sway (L. Nashner, 1993).

Four aspects of postural control can be evaluated using a forceplate: steadiness, symmetry, dynamic stability, and dynamic balance (Guskiewicz & Perrin, 1996). Steadiness is the ability to keep the body as motionless as possible, and is a measure of sway. Symmetry is the ability to distribute weight evenly between the two feet in an upright stance, and is a measure of the location of the center of pressure (COP), center of balance (COB), or center of force (COF) depending on which testing system is being used. Dynamic stability is the ability to transfer the vertical projection of the COG around a stationary supporting base and is often referred to as a measure of one’s perception of safe limits of stability (Goldie, Bach, & Evans, 1989). Dynamic balance measures postural responses to external perturbations.

These external perturbations may be applied to the body or derived from a platform moving in one of four directions; tilting toes up, tilting toes down, shifting medial-lateral, and shifting anterior-posterior. Depending on the testing system, the perturbations may be unpredictable, which allows for determination of the subject's reaction response.

Forceplate systems are capable of measuring the vertical ground reaction force (GRF) and provide a means of computing the COP, which represents the center of distribution of total force applied to the support surface (Guskiewicz & Perrin, 1996). The COP is calculated from horizontal moment and vertical force data generated by triaxial force platforms (Guskiewicz & Perrin, 1996). The total force applied to the forceplate varies due to the inclusion of both body weight and the inertial effects of the slightest movement of the body, which occurs when one attempts to stand motionless.

After the COP, COB, or COF is determined, other balance parameters can be attained. Postural sway is a deviation of this point in any direction, and can be measured in various ways depending on the testing system being used. Length of sway path, sway area, mean displacement, frequency, amplitude and direction of COP movement can be calculated on most systems (Guskiewicz & Perrin, 1996). It should be noted that changes in forceplate measures have been proven to be age and gender related (Baloh et al., 1994; Hageman, Leibowitz, & Blanke, 1995; Murray, Seireg, & Sepic, 1975).

As stated previously, forceplates have been used to measure postural control under many different conditions. Black et al. (Black et al., 1982) used the analysis of fixed forceplate recordings of the Romberg test and found no statistically significant sex or age effect for adults aged 20 through 49 years. The same study also concluded that there is a statistical difference between eyes open and eyes closed standard trials, confirming that removal of the visual input increases postural sway. Other researchers have yielded comparable results (Ekdahl, Jarnlo, & Andersson, 1989; Le Clair & Riach, 1996). Furthermore, there was a statistical difference between stances (Black et al., 1982). Similar results showed an increase in COG displacement when comparing a single leg Romberg stance to the classic double leg stance (Ekdahl et al., 1989). The COG differences were theorized to be caused by decreasing the base of support from the double leg to single leg stances, thus increasing postural sway in an attempt to maintain COG alignment.

In an attempt to determine the reliability and validity of forceplate measures for evaluating postural control, Goldie et al. (Goldie et al., 1989) investigated a set of progressively difficult postural tasks while measures were recorded on a Kistler forceplate. Force measures and COP were recorded for five indices of steadiness over fifteen second trials. It was found that both COP and force measures were sensitive and therefore valid indications of postural control; however, test-retest reliability showed forceplate measures to be more reliable than COP measures for four of the stance positions. The correlation between the two types of measures was generally weak, and it was concluded that force measures provide more reliable results than COP measures in postural control evaluation (Goldie et al., 1989).

Reliability and validity was further investigated using forceplate measures to evaluate steadiness in one-legged stance. The performance scores examined were the standard deviation of the three orthogonal force components and the two horizontal COP coordinates averaged over four consecutive five-second trials. Retest reliability was higher for performance scores based on force measures than for performance scores based on COP measures. The difference was statistically significant in two of the stances, with a similar trend in the other two stances. Further, and similar to previous findings, factor analysis showed that force measures were the best predictors of steadiness in one-legged stance (Goldie, Evans, & Bach, 1992). Reliability and validity has also been supported for root mean square velocity and root mean square amplitude in the clinical quantification of postural control (Geurts, Nienhuis, & Mulder, 1993).

Test duration while forceplate testing has the potential to play a critical factor in obtaining desirable results (Le Clair & Riach, 1996). In previous research, test durations range from five to sixty seconds. In an effort to determine optimum test duration, postural measures were collected for five different test durations (10, 20, 30, 45, 60 s). The stability parameters measured were standard deviation of the COP about the mean position in lateral and anteroposterior planes, average COP velocity, and the standard deviations about the mean force in the lateral, anteroposterior, and vertical planes. A main effect for duration was noted for all outcome parameters except the standard deviation about the mean force in the vertical plane. The authors were able to conclude that test duration affects the measurement of postural sway, with 10s being the least reliable. The optimum test-retest reliability was obtained at 20-second and 30-second trial durations (Le Clair & Riach, 1996).

Balance Error Scoring System (BESS)

Due to the fact that forceplates are expensive and often impractical to use in many sports medicine settings, especially on the sideline of an event, researchers at The University of North Carolina at Chapel Hill developed a clinical, practical, and rather simple procedure to test postural stability. The Balance Error Scoring System (BESS) can be considered an extensive, systematic modification of the Romberg test in which participants complete a battery of six stance variations. Subjects are instructed to stand in three different stance positions: double-leg, single-leg, and tandem, in that sequence. This series of stances was previously used with the intention of progressively increasing the challenge to the postural control system by altering the base of support (Goldie et al., 1989). These stances are performed on two different surfaces: first, a firm surface, such as the floor, and second, a foam block, creating an unstable surface and a more challenging balance task. The subject places his or her hands on their iliac crests, and closing their eyes completes the testing position. The positions, in order, are: 1) double leg, firm 2) single leg, firm 3) tandem, firm 4) double leg, foam 5) single leg, foam 6) tandem, foam (depicted in Figure 3.1). Subjects are asked to stand quietly and remain as motionless as possible in the stance position. Each of the six testing trials lasts 20 seconds, during which an evaluator counts the errors (Figure 3.1), or deviations from the proper stance, accumulated by the subject. If a subject loses test position, they are instructed to make any necessary adjustments and return to the testing position as quickly as possible. The maximum total number of errors allowed for any single trial is ten. If a subject commits multiple errors simultaneously, such as opening their eyes and taking their hands off their hips, only one error is recorded. Subjects that are unable to maintain the testing position for a minimum of five seconds are assigned the highest possible score (ten) for that testing position.

The effectiveness of the BESS in detecting balance deficits in healthy individuals was recently examined (B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999). The primary purpose of the study was to determine whether there was a relationship between the BESS and objective sway measures as recorded on a forceplate. One hundred eleven NCAA Division I male athletes participated in the study. A significant correlation between BESS scores and target sway measures from a forceplate in all the discussed variations were found except for the double leg stance on a firm surface. The results validated the use of the BESS as an alternative method of assessing postural stability in healthy subjects.

The follow-up study observed the effects of mild head injury on postural stability as measured through clinical balance testing using the BESS (B. L. Riemann & Guskiewicz, 2000). Sixteen MHI and sixteen matched control subjects participated in this study. Postural stability was tested at 3 post-injury time intervals (days 1, 3, and 5) using the BESS and a sophisticated force-platform system. Significantly higher postural instability in the MHI subjects was revealed through the BESS, with the 3 stances on the foam surface eliciting significant differences. According to the researchers, the most significant finding was the identification of a clinical balance testing battery sensitive to acute postural stability disruptions after MHI, suggesting that the BESS may be used in sideline evaluations of MHI and return-to-play decisions. Unlike the aforementioned studies conducted by Riemann et al., one of the objectives in the present study is to determine the effects of fatigue on postural control using the BESS in combination with forceplate measures, and determine how long these effects remain present.

Fatigue

Defining Fatigue

Fatigue is often described as the general sensations of tiredness and accompanying decrements in muscular performance (Wilmore, 1999). The sensations of fatigue are markedly different when exercising to exhaustion in events lasting 45 to 60 seconds, such as the 400-m run, than during prolonged exhaustive muscular effort, such as marathon running. Most efforts to describe underlying causes of fatigue focus on the energy systems, the accumulation of metabolic by-products, the nervous system, and the failure of the fiber's contractile mechanism.

In order to better understand the nature of fatigue, it is important to understand the dynamics of two energy metabolic pathways: aerobic and anaerobic metabolism. Aerobic metabolism requires oxygen in order to generate energy and takes place in an organelle called the mitochondria. It is a process whereby energy substrates, such as carbohydrates, fats, and proteins, are broken down to form energy-rich adenosine-triphosphate (ATP); this occurs by way of the Krebs cycle and the electron transport chain. The process of glycolysis ultimately produces pyruvic acid. In the presence of oxygen, pyruvic acid is converted to acetyl coenzyme (coenzyme A) and enters the Krebs cycle. In the Krebs cycle, coenzyme A undergoes a series of chemical reactions, resulting in the formation of ATP and release of hydrogen. In order to prevent excessive acidity inside the cell, the remaining hydrogen is transported to the electron transport chain where the end product is water, thus preventing acidification. Because this process relies on oxygen, it is referred to as oxidative phosphorylation. The body never works exclusively aerobically or anaerobically, but in sustained activities, lasting longer than 3-4 minutes, the primary source of energy is aerobic in nature (Wilmore, 1999).

A critical component to athletic performance is often related to anaerobic, or non-oxidative, metabolic pathways. There are two energy systems that do not rely on oxygen to form ATP. The simplest of the energy systems is the ATP-PCr (phosphocreatine) system. The enzyme creatine kinase acts on PCr to separate phosphate from creatine. The energy released is used to couple inorganic phosphate with an adenosine di-phosphate molecule, forming ATP. The general advantage of the ATP-PCr system is that as energy is released from ATP by the splitting of a phosphate group, your cells can prevent ATP depletion by reducing PCr, thus providing energy to form more ATP. This process is often referred to as the immediate energy system, primarily supplying energy for the initial 3 to 15 seconds of intense exercise. During repeated bouts of exercise, fatigue has been shown to coincide with PCr depletion (Glaister, 2005; Krustrup et al., 2003). As PCr is depleted, the body's ability to quickly replace ATP stores is hindered. As the use of ATP continues (longer than 15 seconds), the ATP-PCr system is less able to replace it, and the body is forced to rely on glycolysis for ATP production.

The second anaerobic energy system involves glycolysis and the production of pyruvic acid. Although this works in a similar mechanism to the aerobic metabolic pathway, the exception in the case of anaerobic activity is that the oxygen necessary to react with pyruvic acid is not present. The end result of anaerobic metabolism is the production and accumulation of lactic acid. During intense exercise, such as sprinting type activities, when the rate of demand for energy is high, lactic acid is produced faster than the ability of the tissues to remove it and concentration begins to rise. When not removed, the lactic acid dissociates, converting to lactate and hydrogen ions. The accumulation of hydrogen ions causes muscle acidification, resulting in acidosis, and eventually leads to the sensation of fatigue. Studies have shown that the sensation of fatigue in long-term exercise coincides with the decrease of muscle glycogen (Baker, Kostov, Miller, & Weiner, 1993). Impaired excitation-contraction coupling following low-intensity exercise may also cause muscle fatigue (Moussavi, Carson, Boska, Weiner, & Miller, 1989).

Fatigue can also result from neuromuscular alterations (Balestra, Duchateau, & Hainaut, 1992). Fatigue occurring at the neuromuscular junction may prevent nerve impulses from transmitting to muscle fiber membranes. Some evidence suggests that fatigue may be due to calcium retention within the sarcoplasmic reticulum, which would decrease the calcium available for muscle contraction (Costill, 1970). These theories of fatigue remain speculative.

Though the aerobic energy system is continually supplying the body with energy, different sports with varying intensity levels demand more ATP production from the anaerobic system. As the duration of activity goes beyond two minutes, an athlete's energy source will progressively shift away from anaerobic pathways toward primarily aerobic pathways.

Effects of Fatigue on Postural Control

The relationship between fatigue and postural control has been thoroughly investigated. One of the earliest studies compared the effects of fatigue on the learning and performance of a balance task using both male and female subjects (Thomas, Cotten, Spieth, & Abraham, 1975). Walking on a treadmill was used to induce the fatigue for the experimental group. Each subject was pre-tested, received 20 trials of the fatigue protocol, and was post-tested the following day. Prior to the first trial, subjects exercised at a heart rate between 175 and 180bpm for 5 minutes. Following every second trial, they were asked to sustain this elevated heart rate for one minute. The control group was not fatigued. Time on balance and total error scores were recorded for each trial. The researchers concluded that severe fatigue is detrimental to both performance and learning of stabilometer balance and fatigue has similar effects on males and females. In a similar study, body sway area, sway path, and center of foot pressure were recorded on a dynamometric platform before and after treadmill walking for 25 minutes, during which subjects approached their own maximum heart rate as determined by the Karvonen equation. Subjects were told to stand quietly with their feet together with eyes open; the testing was repeated with eyes closed. Results showed a significant increase in body sway after exercise under both visual conditions. Both sway area and sway path were affected by fatigue (Nardone et al., 1998).

Local fatigue of the lower limbs has been shown to affect postural stability by several authors (Caron, 2003; Corbeil, Blouin, Begin, Nougier, & Teasdale, 2003; Harkins et al., 2005; Yaggie & McGregor, 2002). These researchers fatigued the ankle dorsi flexor and plantar flexor musculature to varying degrees, and then measured postural stability using a forceplate. Each study concluded that fatigue significantly influenced sway parameters and caused modifications to postural control. Vuillerme et al. (Vuillerme, Forestier, & Nougier, 2002) showed that calf muscle fatigue cause subjects to sway more when compared to their non-fatigued counterparts. They added that the attentional demand for maintaining an upright posture increases with fatigue, possibly placing fatigued individuals at higher risk of falling. These results are consistent with those of previously published studies (Redfern, Jennings, Martin, & Furman, 2001; Teasdale, Bard, LaRue, & Fleury, 1993).

Gribble et al. (Gribble & Hertel, 2004) studied the effects of fatigue of the lower extremity sagittal plane musculature at the hip, knee, and ankle on postural control during single-leg stance. Fourteen recreationally active subjects completed a fatigue protocol using a Biodex System II isokinetic dynamometer. Center of pressure excursion velocity was measured with a forceplate in both the sagittal and frontal planes. The results suggested that there was an effect of localized fatigue of the sagittal plane movers of the lower extremity. However, fatigue at the knee and hip led to postural control impairment in the frontal plane; whereas fatigue at the ankle did not. These findings suggest that proximal musculature has a greater role in maintaining static posture compared to distal musculature (Gribble & Hertel, 2004).

Yaggie and Armstrong (Yaggie J, 2004) further examined the effects of lower extremity fatigue on indices of balance in sixteen college-aged men. Balance indices, including balance index, foreward:back ratio, and right:left ratio, were recorded with the Kinesthetic Ability Trainer 2000 Balance System. Two Wingate supramaximal exercise bouts were performed on a modified Monark cycle ergometer to induce fatigue. Each test was 30 seconds in length and was performed at maximal effort. Balance was assessed pre-fatigue, immediately post-fatigue, and at 10 minutes post-fatigue. Results revealed significant effects of fatigue on balance index, suggesting that fatigue does affect balance. Of greater importance, there was no significant difference between pre-fatigue and 10-minute recovery measures, proposing that balance performance may return to baseline within 10 minutes following a bout of fatigue (Yaggie J, 2004).

The previously mentioned studies used forceplate systems to quantifiably measure postural control. The BESS has recently been used to assess the effects of fatigue on postural control. Crowell et al. (Crowell, 2000) investigated postural stability after a fatigue protocol consisting of squat jumps, sprints, and treadmill running in male and female club-sport athletes. Significant differences between baseline and post-fatigue BESS total scores were found, leading to the conclusion that any decrease in performance on the BESS might be attributed to the fatigue that had occurred in the lower extremity (Crowell, 2000). These findings are supported by Wilkins et al. (Wilkins et al., 2004) who looked at performance on the BESS following a fatigue protocol using twenty-seven male Division I college athletes. Their study used a fatigue protocol that lasted 20 minutes and consisted of seven stages which include the following: a 5-minute moderate jog, 3 minutes of sprints, 2 minutes of pushups, 2 minutes of sit-ups, 3 minutes of step-ups, 3 minutes of sprints, and a 2-minute run. The results demonstrated significant increases in total errors from pre-test to post-test in the fatigue group. Further analyses revealed a significant decrease in errors in the control group when retested after a 20-minute resting period. This suggests that a learning effect may occur with repeat administration following a 20-minute rest period (Wilkins et al., 2004).

In a follow up study, the same seven-stage fatigue protocol was used to observe the recovery of fatigue using the BESS to assess balance (Susco et al., 2004). One hundred recreationally active college students were assigned to 1 of 5 groups of twenty that were broken up depending on the length of rest between post-test. Groups were labeled control, test 0, test 5, test 10, and test 15. Every subject was also post-tested at the 20-minute recovery mark. The results demonstrated a significant decrease in BESS performance after the exercise protocol in all test groups. The authors also state that balance recovery, as indicated by a return to baseline scores, occurred within 20 minutes after cessation of exercise. Though this study seems conclusive, there are some inherent weaknesses. Only one specific exercise protocol was studied, limiting the recovery findings only to activities that create similar levels of exercise. This study also did not use collegiate level athletes as their subject pool. It is not known whether different fatigue protocols stressing the aerobic and anaerobic pathways will affect postural control differently, or elicit independent recovery patterns. It is also unknown whether college athletes will recover at different rates due to enhanced physical conditioning. This thesis study aimed to address both these issues.

Mild Head Injury

Defining Mild Head Injury

The definition of mild head injury is ambiguous and varies between sources. An early definition of concussion comes from the Congress of Neurological Surgeons. In 1966, the committee proposed: “Concussion is a clinical syndrome characterized by immediate and transient post-traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc., due to mechanical forces (Leclerc, Lassonde, Delaney, Lacroix, & Johnston, 2001). This definition has since been modified due to the fact that it fails to include many of the predominant clinical features of concussion, such as headache and nausea.

In 1997, the American Orthopaedic Society for Sports Medicine Concussion Workshop Group suggested a new definition for concussion that was meant to be all-inclusive. This definition defines concussion as any alteration in cerebral function caused by a direct or indirect (rotation) force transmitted to the head resulting in one or more of the following acute signs and symptoms: a brief loss of consciousness, light-headedness, vertigo, cognitive and memory dysfunction, tinnitus, blurred vision, difficulty concentrating, amnesia, headache, nausea, vomiting, photophobia, or a balance disturbance. Delayed signs and symptoms may also include sleep irregularities, fatigue, personality changes, and an inability to perform usual daily activities, depression, or lethargy (Wojtys et al., 1999). Though complete, many of the symptoms included have not been validated in the literature as relevant to concussive injury, and further research is necessary to determine their relationship. (Leclerc et al., 2001).

The Quality Standards Subcommittee of the American Academy of Neurology defines concussion as “a trauma-induced alteration in mental status that may or may not involve loss of consciousness” ("Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee," 1997). This definition proposes that concussion does not have to include loss of consciousness, but unlike the AAOSM criteria, it offers no specific alterations on mental status such as neuropsychological changes or postural stability deficits. This definition also does not state the onset or length of mental status alteration.

In a study investigating the effects of concussion on postural control, Guskiewicz et al. defined concussion as an injury to the brain caused by a sudden acceleration or deceleration of the head that resulted in any immediate, but temporary, alteration in brain functions such as loss of consciousness, blurred vision, amnesia, memory impairment (Guskiewicz, Ross, & Marshall, 2001). This definition was later amended to include common signs and symptoms such as headache, cognitive function alteration, and postural stability deficits (Guskiewicz et al., 2003). As a result of improved knowledge in the area of head injury, the definition of concussion continues be updated and revised. Clinicians and researchers should carefully choose an accurate definition for concussion depending upon which one is most appropriate for their setting.

Evaluation of Mild Head Injury

Accurate assessment and recognition of mild head injury is one of the most important tasks required of certified athletic trainers and sports medicine physicians. Because of the nature of MHI, in which there is rarely an obvious presentation of trauma, a variety of tools are available which can provide an more clearer assessment: subjective history of symptoms, cognitive and neuropsychological tests, balance assessments, and neuroimaging. It is clear that relying solely on an athlete's subjective report of symptoms is not practical. Athletes will quite often deny and underreport symptoms in order to return to play. Recently, the neuropsychological and balance components of concussion assessment have been a focus in the sports medicine community in an effort to objectively determine the presence of mild head injury.

Initial evaluation of a suspected head injury should follow standard a standard emergency protocol. This should involve ruling out other pathologies such as cervical neck fractures. Level of consciousness of the athlete is first recognized. If the athlete is unconscious, they are immobilized and transported to the emergency room for further neurological evaluation. If the athlete is conscious, and a neck fracture is not suspected, the athlete is removed from the playing field, and a thorough sideline evaluation should follow.

The sideline evaluation will include mental status testing, neurological screening, and exertional maneuvers (when necessary). The clinician should first observe for the typical signs and symptoms that accompany a mild head injury such as confusion, headache, incoordination, disorientation, slurred speech, and nausea/vomiting. The complete evaluation will also include a thorough history (including number and severity of previous head injuries), observation (including pupil responses), palpation, and special tests (including simple tests of memory, concentration and coordination, and a cranial nerve assessment) (Guskiewicz et al., 2004).

More formal neuropsychological testing and postural stability testing should be viewed as adjuncts to the initial clinical evaluation and should be administered during the sideline evaluation. A graded symptom checklist provides a list of concussion-related symptoms and allows the athlete to report "yes" or "no" for each symptom being experienced. Due to the subjectivity, the presence of self-reported symptoms serves as a major contraindication for return to play status (Guskiewicz et al., 2004). The Standardized Assessment of Concussion (SAC) was developed to provide sports medicine clinicians with a brief, objective tool for assessing the injured athlete's mental status during the acute period after concussion (McCrea, 2001). The SAC includes measures of orientation, immediate memory, concentration, and delayed recall. Lower scores indicate more severe impairment. This test has been validated at the high school and collegiate levels and has been determined a useful tool in detecting mild head injury (McCrea, 2001; McCrea et al., 1998).

Postural stability tests have been used to assess the effects of concussion during the sideline evaluation. The Romberg and stork stand were basic tests used to assess balance and coordination. Riemann et al. developed the Balance Error Scoring System based on existing theories of posturography (B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999). The BESS has established good test-retest reliability and good concurrent validity when compared with laboratory forceplate measures of postural stability as well as significant group differences when MHI subjects are compared with controls (Guskiewicz et al., 2001; B. L. Riemann & Guskiewicz, 2000; B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999). The BESS is widely used among the sports medicine community to assess postural control in the sideline evaluation.

Return to Play Guidelines Following MHI

Safely returning an athlete to contact or collision sports following a mild head injury has been a primary focus within the medical community, and one of much debate. Many return to play guidelines call for the athlete to be symptom free for at least 7 days before returning to participation after a grade one or two concussion (Cantu, 1992; Kelly, 2001). Recent studies suggest that perhaps the 7-day waiting period can minimize the risk of recurrent injury (Guskiewicz et al., 2003).

Returning an athlete to participation should follow a progression that begins once the athlete is symptom free. This will depend on the severity of injury. All signs and symptoms should be evaluated both at rest and after exertional maneuvers such as biking, jogging, sit-ups, and push-ups. These measurements should be compared to baseline. If these exertional tests do not produce symptoms, the athlete can then participate in sport specific skills, but should remain out of activities that put him or her at risk for recurrent head injury. These restricted and monitored activities should be continued for the first few days after becoming symptom free. Before returning to full contact participation, the athlete should be reassessed. If all scores have returned to baseline or better, return to full participation can be considered (Guskiewicz et al., 2004)

Effects of MHI on Postural Control

Aside from neuropsychological impairments that occur from concussion, there is also a deficit in postural stability. Two methods have been applied to investigate the relationship between MHI and postural stability. Forceplate measures allow for quantitative analysis of postural stability by measuring the ground reaction forces exerted onto the platform. The BESS allows for an objective measure of balance by sequentially challenging the body’s postural control system. Both methods have been thoroughly researched and proven valid to assess postural control deficits in mild head injured athletes.

The first research to investigate the acute effects of mild head injury on postural stability in athletes was completed by Guskiewicz, Perrin, and Gansneder (Guskiewicz, Perrin, &

Gansneder, 1996). A total of nineteen MHI athletes were compared to nineteen control subjects. Each participant was tested on days 1, 3, 5, and 10 post-injury, and one month post-season. Sway index and center of balance was measured using the Chattecx Balance System (Chattanooga Group, Hixon, TN) during three different visual conditions (eyes open, closed, and conflict dome) and three different surface conditions (firm, foam, and tilting platform). Results revealed that MHI subjects demonstrated significant increases in sway on Day 1 post-injury in comparison to prescreening and/or subsequent tests. Mild head injured subjects also showed significant improvement in returning their COP over their base of support from Day 1 to Day 3 post-injury. Based on their findings, the authors concluded that computerized dynamic posturography could be a useful tool in objectively evaluating postural stability in MHI subjects. The authors also recommended that athletes suffering from MHI should be held from full participation for at least 3 days after injury.

In a follow up study conducted by Guskiewicz et al. (Guskiewicz et al., 1997), eleven Division I collegiate athletes who sustained a MHI and eleven matched control subjects were assessed for postural stability and cognitive function at four intervals following injury. Postural stability was assessed using the Sensory Organization Test on the NeuroCom Smart Balance Master. Cognitive functioning was also measured through the use of four neuropsychological tests: Stroop Test, Trail Making Test, Digits Span and Hopkins Verbal Learning Test. Results indicated decreased postural stability on Day 1 post-injury in comparison to control Day 1 scores and Day 3 post-injury scores. There was no statistical difference between MHI and control subjects on Day 3 and 5. Data analysis further revealed a significant day by group interaction for visual input, which the authors suggested could be due to a sensory organization problem that occurs due to the MHI. No significant differences were revealed for any of the neuropsychological tests between control and MHI subjects. The results from this study indicate that athletes demonstrate decreased stability until 3 days post-injury. These findings suggest that measures of postural stability may provide clinicians with a useful clinical tool for determining when an athlete may safely return to competition (Guskiewicz et al., 1997). Additional research by this author has further confirmed that MHI will undoubtedly affect postural control (Guskiewicz, 2001, , 2003; Guskiewicz et al., 2003; Guskiewicz et al., 2001).

Although forceplate measures of postural stability provide objective information concerning MHI resolution, their application remains limited due to the high costs and impracticality for sideline use. Investigation of the efficacy of a clinical balance testing procedure (the BESS) was used to detect acute postural stability disruptions after MHI (B. L. Riemann & Guskiewicz, 2000). Postural stability was tested at 3 post-injury time intervals (days 1, 3, and 5) using two procedures, the BESS and the Sensory Organization Test using a sophisticated force-platform system. Sixteen MHI and sixteen matched control subjects participated in the study. Results found significantly higher postural instability in the MHI subjects as measured by the BESS, with the three stances on the foam surface eliciting significant differences through Day 3 post-injury. The authors concluded that the BESS might be a useful clinical procedure to assist clinicians in making return-to-play decisions in athletes with MHI in the absence of force-platform equipment. Similar results have supported the BESS in evaluating athletes with MHI (Guskiewicz et al., 2001; McCrea et al., 2003)

Methodological Considerations

Design Methods

There are numerous methods available to assess balance. Static balance tests include the standing Romberg, single-leg stance tests, and tandem stance tests; however, these tests have been criticized for their lack of sensitivity and objectivity because a considerable amount of stress is required to make the subject sway enough for an observer to characterize the sway (Jansen et al., 1982). Dynamic balance tests include functional reach, timed agility, and balance beam walking tests. Many of these tests have failed to quantify balance adequately (Guskiewicz & Perrin, 1996). This study will make use of a forceplate and the BESS to assess postural control in fatigued athletes.

The BESS is an objective field test used to assess postural stability during the sideline evaluation of mild head injuries. It has been validated through concomitant use on a forceplate system in which error scores were highly correlated with sway measures. It has been shown to be valid and reliable in both healthy and injured athletes (B. L. Riemann & Guskiewicz, 2000; B. L. Riemann, Guskiewicz, K.M., Shields, E.W., 1999). More recently, the BESS been used to investigate the effects of fatigue on postural control (Crowell, 2000; Susco et al., 2004; Wilkins et al., 2004). Because the current study is interested in how fatigue may interfere with the sideline assessment of mild head injuries, the direct clinical relevance to using the BESS in this regard is understandable.

Forceplate systems yield objective measures that assess postural stability and can detect deficits in postural control. Forceplates have been proven reliable and valid in determining postural stability (Goldie et al., 1989; Goldie et al., 1992; Hageman et al., 1995; Hu, Hung, Huang, Peng, & Shen, 1996) The Sensory Organization Test provides assessment of postural stability utilizing six different conditions, each with the subjects eyes open or closed, sway or stable platform, and sway or stable visual surround. Though this test has been previously used in balance research, it is only applicable in the laboratory setting, and its portability to the sideline assessment is impossible. It is also very expensive, and not readily accessible for many clinicians. Furthermore, this balance system was not the type used when establishing the BESS, and may not enable simultaneous use with the BESS.

A long auxiliary forceplate integrated with the NeuroCom Smart Balance Master was used to validate the BESS. For this study, the BESS will be performed on a forceplate. This set-up will enable the tester to evaluate balance performance using the BESS while objective sway measures are simultaneously recorded by the forceplate. Elliptical sway area and center of pressure velocity will be the dependent measures used to assess postural control. These measures have been applied in detecting postural control deficits and proven reliable throughout the literature (Ekdahl et al., 1989; Hu et al., 1996; Nardone et al., 1998)

The fatigue protocol being used will involve intermittent running similar to the demands of many collegiate sports. The Yo-Yo Intermittent Recovery Test is a 20-meter beep test that involves running at increasing speeds to timed audible beeps. In addition to providing aerobic loading to near maximal levels, the test also places great stress on the anaerobic pathways (Krustrup et al., 2003). This test has been proven reliable and valid and has been used to imitate the physical demands of soccer, rugby, and football (Atkins, 2006; Krustrup et al., 2003). The University of North Carolina also uses this test to determine fitness levels for the soccer, field hockey, lacrosse, and football teams. This study incorporated two separate fatigue protocols. The first aimed to stress the aerobic energy systems whereas the second protocol aimed to fatigue the anaerobic systems.

Previous studies have used the Wingate test to elicit anaerobic fatigue; however, as a maximal exertion bike test, it does not reflect game like demands of running sports. Researchers have also used various fatigue protocols that includes a combination of treadmill running and various exercises performed at pre-set stations. The problem with these protocols is that they stress the aerobic and anaerobic systems similarly. In addition, these researchers only used one specific fatigue protocol in their research and thus are only able to relate their findings to activities that create similar levels of exercise. Because different sports have different metabolic demands, the current study used two separate fatigue protocols that aimed to stress the aerobic and anaerobic systems independently. This allowed the results to be interpreted and applied toward athletes of varying exercise levels.

Summary

The sideline assessment of mild head injury has begun to incorporate more objective and quantifiable measures. Traditional measures of postural stability used to detect MHI have been found to lack sensitivity, leading to the development of more challenging and valid clinical tests. The BESS is an inexpensive yet valid sideline assessment tool, which can allow clinicians to make improved and informed decisions regarding return to play, hopefully increasing the detection of this underreported injury. The use of resting baseline measures for the BESS gives clinicians a comparison when involved in a sideline assessment of head injury. After examination of the literature, it is well known that fatigue will affect postural control. Consequently, the sideline assessment of MHI has the potential to be confounded from fatigue is administered too early.

Various sports will require different levels of exercise and will inherently fatigue individuals at different rates. Endurance athletes, who are aerobically trained, have the potential to respond to fatigue differently than athletes who are anaerobically trained. There is a need for research to identify the difference in anaerobic fatigue and aerobic fatigue and how they relate to deficits in postural control. At the same time, there is a need to determine a recovery time from different types of fatigue so the sideline assessment of MHI may not be confounded from fatigue. This will enable clinicians to have a better measure of postural control as it relates to the head injury, and not the effects of fatigue.

CHAPTER III

METHODS

Subjects

The participants were 36 NCAA Division I male (18) and female (18) athletes (age = 19.00years ± 1.01, height = 172.44cm ± 10.47, mass = 69.72kg ± 12.84). The participants were selected based on their sport involvement. Athletes participating in sports with an increased risk of sustaining a MHI such as soccer, lacrosse, field hockey, or wrestling, were included in this study. A verbal approval from each head coach was obtained prior to contacting his or her athletes for participation in this study.

Participants were excluded from this study if they had any pre-existing lower extremity injury that put them at further risk of injury, had a known visual, vestibular, or balance disorder, or if they had sustained a mild head injury within the last three months. Additionally, any participant that had undergone balance testing in the last three months was excluded from this study. Pre-assessment guidelines were provided for each participant prior to their first testing session (see Table 1).

Participants were given an instructional orientation concerning the exercise protocols and the balance testing prior to participation. All participants were asked to sign an informed consent form in accordance with The University of North Carolina’s Behavioral Institutional Review Board stating that they are healthy individuals with no related health issues and are aware of the risks involved in the study.

Instrumentation

Forceplate

Postural stability measures were performed on a Bertec 4060-NC (Bertec Corp.; Columbus, OH) piezoelectric force sensor platform. This system measures ground reaction forces associated with motion of the body's center of gravity around a fixed base of support. Using forceplate measures to assess postural control has been shown to be reliable and valid (Goldie et al. 1989), and has been used with athletic populations (Cavanaugh et al. 2005; Guskiewicz et al. 2001).

Forceplate raw voltage signals were amplified by a gain of 5 using a Bertec AM-6701 amplifier (Bertec Corp.). Raw forceplate data were collected using The Motion Monitor for Research Software version 6.74 (Innovative Sports Training, Inc.; Chicago, IL). Forceplate data were sampled at a frequency of 1,000 Hz. Offsets for the forceplate were adjusted between each trial. Any error in which a participant touched down or stepped off the forceplate during a balance trial was recorded manually via an electronic triggering device. Forceplate data were used to calculate elliptical sway area and sway velocity for each trial (see Data Reduction for calculation details).

Balance Error Scoring System (BESS)

The BESS (Riemann and Guskiewicz, 2000) measures participants' postural control during three different stances (double-leg stance, single-leg (non-dominant) stance, and tandem stance), using two surface conditions: firm and foam (Figure 1). The firm surface assessment occurred on a forceplate surface in the Motor Control Laboratory, and the foam surface assessment occurred on a 41.6-cm x 50.8-cm Airex Balance Pad (Alcan Airex AG, Switzerland) placed directly on the forceplate.

The balance tasks required the participant to balance for 20 seconds with eyes closed and hands on their iliac crests. Testing started when participants closed their eyes. During the single-leg balance tasks, participants were required to balance on their non-dominant leg, with their contralateral leg in 20° hip flexion and 30° knee flexion. The participants' dominant leg was determined by asking each participant which leg they prefer to use to kick a soccer ball. Participants were instructed to stand quietly and motionless in the stance position, keeping their hands on the iliac crests and eyes closed. Participants were instructed that upon losing their balance, they should make any necessary adjustments and return to the initial testing position within five seconds. Instructions and demonstration of the BESS were viewed using video media prior to testing each participant.

Participants were scored based upon the errors recorded during each of the six balance tasks. Errors included lifting their hands off their iliac crest; opening their eyes; stepping, stumbling, or falling; moving their hip into more than 30° abduction; lifting their forefoot or heel; and remaining out of test position for more than five seconds. A higher score (more errors) on the BESS compared to baseline measures indicated a deficit in postural control. The BESS has a strong interrater reliability with coefficients ranging from 0.78 to 0.96 (Riemann, Guskiewicz et al. 1999; Riemann and Guskiewicz 2000) and has been proven to be a reliable and valid test to assess postural control in college aged athletes (Riemann, Guskiewicz et al. 1999)

Exercise Protocol

For the aerobic exercise protocol, this study used the Yo-Yo intermittent recovery test, level 1, to elicit fatigue in all participants. This test consists of repeated 20-meter runs down and back between the starting, turning, and finish line at progressively increased speeds controlled by audio beeps from a tape player (Figure 2). The aerobic exercise protocol began with 4 running bouts at 10-13 kilometers per hour (kph) over the first 160 meters followed by 7 running bouts at 13.5-14 kph (160-440m). It continued with stepwise 0.5 kph speed increments after every 8 running bouts (i.e., after 760, 1080, 1400, 1720m, etc.) until exhaustion (see Figure 3). Between running bouts, the participants had a 10s active rest period consisting of 5-meter walk/jog at their own pace. When the participant failed on two runs to reach the finish line before the audible beep, the participant was considered fatigued, and the test was terminated. It should be noted that the missed runs did not have to occur in consecutive order (i.e. back to back) for the participant to be deemed fatigued. Their first miss was recorded, and whenever the second miss occurred, the exercise was terminated. The test was performed indoor on running lanes marked by cones, having a width of 2m and a length of 20m. Another cone placed 5m behind the finishing line marked the running distance during the active recovery period. Before the exercise protocol, all participants carried out a warm-up and stretching period consisting of the first two running intervals followed by low back and lower extremity stretching. All participants were familiarized to the exercise protocols through verbal explanation. The Yo-Yo intermittent recovery test has been shown to be both reliable and valid in relation to the demands of soccer play, stressing both the aerobic and anaerobic metabolic pathways (Krustrup et al., 2003).

The anaerobic exercise protocol started at level 23.1 and consisted of maximum effort sprints between the cones. Participants were instructed that the test would run for two full minutes in which they were to make as many beep intervals as possible. For this protocol, the beeps were used as an external cue that informed the participants where they should be throughout the trial. If participants failed to reach the finish line twice during the two-minute period, they did not end the test as they did in the aerobic protocol; participants continued for the full two minutes. Verbal encouragement was used during both the aerobic and anaerobic exercise protocols in an effort to maintain the athletes intensity level.

Heart Rate Monitor

Heart rate was recorded before, during, and after each fatigue protocol with a Polar Digital Heart Rate Monitor (Polar Electro Inc., Lake Success, NY). The athletes were monitored to check percentage of maximal heart rate during each exercise protocol as well as to observe their recovery rates from exercise. Age-predicted maximal heart rate was determined using the age-adjusted maximal heart rate formula calculated by subtracting one's age from 220.

Ratings of Perceived Exertion

The Borg 15-point category rating scale (6-20) was used to measure each participant's Rating of Perceived exertions (RPE) to try to ensure adequate exertion was achieved (Table 2). Adequate exertion was deemed to be achieved with an RPE score of 15. For all participants, RPE scores were monitored before, immediately following, and at each recovery time period following the exertion protocol.

Procedures

Each participant reported to the laboratory for two testing sessions. The first session for all participants included an orientation, collection of baseline BESS scores and forceplate measures, and one of the exercise protocols. The exercise protocol that each subject performed during the first session was assigned via a counterbalanced design. Each participant was briefed on the study and asked to sign an informed consent form during the first session prior to any data collection. Upon completion of the orientation, participants were asked to perform two separate practice trials of the complete BESS test while standing on the forceplate. Five minutes of rest were given between each trial. This was done in an effort to establish a learning effect for the BESS. By establishing a learning effect, this can limit potential learning from occurring during subsequent testing periods. A third trial of the BESS was performed following the two practice trails. The participants' BESS scores and forceplate measures collected on the third trial were used as their baseline in subsequent statistical analyses.

Both the first and second testing sessions included one of the exercise protocols. Aerobic and anaerobic exercise protocols were counterbalanced between sessions and participants for the purpose of neutralizing an order effect. Each testing session was between 1-7 days apart to allow for an adequate recovery, and to retain any learning effects that occurred during the first session. For each session, participants met the primary investigator at the Motor Control Research Laboratory (MCRL) where explanations of the testing procedure and exercise protocols were given. The exercise protocols took place in Fetzer Gymnasiums. Participants were required to wear shorts, a t-shirt, and athletic shoes while performing the protocols. Before the exercise protocol, all participants carried out a warm-up consisting of the first two running intervals followed by a stretching period comprised of low back and lower extremity static and dynamic stretching. Upon completion of the exercise protocol, participants were escorted back to the MCRL where they began the BESS test. There were three minutes between the end of the protocol and the first BESS testing. Each participant was then tested at eight minutes, thirteen minutes, and eighteen minutes post exercise in order to establish a recovery timeline. Heart rate and RPE were recorded at each testing interval.

Data Reduction

The analog data were converted into a digital signal via an analog-to-digital (A/D) converter board in order for the computer to recognize and interpret the measures. The data were then imported into a custom MatLab 7 program (The Mathworks, Inc.; Natick, MA). For this study, forceplate measures included center of pressure average sway velocity and elliptical sway area. Center of pressure sway velocity was defined as the speed at which an individual's COP moves within his or her base of support (see Figure 4 for formula). Elliptical sway area was the area defined by the minor and major axes of an ellipse that statistically encompasses an area containing 95% of the COP data points.

Statistical Analyses

Means and standard deviations were calculated for both the forceplate measures and the BESS total scores. Six separate one way repeated measures ANOVA were calculated; three for research question one, and three for research question two. Additionally, three separate 2 (protocol) x 4 (recovery time interval) repeated measures ANOVA were calculated for research question three. Any significant differences were further examined using a Bonferroni post hoc analysis. An alpha level of 0.05 was set *a priori* for all analyses. All data were analyzed using SPSS statistical software (version 13.0; SPSS Inc, Chicago, IL).

Table 1: Pre Assessment Guidelines

1. Participants should make sure to drink plenty of fluids and stay properly hydrated in the days leading up to testing.

2. Participants should not participate in any extra conditioning or weight training exercises the day prior to testing.

3. Participants should avoid excessive caffeine as well as any alcoholic beverage the day prior to testing.

4. Participants should not practice any extra balancing exercises prior to testing.

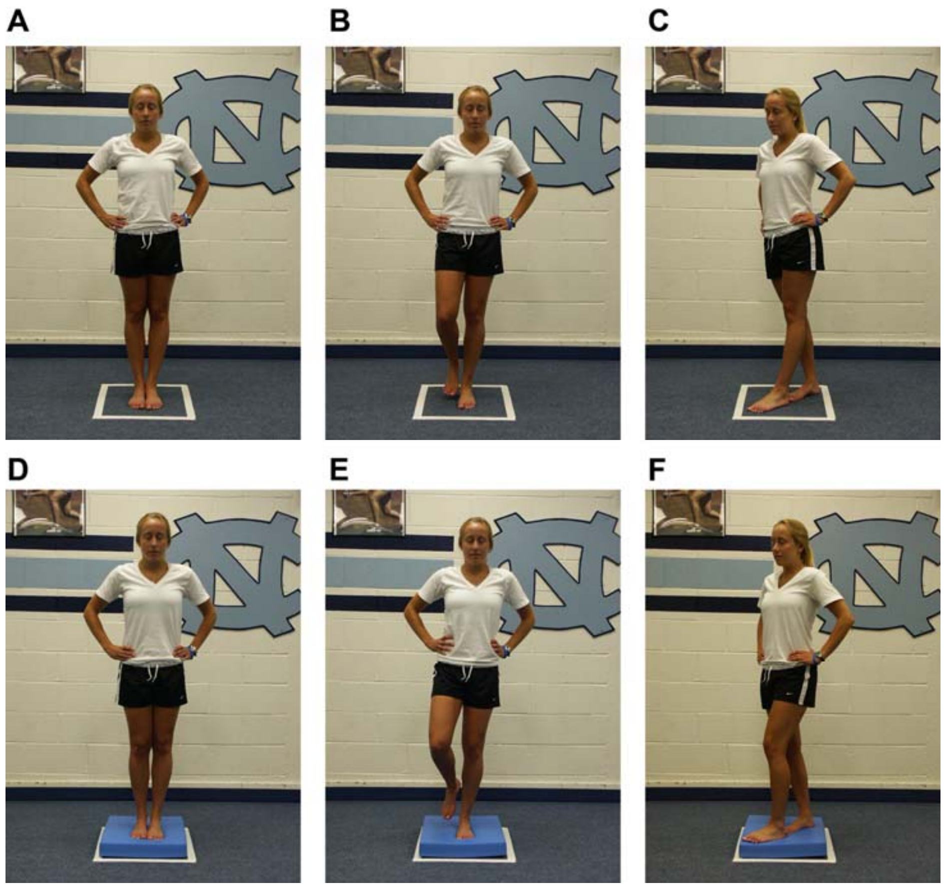
Table 2: Borg Rating of Perceived Exertion Scale

6 - no exertion at all
7 - extremely light
8
9 - very light
10
11 - fairly light
12
13 - somewhat hard
14
15 – hard (heavy)
16
17 - very hard
18
19 - extremely hard
20 – absolute maximal exertion

Table 3: Statistical Analysis

RQ	Description	Data Source	Comparison	Method
1	**Is there a difference between baseline and post exercise postural control following an anaerobic exercise protocol as measured by a forceplate and the BESS?**	IV: Primarily anaerobic exercise protocol, BESS condition DV: BESS scores, Elliptical Sway Area, COP velocity	Postural control measures at baseline to postural control measures post-anaerobic exertion.	3 separate repeated measures ANOVA for interaction between baseline and post exertion postural control measures
2	**Is there a difference between baseline and post exercise postural control following an aerobic exercise protocol as measured by a forceplate and the BESS?**	IV: Primarily aerobic exercise protocol, BESS condition DV: BESS scores, Elliptical Sway Area, COP velocity	Postural control measures at baseline to postural control measures post-aerobic exertion.	3 separate repeated measures ANOVA for interaction between baseline and post exertion postural control measures
3	**Will there be an interaction effect between each exercise protocol and immediate recovery time?**	IV: Time interval, anaerobic and aerobic exercise protocols DV: BESS scores, Elliptical Sway Area, COP velocity	Postural control measures at baseline to postural control measures post-exertion at 3, 8, 13, 18 minute intervals	3 separate 2x4 repeated measures ANOVA (protocol x time) for interaction between time and exercise protocol

Figure 1: Balance Error Scoring System



Errors

- Hands lifted off iliac crests
- Opening eyes
- Step, stumble, or fall
- Moving hip into more than 30° of flexion or abduction
- Lifting forefoot or heel
- Remaining out of testing position for more than 5 seconds

BESS score calculated by adding 1 error point for each error committed.

Figure 2: Diagrammatic Representation of the Yo-Yo Intermittent Recovery Test, Level 1

Repeated 2x20-meter runs back and forth between the starting, turning, and finish line at progressively increased speeds controlled by audio beeps. A 10 second active recovery takes place following each run.

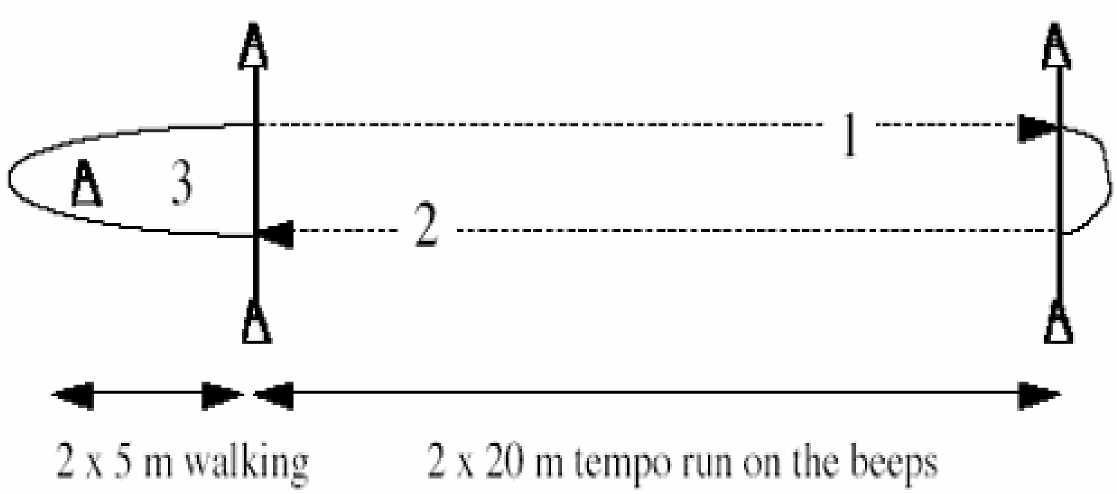


Figure 3: Yo-Yo Intermittent Recovery Test, Level 1, Stage-by-Stage

Speed Level Intervals

5*	1 (40)							
9*	1 (80)							
11*	1 (120)	2 (160)						
12**	1 (200)	2 (240)	3 (280)					
13**	1 (320)	2 (360)	3 (400)	4 (440)				
14	1 (480)	2 (520)	3 (560)	4 (600)	5 (640)	6 (680)	7 (720)	8 (760)
15	1 (800)	2 (840)	3 (880)	4 (920)	5 (960)	6 (1000)	7 (1040)	8 (1080)
16	1 (1120)	2 (1160)	3 (1200)	4 (1240)	5 (1280)	6 (1320)	7 (1360)	8 (1400)
17	1 (1440)	2 (1480)	3 (1520)	4 (1560)	5 (1600)	6 (1640)	7 (1680)	8 (1720)
18	1 (1760)	2 (1800)	3 (1840)	4 (1880)	5 (1920)	6 (1960)	7 (2000)	8 (2040)
19	1 (2080)	2 (2120)	3 (2160)	4 (2200)	5 (2240)	6 (2280)	7 (2320)	8 (2360)
20	1 (2400)	2 (2440)	3 (2480)	4 (2520)	5 (2560)	6 (2600)	7 (2640)	8 (2680)
21	1 (2720)	2 (2760)	3 (2800)	4 (2840)	5 (2880)	6 (2920)	7 (2960)	8 (3000)
22	1 (3040)	2 (3080)	3 (3120)	4 (3160)	5 (3200)	6 (3240)	7 (3280)	8 (3320)
23	1 (3360)	2 (3400)	3 (3440)	4 (3480)	5 (3520)	6 (3560)	7 (3600	8 (3640)

Numbers in parenthesis indicate the total distance covered in meters through that interval.

*First 4 running bouts (0-160m) at 10-13 km / hour

**Next 7 running bouts (160m-440m) at 13.5-14 km / hour

Test continues with a stepwise 0.5 km / hour speed increase after every 8 running bouts (760m, 1080m, 1400m, etc)

Figure 4: Formula for Center of Pressure Average Sway Velocity

$$\frac{\sum_{t=1}^{T}\sqrt{(x_{cop,t}-x_{cop,t-1})^2+(y_{cop,t}-y_{cop,t-1})^2}}{time}$$

CHAPTER IV

RESULTS

Thirty-six healthy NCAA Division I athletes (18 males, 18 females) volunteered to participate in this study (Descriptive statistics of the participants are presented in Table 4 and 5). The first testing session established baseline postural control measures for each participant. Postural control was assessed using forceplate elliptical sway area and sway velocity measures as well as total BESS score. Following baseline testing, one of two exercise protocols was performed: anaerobic or aerobic. At the conclusion of each exercise protocol, postural control was then re-assessed at 3, 8, 13, and 18 minutes post exercise. The second session, which took place no later than 7 days following the first session, included the exercise protocol only, followed by the post exercise postural control testing. The data used for each repeated measures ANOVA are presented in Table 6.

Research Question 1: Three separate one-way repeated measures ANOVA were performed to determine if significant differences existed between baseline and post exercise measures of postural control following an *anaerobic* exercise protocol. One ANOVA model was used for each dependent variable.

Elliptical Sway Area: The ANOVA analysis revealed a significant effect of time on postural control as measured by elliptical sway area following the *anaerobic* exercise protocol ($F_{(4,140)} = 11.927$, $p < 0.001$). Bonferroni post hoc analyses revealed a significant difference between baseline and 3 minutes post anaerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes, 13 minutes and 18 minutes post anaerobic exercise.

Sway Velocity: The ANOVA analysis revealed a significant effect of time on postural control as measured by sway velocity following the *anaerobic* exercise protocol ($F_{(3.110,140)} = 11.947$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post anaerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes, 13 minutes and 18 minutes post anaerobic exercise.

Total BESS score: The ANOVA analysis revealed a significant effect of time on postural control as measured by total BESS score following the *anaerobic* exercise protocol ($F_{(4,140)} = 24.157$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post anaerobic exercise ($p < 0.001$) and between baseline and 8 minutes post anaerobic exercise ($p = 0.018$), but no significant differences between baseline and 13 or 18 minutes post anaerobic exercise.

Research Question 2: Three separate one-way repeated measures ANOVA were performed to determine if significant differences existed between baseline and post exercise measures of postural control following an *aerobic* exercise protocol. One ANOVA model was used for each dependent variable.

Elliptical Sway Area: The ANOVA analysis revealed a significant effect of time on postural control as measured by elliptical sway area following the *aerobic* exercise protocol ($F_{(3.493, 140)} = 15.546$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes 13 minutes and 18 minutes post aerobic exercise.

Sway Velocity: The ANOVA analysis revealed a significant effect of time on postural control as measured by sway velocity following the *aerobic* exercise protocol ($F_{(4,140)}$ = 35.692, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise (p = < 0.001) and between baseline and 8 minutes post aerobic exercise ($p = 0.004$), but no significant differences between baseline and 13 or 18 minutes post aerobic exercise.

Total BESS score: The ANOVA analysis revealed a significant effect of time on postural control as measured by total BESS score following the *aerobic* exercise protocol ($F_{(4,140)}$ = 56.675, p = < 0.001). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise ($p < 0.001$) and between baseline and 8 minutes post aerobic exercise ($p < 0.001$), but no significant differences between baseline and 13 or 18 minutes post aerobic exercise.

Research Question 3: Three separate 2x4 (protocol x post exercise time) repeated measures ANOVA were performed to determine if there was an interaction effect between exercise protocol and post exercise recovery time. Baseline measures were not included as part of the time factor in the ANOVA analysis as research questions one and two previously established significant differences between baseline measures and immediate post exercise measures of postural control.

Elliptical Sway Area: The ANOVA analysis revealed a significant main effect for recovery time ($F_{(3,105)}$ = 28.704, p < 0 .001) while the main effect for exercise protocol was not significant ($F_{(1,35)} = 0.740$, $p = 0.396$). The protocol by time interaction was also non-significant ($F_{(2.535, 88.742)} = 0.788$, $p = 0.485$).

Sway Velocity: Paralleling elliptical sway area, the ANOVA analysis for sway velocity revealed a significant main effect for recovery time ($F_{(2.746, 96.125)} = 43.361$, $p < 0.001$) while the main effect for exercise protocol was not significant ($F_{(1,35)} = 1.355$, $p = 0.252$). Similarly, the protocol by time interaction was non-significant ($F_{(2.525,88.368)} = 1.912$, $p = 0.143$).

Total BESS score: The ANOVA analysis for total BESS score revealed a significant main effect for time ($F_{(2.471,86.472)} = 96.701$, $p < 0.001$) as well as a main effect for exercise protocol ($F_{(1,35)} = 5.988$, $p = 0.020$). More importantly, a significant interaction effect between exercise protocol and time ($F_{(3,105)} = 5.437$, $p = 0.002$) was revealed. Bonferroni post hoc analyses showed a significant difference for total BESS score between exercise protocols at three minutes post exercise. However, at eight, thirteen, and eighteen minutes post exercise, no significant post hoc analyses were found between exercise protocols (Figure 5). The significant interaction at the 3-minute post exercise interval between protocol and time suggests that the recovery time is different for each exercise protocol for total BESS score.

Table 4: Descriptive Statistics for all participants (n = 36)

	Mean	SD
Age (years)	19.00	1.01
Height (cm)	172.44	10.47
Mass (kg)	69.72	12.84

Table 5: Descriptive statistics presented by sport participation (means (SD))

Team	N	Age (yrs)	Height (cm)	Mass (kg)
Men's Lacrosse	6	18.67 (0.82)	183.83 (5.85)	79.32 (6.25)
Women's Lacrosse	6	18.83 (0.75)	166.33 (8.61)	64.92 (11.25)
Men's Soccer	6	18.83 (0.75)	183.17 (5.04)	85. 83 (6.77)
Women's Soccer	6	19.00 (0.89)	162.50 (5.58)	57.35 (5.30)
Men's Wrestling	6	19.33 (1.03)	176.67 (8.98)	76.44 (12.15)
Women's Field Hockey	6	19.50 (1.64)	166.33 (5.35)	61.06 (5.04)

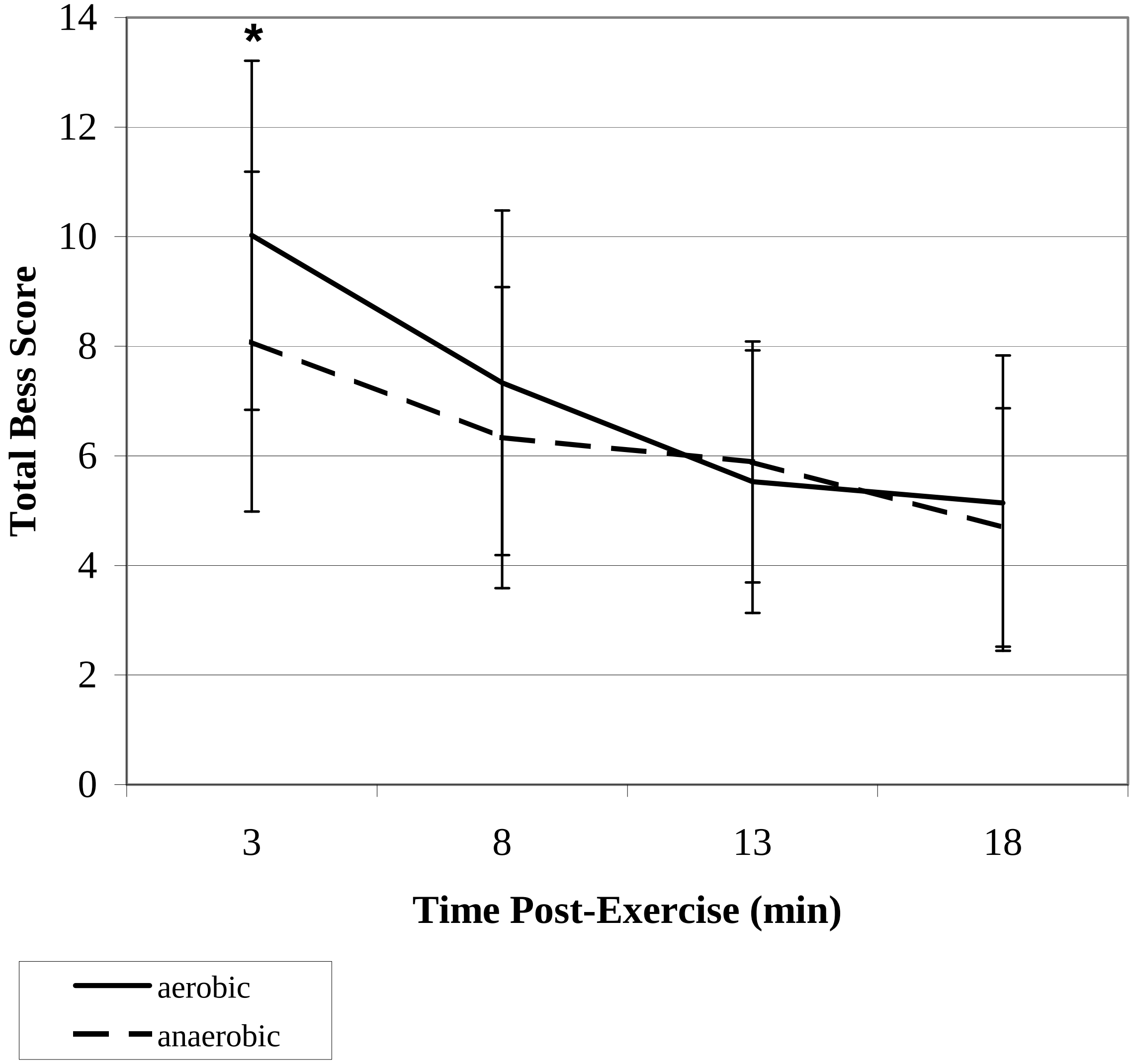
Table 6: Exercise protocol data used for statistical analyses (means (SD))

	Baseline	3 minutes	8 minutes	13 minutes	18 minutes	Time Main Effect	Protocol x Time Effect
Elliptical Sway Area							
Anaerobic	49.14 (17.56)	72.82 (31.98)*	62.46 (30.89)	56.54 (21.69)	47.80 (22.18)	$F_{(4,140)}$ = 11.93 P < 0.001*	$F_{(2.535, 88.742)}$ = 0.79 P = 0.485
Aerobic		80.10 (28.23)*	61.82 (27.44)	55.25 (21.84)	51.70 (22.29)	$F_{(3.493, 140)}$ = 15.55 P < 0.001*	
Sway Velocity							
Anaerobic	8.15 (2.06)	9.47 (2.61)*	9.00 (2.85)	8.47 (2.43)	7.89 (2.17)	$F_{(3.110,140)}$ = 11.95 P < 0.001*	$F_{(2.525,88.368)}$ = 1.91 P = 0.143
Aerobic		10.18 (2.41)*	9.06 (2.59)*	8.39 (2.30)	8.11 (2.28)	$F_{(4,140)}$ = 35.69 P < 0.001*	
Total BESS Score							
Anaerobic	4.89 (2.29)	8.08 (3.10)*	6.33 (2.75)*	5.89 (2.20)	4.69 (2.18)	$F_{(4,140)}$ = 24.16 P < 0.001*	$F_{(3,105)}$ = 5.44 P = 0.002+
Aerobic		10.03 (3.19)*	7.33 (3.14)*	5.53 (2.40)	5.14 (2.70)	$F_{(4,140)}$ = 56.68 P< 0.001*	

Baseline measures are the same for both aerobic and anaerobic exercise protocols because baseline was assessed during the first session only.

* Significant difference from baseline
+ Significant difference between exercise protocols at 3 minutes post exercise

Figure 5: Protocol x Time interaction effect for total BESS score



*** = Significantly different between protocols at recovery time interval 3.**

CHAPTER V

DISCUSSION

The most important finding of this investigation was that both anaerobic and aerobic exercise protocols adversely affected postural control as measured through the Balance Error Scoring System (BESS), elliptical sway area, and sway velocity. More importantly for athletic trainers and clinicians, the effects of fatigue appear to persist up to eight minutes post exercise, regardless of exercise protocol, with postural control returning to baseline on average between eight and thirteen minutes following exercise.

Proper management of sport-related mild head injury (MHI) requires a comprehensive assessment by athletic trainers and other clinicians. Postural control batteries such as the BESS have been developed in recent years in an effort to obtain more objective measures from injured athletes (Guskiewicz et al., 1997). BESS error scores are typically taken at rest before the athlete's season begins in order to obtain baseline measures for each individual. Following a suspected MHI, the BESS is administered on the sideline, and a post-injury score is compared to the athlete's baseline score. However, there is little research examining the effect of fatigue on postural control during these sideline examinations if administered too soon after exercise. The primary purpose of this study was to evaluate the effects of fatigue on postural control in healthy college-aged athletes. Fatigue was introduced between two separate sessions by means of two different exercise protocols: ***anaerobic*** exercise and ***aerobic*** exercise. A secondary purpose of this study was to establish the immediate recovery time course from each exercise protocol over which the effects of fatigue lessen and postural control measures return to baseline status. Forceplate measures of elliptical sway area and sway velocity, as well as total BESS score, were used to assess postural control differences pre and post exercise.

Postural Control and Recovery Time from Fatigue

We observed an effect of fatigue on postural control on all three dependent measures. Total BESS score, the sum of all six trials, was significantly greater at three minutes post exercise when compared to the athletes' baseline for both the anaerobic and aerobic exercise protocols, increasing from 4.889 to 8.083 errors (mean difference of 3.194) following ***anaerobic*** exercise, and 4.889 to 10.028 errors (mean difference of 5.139) following ***aerobic*** exercise. Similarly, forceplate measures revealed a significant increase from baseline in elliptical sway area and sway velocity at three minutes post exercise for both anaerobic and aerobic exercise protocols. Elliptical sway area increased from 49.143 to 72.824 and sway velocity increased from 8.147 to 9.471 following ***anaerobic*** exercise. Following ***aerobic*** exercise, elliptical sway area and sway velocity values increased from 49.143 to 80.102 and from 8.147 to 10.178, respectively. From these measures, it is clear that postural control remained affected at three minutes following the anaerobic and aerobic exercise protocols. These results are comparable to previous literature (Crowell, 2000; Nardone et al., 1998; Nardone et al., 1997; Thomas et al., 1975; Wilkins et al., 2004; Yaggie & McGregor, 2002).

At eight minutes post exercise, total BESS score remained significantly worse when compared to baseline for both exercise protocols. The total BESS error score was 6.333 following the ***anaerobic*** exercise protocol and 7.333 following the ***aerobic*** exercise protocol (mean differences from baseline of 1.444 and 2.444 respectively). Sway velocity was significantly different following the aerobic exercise protocol, but not significantly different following the anaerobic protocol (though it was close with a p value = 0.071). Interestingly, elliptical sway area was not significantly different from baseline at eight minutes post exercise following either protocol. At this point post exercise, it appears forceplate measures recover to baseline faster than total BESS scores. The results suggest that postural control remains affected by fatigue at eight minutes post exercise. These findings are also analogous to prior research (Baker et al., 1993; Nardone et al., 1997; Yaggie & McGregor, 2002).

At thirteen minutes post exercise, postural control (according to all three measures) had returned to baseline levels following both the anaerobic and aerobic exercise protocols. It can be concluded that the effects of fatigue no longer affect postural control at this recovery time interval following exercise. The recovery trend continued through the eighteen-minute recovery time interval, as we observed no significant differences on any of the dependent variables. Interestingly, although not statistically significant, postural control measures for all three dependent variables improved at the eighteen-minute recovery mark following the anaerobic exercise protocol when compared to the baseline measures. A reasonable explanation for this trend can be attributed to sampling error, as all of the differences were less than five percent.

Effect of Each Exercise Protocol, Heart Rate, and RPE

The anaerobic and aerobic exercise protocols used in this study were chosen in an effort to replicate the different feelings of fatigue athletes may experience during the course of exercise. The idea was to have two different exercise protocols that would fatigue athletes at different metabolic demanding tasks (think football wide receiver performing short duration sprints versus soccer midfielder running continuously for longer durations). The Borg 15-point scale was used to measure each participants rating of perceived exertion (RPE) as the criterion established to confirm fatigue following each exercise protocol (Borg, 1982). Heart rate was also monitored throughout each testing session due to its strong positive correlation with RPE scores. These measures were taken at baseline, immediately following each exercise protocol, and at each post exercise recovery time interval. Prior investigators have used the RPE scale with a similar population and found that a score of 15 correlated to a 75% to 90% maximum oxygen consumption (Moyna et al., 2001; Robertson et al., 2000).

Immediately following the aerobic exercise protocol, RPE values had a mean of 18.3 while the anaerobic exercise protocol produced a mean RPE value of 17.6. Both values suggest participant's level of exertion reached "very, very hard." The corresponding heart rate measures immediately post aerobic and anaerobic exercise were 191 and 180 beats per minute, respectively. Using the age predicted heart rate formula, participants exercised at an intensity equal to 95 and 90 percent maximal heart rate for the aerobic and anaerobic exercise protocols, respectively. From these measures, we are confident that participants were adequately exerted, and that the decrease in postural control was a result of the very high exertion, which could lead to fatigue.

Of importance was the finding that two different exercise protocols, one aerobic in nature, and the other anaerobic, yielded similar postural control recovery rates from fatigue. Postural control deficits from fatigue were no longer statistically different at thirteen minutes post exercise following both anaerobic and aerobic exercise protocols. Even though the aerobic protocol was designed to reproduce in a similar fashion the demands of long duration exercise, such as soccer, the ending minutes of the protocol imposed very similar demands observed with the anaerobic protocol, were participants seemed to have been fatigued in a similar way. Local muscle fatigue is induced by a decrease in the metabolic substrates available for muscle contraction, leading to an accumulation of metabolic by-products, resulting in an inability to maintain force output, and is often associated with repeated short, quick bursts of energy (Wilmore, 1999). The end of the aerobic protocol lead subjects to exert as levels where heart rate and RPE values were very similar to the anaerobic protocol. The accumulation of metabolites and depletion of energy substrates that occurred in both protocols (apparently in the same way) may help explain the similarities of postural control deficits and recovery following exercise. For fatigue to be truly characterized within an aerobic protocol, the results of this study suggests that a sub-maximal protocol, exercising at a high enough intensity for fatigue to be reached between 8 and 12 minutes, would be more appropriate. Further researchers should be cautious when utilizing an aerobic protocol of varied exercise intensity. More research is needed to truly compare the impact of fatigue on postural control between two protocols that impose different metabolic demands.

Research Hypotheses

Research hypothesis one stated that there would be a decrease in postural control following both an anaerobic and aerobic exercise protocol as measured by elliptical sway area and sway velocity on a forceplate. Our results support this hypothesis. Using varied fatigue protocols, several other researchers have found similar results, observing postural control deficits following bouts of exercise (Derave et al., 1998; Lepers et al., 1997; Nardone et al., 1998; Nardone et al., 1997; Seliga et al., 1991). Yaggie and Armstrong (2004) concluded that postural sway will increase and might transiently degrade postural control following fatigue from bouts of exercise performed on a cycle ergometer. Changes in balance indices were observed immediately post fatigue and returned to baseline values within ten minutes of recovery (Yaggie J, 2004). Our results are consistent with the results from their study. Harkins et al. (2005) found sway velocity to be significantly greater when ankle local musculature was fatigued, but that the effects lasted only 75-90 seconds (Harkins et al., 2005). The short recovery time can be attributed to local muscle fatigue rather than systemic, or whole-body, fatigue.

Research hypothesis two stated that there would be an increase in errors from baseline to post-fatigue following both anaerobic and aerobic exercise protocols as scored by the BESS. Our results support this hypothesis. Research by (Crowell, 2000) and (Wilkins et al., 2004) found very similar results. Both researchers observed an increase in post-fatigue errors as measured by the BESS following bouts of exercise. Crowell et al. investigated postural stability after a fatigue protocol consisting of squat jumps, sprints, and treadmill running in male and female club-sport athletes. Significant differences between baseline and post-fatigue BESS total scores were observed, leading to the conclusion that any decrease in performance on the BESS might be attributed to the fatigue that had occurred in the lower extremity. Likewise, Wilkins et al. looked at performance on the BESS following a fatigue protocol using Division I collegiate athletes. Their study used a fatigue protocol lasting 20 minutes consisting of seven stages including a 5-minute moderate jog, 3 minutes of sprints, 2 minutes of pushups, 2 minutes of sit-ups, 3 minutes of step-ups, 3 minutes of sprints, and a 2-minute run. The results demonstrated significant increases in total errors from pre-test to post-test in the fatigue group. Both researchers concluded that clinicians who use the BESS as part of their sideline assessment for concussion should not administer the test immediately after a concussion due to the effects of fatigue. Our findings agree with previous results; however, our study also examined a recovery time from fatigue as well as compared two different exercise protocols.

Research hypothesis three stated that there would be a quicker return to baseline following the anaerobic exercise protocol when compared to the aerobic exercise protocol. Although the results suggest that postural control returns to baseline for both exercise protocols between the eight and thirteen-minute recovery interval, a significant interaction effect between exercise protocol and time was revealed for total BESS score. Further post hoc analyses revealed a significant difference only at the three-minute post exercise interval (mean difference of 1.94, aerobic-anaerobic) with the eight-minute post exercise interval approaching significance (mean difference of 1.0, aerobic-anaerobic).

These results differ slightly from previous literature. In a study observing postural sway deviations after a twenty-five minute treadmill run, Nardone found that sway measures were still elevated after thirteen minutes of recovery but had returned to baseline after 23 minutes (Nardone et al., 1998). Most recently, researchers tried to determine a balance recovery timeline using the BESS and a 7-station exertion protocol. The results of this study not only supported that balance was affected by fatigue, but balance recovery (i.e., return to pretest score) will occur within twenty minutes after exercise is ceased (Susco et al., 2004). The difference in recovery time from the Susco study to our study can be attributed to many factors. The subject pool in their study was “recreationally active college students”, yet our study observed Division I collegiate athletes. Different physiological levels between active students and collegiate athletes might best explain these differences. Another explanation might be that the study design was different. For example, their study divided the subjects into post test groups tested at different time intervals following exercise, thus using a between subjects repeated measure testing design. Our study tested everyone at the same post test time intervals, utilizing a completely within subjects repeated measures design. It should be reinforced that both studies revealed significant differences between baseline and post exercise postural control using the BESS. Of equal importance, both studies showed that postural control needs time to recover from the effects of fatigue.

Clinical Significance

Sideline assessment of mild head injury has evolved into a comprehensive approach, which should involve an evaluation of balance and/or postural control (Guskiewicz, 2001, , 2003; Guskiewicz et al., 2004; Guskiewicz et al., 2001; McCrea et al., 2005; McCrea et al., 2003). While baseline postural control measures for each athlete are taken at rest, the majority of post injury measures are taken following bouts of exercise. It is well established that fatigue will affect postural control, but how long do these deficits last? Prior research states it would be contraindicated to administer the BESS to an athlete who was recently taken off the field. In this situation, the athlete may score a high number of errors due to the combined effect of fatigue and injury (Crowell et al., 2000; Wilkins et al., 2004). Thus, a post exercise recovery time of twenty minutes has been recommended so that the effect of fatigue does not compound the postural control assessment (Derave et al., 1998; Nardone et al., 1998; Nardone et al., 1997; Susco et al., 2004; Yaggie & McGregor, 2002). Our findings suggest athletic trainers and clinicians who choose to use the BESS as part of their sideline assessment following a suspected MHI should wait at least thirteen minutes in order for the effects of fatigue to dissipate. This will allow adequate rest for the athlete, which should enable him or her to return to a resting state. The sideline assessment will consequently provide a better comparison to their baseline, which increases the likelihood that any postural control deficits noted during the sideline assessment can be attributed to a potential MHI. Regardless of exercise type, the recovery period suggested could be applied to all sports in which athletes participate at high levels of intensity, similar to our exercise protocols.

Limitations

Different sports require different metabolic demands, thus, athletes experience different levels of exertion (Susco et al., 2004). In our study, we attempted to isolate the effects of a primarily anaerobic exercise protocol from a primarily aerobic exercise protocol. The aerobic exercise protocol began at a low intensity, and gradually increased as participants successfully made each stage. Eventually, participants had to give a near maximal effort to reach the finish line marker before the beep. Therefore, there was a strong similarity between the ending period of the aerobic exercise protocol and the anaerobic exercise protocol; as participants advanced stages during the aerobic exercise protocol, their intensity was approaching that of a sprint in order to make the beeps. This may have too closely paralleled the effort expended during the anaerobic exercise protocol, thus yielding similar results at the end of each protocol. This may help explain why recovery time was the same following each exercise. On top of that, standardizing two different fatigue protocols, given on two separate occasions, is a difficult task due to so many extraneous variables that can alter how a specific individual respond to exercise (psychological state, level of fitness, environmental conditions to name a few).

Another limitation of this study may have been the presence of a learning effect from baseline to post fatigue following the anaerobic exercise protocol. Participants' mean BESS scores, elliptical sway areas, and sway velocities were all lower at recovery interval 18 when compared to baseline. We tried to control for a learning effect by giving subjects 2 practice trials prior to their baseline; however, each participant performed seven total BESS trials during the first session, and another four during the second session (within seven days). So many trials in such a short period of time may have contributed to improved scores following the shorter duration, anaerobic exercise protocol. A learning effect has been demonstrated in control groups(Valovich, Perrin, & Gansneder, 2003; Wilkins et al., 2004), but further research is needed to specifically examine the learning effects following exercise. It may be that the recovery trend recognized was due to sampling error.

Future Research

Future investigators should examine the recovery rate from exercise with specific teams, and possibly take it one step further into looking at specific positions in sport. It is irrational to think that a wide receiver is fatigued similar to a soccer player, or a track and field sprinter to a lacrosse player. This study attempted to differentiate between strictly anaerobic and strictly aerobic exercise, but more research is needed. Comparing multiple aerobic exercise protocols against multiple anaerobic exercise protocols, and at different recovery time intervals may also lead to a regression model being used to help predict recovery time following exercise. Other research should also evaluate the effects of fatigue and its recovery rate on other MHI tools, such as Standardized Assessment of Concussion and Graded Symptoms Checklist.

Future research should also focus on how local fatigue of the lower extremity stabilizing musculature effects balance using the BESS as their postural control assessment. Sideline BESS testing during practice at different intervals may also provide important, relevant research into the effects of fatigue on postural control.

Summary

In a participant pool of collegiate athletes, postural control was affected by anaerobic and aerobic exercise protocols as measured by total BESS score, elliptical sway area, and sway velocity. Of further importance, the effect of fatigue seems to remain present until thirteen minutes following both aerobic and anaerobic exercise. At this time, the athlete's postural control returned to baseline. Athletic trainers and clinicians should be aware of these effects and their recovery time course when determining an appropriate time to administer sideline assessments of postural control following a suspected MHI.

APPENDIX A:

Manuscript

Postural Control Returns to Baseline within 13 Minutes Following both Anaerobic and Aerobic Exercise Protocols.

Context: Research to date has not examined the effect of fatigue from different exercise types on postural control in relation to sideline concussion testing.

Objective: To evaluate the effects of fatigue on postural control in healthy college-aged athletes using both anaerobic and aerobic exercise protocols, and to establish an immediate recovery time course from each exercise protocol for postural control measures to return to baseline status.

Design: Counterbalanced, repeated measures design

Setting: Research laboratory

Patients or Other Participants: Thirty-six male and female collegiate athletes participated in this study.

Interventions: Participants completed two counterbalanced sessions within seven days. Each session consisted of one exercise protocol followed by post-exercise measures of postural control taken at 3-, 8-, 13-, and 18-minute time intervals. Baseline measures were established during the first session.

Main Outcome Measures: We used the BESS, in conjunction with forceplate measures, to assess postural control. Sway velocity and elliptical sway area were measured from data collected by the forceplate.

Results: We found a significant decrease in postural control following each exercise protocol for all dependent measures. A significant interaction effect between exercise protocol and time was revealed for total BESS score. Postural control measures returned to baseline within 13 minutes for both exercise protocols.

Conclusions: Postural control was affected following anaerobic and aerobic exercise protocols as measured by total BESS score, elliptical sway area, and sway velocity. The effect of fatigue seems to remain present until 13 minutes following strenuous exercise. Athletic trainers and clinicians should be aware of these effects and their recovery time course when determining an appropriate time to administer sideline assessments of postural control following a suspected MHI.

Key Words: balance, postural control, fatigue, recovery, mild head injury.

INTRODUCTION

Proper management of sport related mild head injuries (MHI) has gained a great deal of interest within the sports-medicine community in recent years. In the past, assessment of MHI has relied heavily on subjective symptoms self-reported by the athlete.[1] This can become dangerously problematic due to the potential for athletes to withhold information in order to return to competition, leaving the clinician without a clear picture of the athlete's true mental status.[1, 2] This lack of objective and quantifiable information on which to make return to play decisions following a MHI poses a quandary for sports medicine clinicians. Thus, recent trends in the clinical management of MHI have resorted to alternative means of identifying deficits following a suspected head injury, which may help prevent premature return to competition and serious injury.[3-6]

Postural control testing has been the catalyst in obtaining objective measures of MHI. Using forceplate measures, researchers developed The Balance Error Scoring System (BESS) which is used on the sideline to measure an athlete's balance following a suspected MHI.[7] Baseline scores for the BESS are established during pre-season screenings, and are taken at rest. However, sideline evaluations of MHI are most often taken during practice or competition, not at rest. Therefore, numerous extraneous factors, aside from the MHI, may influence postural control.[8-10]

Fatigue has been shown to negatively affect postural control.[2, 11-14] However, few studies have measured the effect of fatigue on the performance of the BESS. Crowell et al. (2000) demonstrated decreased postural stability after an exercise protocol consisting of squat jumps, sprints, and treadmill running. Similarly, Wilkins et al. (2004) found a decrease in postural stability as a result of a seven-station, twenty-minute exercise protocol as measured by the BESS total error score. Both studies used lengthened exercise protocols to elicit fatigue that included both anaerobic and aerobic characteristics. Neither study investigated the effects of fatigue resulting from exercise protocols that were explicitly anaerobic or aerobic in nature.

There are also few studies that have investigated the immediate recovery time following fatigue for postural control measures to return to baseline. The limited research available shows decreased postural stability immediately post-exercise, but no deficits as early as twenty minutes post exercise.[15-18] More importantly, these studies examined aerobic exercise protocols that lasted twenty minutes or longer. The recovery timeline may differ when compared to an anaerobic exercise protocol.

The aforementioned studies examined exercise protocols that were aerobic in nature. To our knowledge, the immediate effects of an anaerobic exercise protocol on postural control have yet to be established. In addition, the effects of fatigue induced by an anaerobic exercise protocol have not been compared to an aerobic exercise protocol. Therefore, the primary purpose of this study was to evaluate the effects of fatigue on postural control in healthy college-aged athletes. A secondary purpose of this study was to establish an immediate recovery time course from each exercise protocol over which the effects of fatigue lessen, and postural control measures returned to baseline status.

METHODS

Subjects

The participants were 36 NCAA Division I male (18) and female (18) athletes (age = 19yrs (1.01), height = 172.44cm (10.47), weight =69.72kg (12.84)) who were recruited based on their sport involvement. Athletes participating in sports with an increased risk of sustaining a MHI such as soccer, lacrosse, field hockey, or wrestling, were included in this study.

Participants were excluded from this study if they had any pre-existing lower extremity injury that put them at further risk of injury, had a known visual, vestibular, or balance disorder, or if they had sustained a MHI within the last three months. Additionally, any participant that had undergone balance testing in the last three months was excluded from this study. Pre-assessment guidelines were provided for each participant prior to their first testing session (see Table 1).

Participants were given an instructional orientation concerning the exercise protocols and the balance testing prior to participation. All participants were asked to sign an approved informed consent form prior to data.

Instrumentation

Force plate

Postural stability measures were performed on a Bertec 4060-NC piezoelectric force sensor platform (Bertec Corp.; Columbus, OH). This system measures ground reaction forces produced by movement of the body's center of gravity about a fixed base of support. Using force plate measures to assess postural control has been shown to be reliable and valid (Goldie et al. 1989), and has been used with athletic populations (Cavanaugh et al. 2005; Guskiewicz et al. 2001).

Force plate raw voltage signals were amplified by a gain of 5 using a Bertec AM-6701 amplifier (Bertec Corp.). Raw force plate data were sampled using The Motion Monitor for Research Software version 6.74 (Innovative Sports Training, Inc.; Chicago, IL) at a frequency of 1,000 Hz. Any error in which a participant touched down or stepped off the forceplate during a balance trial was recorded manually, and these trials were discarded.

Balance Error Scoring System (BESS)

The BESS (Riemann and Guskiewicz, 2000) measures participants' postural control during three different stances (double-leg stance, single-leg (non-dominant) stance, and tandem stance), using two surface conditions: firm and foam (Figure 1). The firm surface assessment occurred on the force plate surface, and the foam surface assessment occurred on a 41.6-cm x 50.8-cm Airex Balance Pad (Alcan Airex AG, Switzerland), placed directly on the force plate.

The balance tasks required the participant to balance for 20 seconds with eyes closed and hands on their iliac crests. Testing started when participants closed their eyes. During the single-leg balance tasks, participants were required to balance on their non-dominant leg, with their contralateral leg in 20° hip flexion and 30° knee flexion. The participants' dominant leg was determined by asking each participant which leg they prefer to use to kick a soccer ball. Participants were instructed to stand quietly and motionless in the stance position, keeping their hands on the iliac crests and eyes closed. Participants were instructed that upon losing their balance, they should make any necessary adjustments and return to the initial testing position within five seconds. Instructions and demonstration of the BESS were viewed using video media prior to testing each participant.

Participants were scored based upon the errors recorded during each of the six balance tasks. Errors included lifting their hands off their iliac crest; opening their eyes; stepping, stumbling, or falling; moving their non-stance hip into more than 30° abduction; lifting their forefoot or heel; and remaining out of test position for more than five seconds. A higher score (more errors) on the BESS compared to baseline measures indicated a deficit in postural control. The BESS has a strong interrater reliability with coefficients ranging from 0.78 to 0.96 (Riemann, Guskiewicz et al. 1999; Riemann and Guskiewicz 2000) and has been proven to be a reliable and valid test to assess postural control in college aged athletes (Riemann, Guskiewicz et al. 1999)

Exercise Protocol

For the aerobic exercise protocol, we used the Yo-Yo intermittent recovery test, level 1, to elicit fatigue in all participants. This test consists of repeated 20-meter runs down and back between the starting, turning, and finish line at progressively increased speeds controlled by audible tones delivered at known frequencies (Figure 2). The protocol began with 4 running bouts at 10-13 kilometers per hour (kph) over the first 160 meters followed by 7 running bouts at 13.5-14 kph (160-440m). It continued with stepwise 0.5 kph speed increments after every 8 running bouts (i.e., after 760, 1080, 1400, 1720m, etc.) until exhaustion. Between running bouts, the participants had a 10s active rest period consisting of 5-meter walk/jog at their own pace. When the participant failed on two runs to reach the finish line before the audible beep, the participant was considered fatigued, and the exercise was finished. It should be noted that the missed runs did not have to occur in consecutive order (i.e. back to back) for the participant to be deemed fatigued. Their first miss was recorded, and whenever the second miss occurred, the exercise was terminated. The protocol was performed indoor on running lanes marked by cones, having a width of 2m and a length of 20m. Another cone placed 5m behind the finishing line marked the running distance during the active recovery period. Before the exercise protocol, all participants carried out a warm-up and stretching period consisting of the first two running intervals followed by low back and lower extremity stretching. All participants were familiarized to the exercise protocols through verbal explanation. The Yo-Yo intermittent recovery test has been shown to be both reliable and valid in relation to the demands of soccer play, stressing both the aerobic and anaerobic metabolic pathways.[19]

The anaerobic exercise protocol started at level 23.1 and consisted of maximum effort sprints between the cones. Participants were instructed that the test would run for two full minutes in which they were to attempt to make as many beep intervals as possible. For this protocol, the beeps were used as an external cue that informed the participants where they should be throughout the trial. If participants failed to reach the finish line twice during the two-minute period, they did not end the test as they did in the aerobic protocol; participants continued for the full two minutes. Verbal encouragement was used during both the aerobic and anaerobic exercise protocols in an effort to maintain the athletes intensity level.

Heart Rate Monitor

Heart rate was recorded before, during, and after each fatigue protocol with a Polar Digital Heart Rate Monitor (Polar Electro Inc., Lake Success, NY). The athletes were monitored to check percentage of maximal heart rate during each exercise protocol as well as to observe their recovery rate from exercise. Age-predicted maximal heart rate was determined using the age-adjusted maximal heart rate formula calculated by subtracting one’s age from 220.

Ratings of Perceived Exertion

The Borg 15-point category rating scale (6-20) was used to measure each participant’s Rating of Perceived Exertion (RPE) to try to ensure adequate exertion was achieved (Table 2). Adequate exertion was deemed to be achieved with an RPE score of 15. For all participants, RPE scores were monitored before, immediately following, and at each recovery time period following the exertion protocol.

Procedures

Each participant reported to the laboratory for two testing sessions. The first session for all participants included an orientation, collection of baseline BESS scores and forceplate measures, and one of the exercise protocols. The exercise protocol that each participant performed in the first testing session was counterbalanced, thus eliminating the potential for an order effect. Each participant was briefed on the study and asked to sign an informed consent form during the first session prior to any data collection. Upon completion of the orientation, participants were asked to perform two separate practice trials of the complete BESS test while standing on the forceplate. Five minutes rest was given between each trial. Practice trials were administered in an effort to establish a learning effect for the BESS. By establishing a learning effect, this can limit potential learning from occurring during subsequent testing periods. A third trial of the BESS was performed following the two practice trails. The participants' BESS scores and forceplate measures collected on the third trial was used as their baseline in subsequent statistical analyses.

Both the first and second testing sessions included one of the exercise protocols. Each testing session was between 1-7 days apart (average of 3 days) to allow for an adequate recovery and to retain any learning effects that occurred during the first session. Participants were required to wear shorts, a t-shirt, and athletic shoes while performing the protocol. Before the exercise protocol, all participants carried out a warm-up and stretching period consisting of the first two running intervals followed by low back and lower extremity static and dynamic stretching. Upon completion of the exercise protocol, participants were escorted back to the MCRL where they began the BESS test. There were three minutes between the end of the protocol and the first BESS testing. Each participant was then tested at eight minutes, thirteen minutes, and eighteen minutes post exercise in order to establish a recovery timeline. Heart rate and RPE were recorded at each testing interval.

Data Reduction

The analog force plate data were converted into a digital signal via an analog-to-digital (A/D) converter board in order for the computer to recognize and interpret the measures. The data were then imported into a custom MatLab 7 program (The Mathworks, Inc.; Natick, MA). For this study, forceplate measures included center of pressure average sway velocity and elliptical sway area. Center of pressure sway velocity was defined as the speed at which an individual's COP moves within his or her base of support. Elliptical sway area was the area defined by the minor and major axes of an ellipse that statistically encompasses an area containing 95% of the COP data points.

Statistical Analysis

Means and standard deviations were calculated for both the force plate measures and the BESS total scores. Six separate one way repeated measures ANOVA were calculated to determine the recovery time course for each force plate measure and the BESS total score (three for each exercise protocol). Additionally, three separate 2 (protocols) x 4 (recovery time intervals) repeated measures ANOVA were performed to determine if an interaction effect existed between exercise protocol and recovery time. Pairwise comparisons as each post exercise recovery time interval were conducted via Bonferroni adjustments. An alpha level of 0.05 was set *a priori* for all analyses. All data were analyzed using SPSS statistical software (version 13.0; SPSS Inc, Chicago, IL).

RESULTS

Thirty-six healthy NCAA Division I athletes (18 males, 18 females) volunteered to participate in this study (Descriptive statistics of the participants are in Table 3). The data used for each repeated measures ANOVA are presented in Table 4.

Research Question 1: Three separate one-way repeated measures ANOVA were performed to determine if significant differences existed between baseline and post exercise measures of postural control following an *anaerobic* exercise protocol. One ANOVA model was used for each dependent variable.

Elliptical Sway Area: The ANOVA analysis revealed a significant effect of time on postural control as measured by elliptical sway area following the *anaerobic* exercise protocol ($F_{(4,140)} = 11.927$, $p < 0.001$). Bonferroni post hoc analyses revealed a significant difference between baseline and 3 minutes post anaerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes, 13 minutes and 18 minutes post anaerobic exercise.

Sway Velocity: The ANOVA analysis revealed a significant effect of time on postural control as measured by sway velocity following the *anaerobic* exercise protocol ($F_{(3.110,140)} = 11.947$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post anaerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes, 13 minutes and 18 minutes post anaerobic exercise.

Total BESS score: The ANOVA analysis revealed a significant effect of time on postural control as measured by total BESS score following the *anaerobic* exercise protocol ($F_{(4,140)} = 24.157$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post anaerobic exercise ($p < 0.001$), significant differences between baseline and 8 minutes post anaerobic exercise ($p = 0.018$), but no significant differences between baseline and 13 or 18 minutes post anaerobic exercise.

Research Question 2: Three separate one-way repeated measures ANOVA were performed to determine if significant differences existed between baseline and post exercise measures of postural control following an *aerobic* exercise protocol. One ANOVA model was used for each dependent variable.

Elliptical Sway Area: The ANOVA analysis revealed a significant effect of time on postural control as measured by elliptical sway area following the *aerobic* exercise protocol ($F_{(3.493, 140)} = 15.546$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise ($p < 0.001$), but no significant differences between baseline and 8 minutes 13 minutes and 18 minutes post aerobic exercise.

Sway Velocity: The ANOVA analysis revealed a significant effect of time on postural control as measured by sway velocity following the *aerobic* exercise protocol ($F_{(4,140)} = 35.692$, $p < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise ($p = < 0.001$) and significant differences between baseline and 8 minutes post aerobic exercise ($p = 0.004$), but no significant differences between baseline and 13 or 18 minutes post aerobic exercise.

Total BESS score: The ANOVA analysis revealed a significant effect of time on postural control as measured by total BESS score following the *aerobic* exercise protocol ($F_{(4,140)} = 56.675$, $p = < 0.001$). Bonferroni post hoc analyses revealed significant differences between baseline and 3 minutes post aerobic exercise ($p < 0.001$) and significant differences between baseline and 8 minutes post aerobic exercise ($p < 0.001$), but no significant differences between baseline and 13 or 18 minutes post aerobic exercise.

Research Question 3: Three separate 2x4 (protocol x post exercise time) repeated measures ANOVA were performed to determine if there was an interaction effect between exercise protocol and post exercise recovery time. Baseline measures were not included as part of the time factor in the ANOVA analysis as research questions one and two previously established significant differences between baseline measures and immediate post exercise measures of postural control.

Elliptical Sway Area: The ANOVA analysis revealed a significant main effect for recovery time ($F_{(3,105)} = 28.704$, $p < 0 .001$) while the main effect for exercise protocol was not significant ($F_{(1,35)} = 0.740$, $p = 0.396$). The protocol by time interaction was also non-significant ($F_{(2.535, 88.742)} = 0.788$, $p = 0.485$).

Sway Velocity: Paralleling elliptical sway area, the ANOVA analysis for sway velocity revealed a significant main effect for recovery time ($F_{(2.746, 96.125)} = 43.361$, $p < 0.001$) while the main effect for exercise protocol was not significant ($F_{(1,35)} = 1.355$, $p = 0.252$). Similarly, the protocol by time interaction was non-significant ($F_{(2.525,88.368)} = 1.912$, $p = 0.143$).

Total BESS score: The ANOVA analysis for total BESS score revealed a significant main effect for time ($F_{(2.471,86.472)} = 96.701$, $p < 0.001$) as well as a main effect for exercise protocol ($F_{(1,35)} = 5.988$, $p = 0.020$). More importantly, a significant interaction effect between exercise protocol and time ($F_{(3,105)} = 5.437$, $p = 0.002$) was revealed. Bonferroni post hoc analyses showed a significant difference for total BESS score between exercise protocols at three minutes post exercise. However, at eight, thirteen, and eighteen minutes post exercise, no significant post hoc analyses were found between exercise protocols (Figure 3). The significant interaction at the 3-minute post exercise interval between protocol and time suggests that the recovery time is different for each exercise protocol for total BESS score.

DISCUSSION

The most important finding of this research was that both anaerobic and aerobic exercise protocols adversely affected postural control as measured through the Balance Error Scoring System (BESS), elliptical sway area, and sway velocity. More importantly for athletic trainers and clinicians, the effects of fatigue appear to last up to eight minutes post exercise, regardless of exercise protocol, with postural control returning to baseline on average between eight and thirteen minutes following exercise.

Proper management of sport-related mild head injury (MHI) requires a comprehensive assessment by athletic trainers and other clinicians. Postural control batteries, such as the BESS have been developed in recent years in an effort to obtain more objective measures from injured athletes [7]. BESS error scores are typically taken at rest before the athlete's season begins in order to obtain baseline measures for each individual. Following a suspected MHI, the BESS is administered on the sideline, and a post-injury score is compared to the athlete's baseline score. However, there is little research examining the effect of fatigue on postural control during these sideline examinations if administered too soon after exercise. The primary purpose of this study was to evaluate the effects of fatigue on postural control in healthy college-aged athletes. Fatigue was introduced between two separate sessions by means of two different exercise protocols: ***anaerobic*** exercise and

aerobic exercise. A secondary purpose of this study was to establish the immediate recovery time course from each exercise protocol over which the effects of fatigue lessen and postural control measures return to baseline status. Forceplate measures of elliptical sway area and sway velocity, as well as total BESS score, were used to assess postural control differences pre and post exercise.

Postural Control and Recovery Time from Fatigue

We observed an effect of fatigue on postural control on all three dependent measures. Total BESS score, the sum of all six trials, was significantly greater at three minutes post exercise when compared to the athletes' baseline for both the anaerobic and aerobic exercise protocols, increasing from 4.889 to 8.083 errors (mean difference of 3.194) following the ***anaerobic*** exercise and 4.889 to 10.028 errors (mean difference of 5.139) following the ***aerobic*** exercise. Similarly, forceplate measures revealed a significant increase from baseline in elliptical sway area and sway velocity at three minutes post exercise for both anaerobic and aerobic exercise protocols. Elliptical sway area increased from 49.143 to 72.824 and sway velocity increased from 8.147 to 9.471 following the ***anaerobic*** exercise. Following the ***aerobic*** exercise, elliptical sway area and sway velocity values increased from 49.143 to 80.102 and from 8.147 to 10.178, respectively. From these measures, it is clear that postural control remained affected at three minutes following the anaerobic and aerobic exercise protocols. These results are comparable to previous literature [2, 9, 15-17, 20]

At eight minutes post exercise, total BESS score remained significantly worse compared to baseline for both exercise protocols. The total BESS error score was 6.333 following the ***anaerobic*** exercise protocol and 7.333 following the ***aerobic*** exercise protocol (mean differences from baseline of 1.444 and 2.444 respectively). Sway velocity was significantly different following only the aerobic exercise protocol, but not significantly different following the anaerobic protocol (though it was close with a p value = 0.071). Interestingly, elliptical sway area was not significantly different from baseline at eight minutes post exercise following either protocol. At this point post exercise, it appears forceplate measures recover to baseline faster than total BESS scores. The results suggest that postural control remains affected by fatigue at eight minutes post exercise. These findings are also analogous to prior research [16, 17, 21]

At thirteen minutes post exercise, postural control (according to all three measures) had returned to baseline levels following both the anaerobic and aerobic exercise protocols. It can be concluded that the effects of fatigue no longer affect postural control at this recovery time interval following exercise. The recovery trend continued through the eighteen-minute recovery time interval, as we observed no significant differences on any of the dependent variables. Interestingly, although not statistically significant, postural control measures for all three dependent variables were slightly lower at the eighteen-minute recovery mark following the anaerobic exercise protocol when compared to the baseline measures. Though each exercise protocol was counterbalanced in order of session, a reasonable explanation for this trend can be attributed to a learning effect.

Effect of Each Exercise Protocol, Heart Rate, and RPE

The anaerobic and aerobic exercise protocols used in this study were chosen in an effort to replicate the different feeling of fatigue athletes may experience during the course of exercise. The idea was to have two different exercise protocols that would fatigue athletes at different metabolic demanding tasks (think football wide receiver performing short duration sprints versus soccer midfielder running continuously for longer durations). The Borg 15-

point scale was used to measure each participants rating of perceived exertion (RPE) to try to make certain adequate fatigue was achieved for each protocol.[22] Heart rate was also monitored throughout each testing session due to its strong positive correlation with RPE scores. These measures were taken at baseline, immediately following each exercise protocol, and at each post exercise recovery time interval. Prior investigators have used the RPE scale with a similar population and found that a score of 15 correlated to a 75% to 90% maximum oxygen consumption.

Immediately following the aerobic exercise protocol, RPE values had a mean of 18.3 while the anaerobic exercise protocol produced a mean RPE value of 17.6. Both values suggest participant's level of exertion reached "very, very hard." The corresponding heart rate measures immediately post aerobic and anaerobic exercise were 191 and 180 beats per minute, respectively. Using the age predicted heart rate formula, participants exercised at an intensity equal to 95 and 90 percent maximal heart rate for the aerobic and anaerobic exercise protocols, respectively. From these measures, we are confident that participants were adequately exerted, and the decrease in postural control was a result of their fatigue.

Of importance was the finding that two different exercise protocols, one aerobic in nature, and the other anaerobic, yielded similar postural control recovery rates from fatigue. Postural control deficits from fatigue were no longer statistically different at thirteen minutes post exercise following both anaerobic and aerobic exercise protocols. One explanation for this could be that the exercise protocols fatigued participants in a similar fashion. Local muscle fatigue is induced by a decrease in the metabolic substrates available for muscle contraction, leading to an accumulation of metabolic by-products, resulting in an inability to maintain force output, and is often associated with repeated short, quick bursts of energy.[23] The ending minutes of the aerobic protocol had participants exerting at a high level of intensity to make the beeps, and therefore, heart rate and RPE values were very similar across exercise protocols. Further research is needed to evaluate postural control deficits under isolated fatiguing conditions.

Research Hypotheses

Research hypothesis one stated that there would be a decrease in postural control following both an anaerobic and aerobic exercise protocol as measured by elliptical sway area and sway velocity on a forceplate. Our results support this hypothesis. Using varied fatigue protocols, several other researchers have found similar results observing postural control deficits following bouts of exercise.[8, 11, 15, 16, 24] Yaggie and Armstrong (2004) conclude that postural sway will increase and might transiently degrade postural control following fatigue from bouts of exercise performed on a cycle ergometer. Changes in balance indices were observed immediately post fatigue and returned to baseline values within ten minutes of recovery.[25] Our results are consistent with the results from their study. Harkins et al. (2005) found sway velocity to be significantly greater when ankle local musculature was fatigued, but that the effects lasted only 75-90 seconds.[14] The short recovery time can be attributed to local muscle fatigue rather than systemic, or whole-body, fatigue.

Research hypothesis two stated that there would be an increase in errors from baseline to post-fatigue following both anaerobic and aerobic exercise protocols as scored by the BESS. Our results support this hypothesis. Research by Crowell (2000) and Wilkins (2004) found very similar results. Both researchers observed an increase in post-fatigue errors as measured by the BESS following bouts of exercise. Crowell et al. investigated postural stability after a fatigue protocol consisting of squat jumps, sprints, and treadmill running in male and female club-sport athletes. Significant differences between baseline and post-fatigue BESS total scores were observed, leading to the conclusion that any decrease in performance on the BESS might be attributed to the fatigue that had occurred in the lower extremity. Likewise, Wilkins et al. looked at performance on the BESS following a fatigue protocol using Division I collegiate athletes. Their study used a fatigue protocol lasting 20 minutes and consisted of seven stages including a 5-minute moderate jog, 3 minutes of sprints, 2 minutes of pushups, 2 minutes of sit-ups, 3 minutes of step-ups, 3 minutes of sprints, and a 2-minute run. The results demonstrated significant increases in total errors from pre-test to post-test in the fatigue group. Both researchers concluded that clinicians who use the BESS as part of their sideline assessment for concussion should not administer the test immediately after a concussion due to the effects of fatigue. Our findings agree with previous results; however, our study also examined a recovery time from fatigue as well as compared two different exercise protocols.

Research hypothesis three stated that there would be a quicker return to baseline following the anaerobic exercise protocol when compared to the aerobic exercise protocol. Although the results suggest that postural control returns to baseline for both exercise protocols between the eight and thirteen-minute recovery interval, a significant interaction effect between exercise protocol and time was revealed for total BESS score. Further post hoc analyses revealed a significant difference only at the three-minute post exercise interval (mean difference of 1.94, aerobic-anaerobic) with the eight-minute post exercise interval approaching significance (mean difference of 1.0, aerobic-anaerobic).

These results differ slightly from previous literature. In a study observing postural sway deviations after a twenty-five minute treadmill run, Nardone found that sway measures were still elevated after thirteen minutes of recovery but had returned to baseline after 23 minutes.[15] Most recently, researchers tried to determine a balance recovery timeline using the BESS and a 7-station exertion protocol. The results of this study not only supported that balance was affected by fatigue, but balance recovery (i.e., return to pretest score) will occur within twenty minutes after exercise is ceased.[18] The difference in recovery time from the Susco study to our study can be attributed to many factors. The subject pool in their study was "recreationally active college students", yet our study observed Division I collegiate athletes. Different physiological levels between active students and collegiate athletes might best explain these differences. Another explanation might be that the study design was different. For example, their study divided the subjects into post test groups tested at different time intervals following exercise, thus using a between subjects repeated measure testing design. Our study tested everyone at the same post test time intervals, utilizing a completely within subjects repeated measures design. It should be reinforced that both studies revealed significant differences between baseline and post exercise postural control using the BESS. Of equal importance, both studies showed that postural control needs time to recover from the effects of fatigue.

Clinical Significance

Sideline assessment of mild head injury has evolved into a comprehensive approach, which should involve an evaluation of balance and/or postural control.[4, 5, 26-29] While baseline postural control measures for each athlete are taken at rest, the majority of post injury measures are taken following bouts of exercise. It is well established that fatigue will affect postural control, but how long do these deficits last? Prior research states it would be contraindicated to administer the BESS to an athlete who just was taken off the field. In this situation, the athlete may score a high number of errors due to the combined effect of fatigue and injury.[9, 30] Thus, a post exercise recovery time of twenty minutes has been recommended so the effect of fatigue does not compound the postural control assessment.[8, 15-18] Our findings suggest athletic trainers and clinicians who choose to use the BESS as part of their sideline assessment following a suspected MHI should wait at least thirteen minute in order for the effects of fatigue to lessen. This will allow adequate rest for the athlete, which should enable him or her to return to a resting state. The sideline assessment will consequently be more comparable to their baseline which increases the likelihood that any postural control deficits noted during the sideline assessment can be attributed to a potential MHI. Regardless of exercise type, the recovery period suggested could be applied to all sports in which athletes participate at high levels of intensity, similar to our exercise protocols.

Limitations

Different sports require different metabolic demands, thus, athletes experience different levels of exertion.[18] In our study, we attempted to isolate the effects of a primarily anaerobic exercise protocol from a primarily aerobic exercise protocol. The aerobic exercise protocol began at a low intensity, and gradually increased as participants successfully made each stage. Eventually, participants had to give a near maximal effort to reach the finish line marker before the beep. Therefore, there was a strong similarity between the ending period of the aerobic exercise protocol and the anaerobic exercise protocol; as participants advanced stages during the aerobic exercise protocol, their intensity was approaching that of a sprint in order to make the beeps. This may have too closely paralleled the effort expended during the anaerobic exercise protocol, thus yielding similar results at the end of each protocol. This may explain why recovery time was same following each exercise. Further, standardizing two fatigue protocols is a difficult task due to so many extraneous variables that can alter how a specific individual views the exercise (psychological state, level of fitness, environmental conditions to name a few).

Another possible limitation of this study was the presence of a learning effect from baseline to post fatigue following the anaerobic exercise protocol. Participants' mean BESS scores, elliptical sway areas, and sway velocities were all lower at recovery interval 18 when compared to baseline. We tried to control for a learning effect by giving subjects 2 practice trials prior to their baseline; however, each participant performed seven total BESS trials during the first session, and another four during the second session (within seven days). So many trials in such a short period of time may have contributed to improved scores following the shorter duration, anaerobic exercise protocol. A learning effect has been demonstrated in control groups [9, 30], but further research is needed to specifically examine the learning effects following exercise. Another reasonable explanation for this trend may also be attributed to sampling error.

Future Research

Future investigators should examine the recovery rate from exercise with specific teams, and possibly take it one step further into looking at specific positions in sport. It is irrational to think that a wide receiver is fatigued similar to a soccer player, or a track and field sprinter to a lacrosse player. This study attempted to differentiate between strictly anaerobic and strictly aerobic exercise, but more research is needed. Comparing multiple aerobic exercise protocols against multiple anaerobic exercise protocols, and at different recovery time intervals may also lead to a regression model being used to help predict recovery time following exercise. Other research should also evaluate the effects of fatigue and its recovery rate on other MHI tools, such as Standardized Assessment of Concussion forms and Graded Symptoms Checklist forms.

Future research should also focus on how local fatigue of the lower extremity stabilizing musculature effect fatigue using the BESS as their postural control assessment. Sideline BESS testing athletes during practice at different intervals may also provide important, relevant research into the effects of fatigue on postural control.

CONCLUSION

In a participant pool of collegiate athletes, postural control was affected by anaerobic and aerobic exercise protocols as measured by total BESS score, elliptical sway area, and sway velocity. Of further importance, the effect of fatigue seems to remain present until thirteen minutes following both aerobic and anaerobic exercise. At this time, the athlete’s postural control returned to baseline. Athletic trainers and clinicians should be aware of these effects and their recovery time course when determining an appropriate time to administer sideline assessments of postural control following a suspected MHI.

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Table 1: Pre Assessment Guidelines

1. Participants should make sure to drink plenty of fluids and stay properly hydrated in the days leading up to testing.

2. Participants should not participate in any extra conditioning or weight training exercises the day prior to testing.

3. Participants should avoid excessive caffeine as well as any alcoholic beverage the day prior to testing.

4. Participants should not practice any extra balancing exercises prior to testing.

Table 2: Borg Rating of Perceived Exertion Scale

6 - no exertion at all

7 - extremely light

8

9 - very light

10

11 - fairly light

12

13 - somewhat hard

14

15 – hard (heavy)

16

17 - very hard

18

19 - extremely hard

20 – absolute maximal exertion

Table 3: Descriptive Statistics for all participants (n = 36)

Team	N	Age (yrs)	Height (cm)	Mass (kg)
Men's Lacrosse.	6	18.67 (0.82)	183.83 (5.85)	79.32 (6.25)
Women's Lacrosse.	6	18.83 (0.75)	166.33 (8.61)	64.92 (11.25)
Men's Soccer	6	18.83 (0.75)	183.17 (5.04)	85. 83 (6.77)
Women's Soccer	6	19.00 (0.89)	162.50 (5.58)	57.35 (5.30)
Men's Wrestling	6	19.33 (1.03)	176.67 (8.98)	76.44 (12.15)
Women's Field Hockey	6	19.50 (1.64)	166.33 (5.35)	61.06 (5.04)
Totals	36	19.00 (1.01)	172.44 (10.47)	69.72 (12.84)

Table 4: Exercise protocol data used for statistical analyses (means (SD))

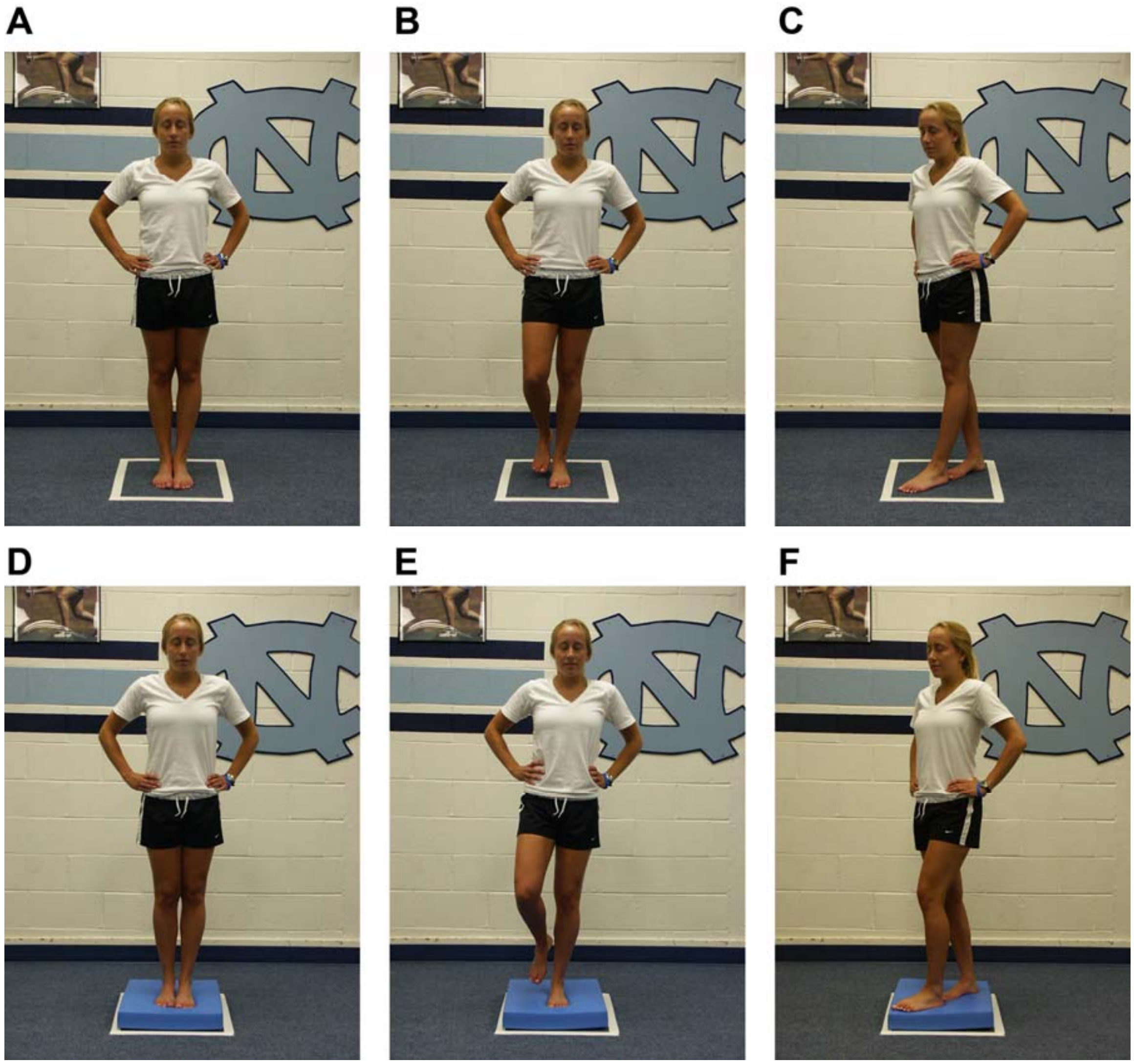
	Baseline	3 minutes	8 minutes	13 minutes	18 minutes	Time Main Effect	Protocol x Time Effect
Elliptical Sway Area							
Anaerobic	49.14 (17.56)	72.82 (31.98)*	62.46 (30.89)	56.54 (21.69)	47.80 (22.18)	$F_{(4,140)}$ = 11.93 P < 0.001*	$F_{(2.535, 88.742)}$ = 0.79 P = 0.485
Aerobic		80.10 (28.23)*	61.82 (27.44)	55.25 (21.84)	51.70 (22.29)	$F_{(3.493, 140)}$ = 15.55 P < 0.001*	
Sway Velocity							
Anaerobic	8.15 (2.06)	9.47 (2.61)*	9.00 (2.85)	8.47 (2.43)	7.89 (2.17)	$F_{(3.110,140)}$ = 11.95 P < 0.001*	$F_{(2.525,88.368)}$ = 1.91 P = 0.143
Aerobic		10.18 (2.41)*	9.06 (2.59)*	8.39 (2.30)	8.11 (2.28)	$F_{(4,140)}$ = 35.69 P < 0.001*	
Total BESS Score							
Anaerobic	4.89 (2.29)	8.08 (3.10)*	6.33 (2.75)*	5.89 (2.20)	4.69 (2.18)	$F_{(4,140)}$ = 24.16 P < 0.001*	$F_{(3,105)}$ = 5.44 P = 0.002+
Aerobic		10.03 (3.19)*	7.33 (3.14)*	5.53 (2.40)	5.14 (2.70)	$F_{(4,140)}$ = 56.68 P< 0.001*	

Baseline measures are the same for both aerobic and anaerobic exercise protocols because baseline was assessed during the first session only.

* Significant difference from baseline
+ Significant difference between exercise protocols at 3 minutes post exercise

Legend of Figures

FIGURE 1



Errors

- Hands lifted off iliac crests
- Opening eyes
- Step, stumble, or fall
- Moving hip into more than 30° of flexion or abduction
- Lifting forefoot or heel
- Remaining out of testing position for more than 5 seconds

BESS score calculated by adding 1 error point for each error committed.

FIGURE 2

Repeated 2x20-meter runs back and forth between the starting, turning, and finish line at progressively increased speeds controlled by audio beeps. A 10 second active recovery takes place following each run.

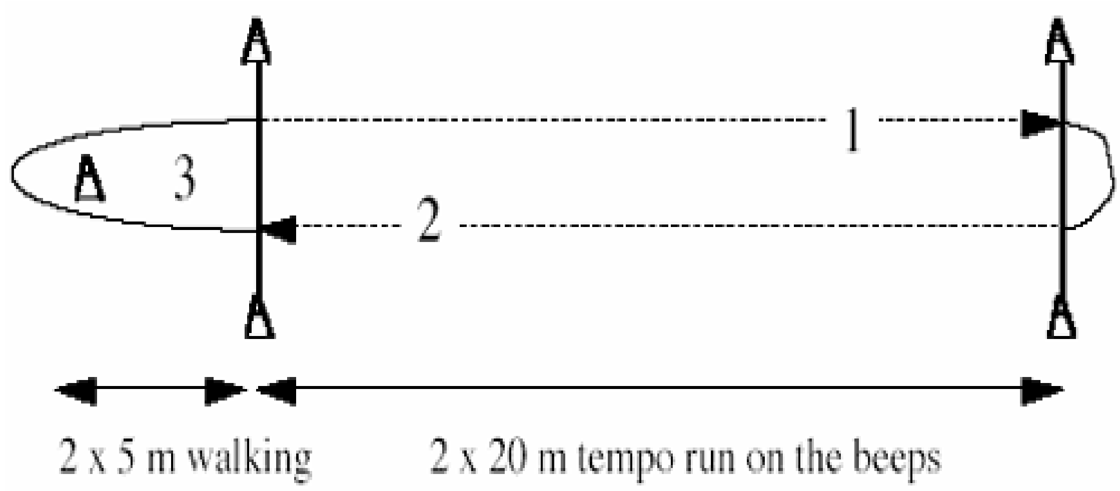
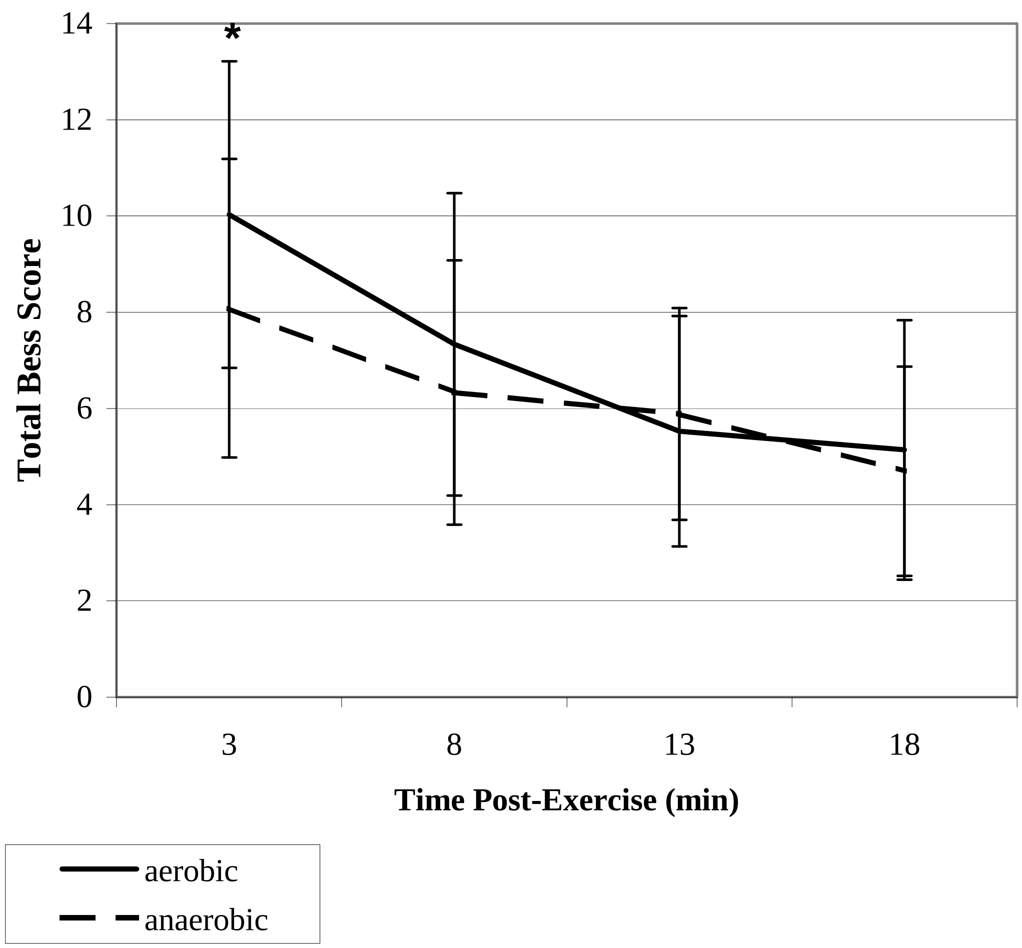


FIGURE 3



* **Significantly different between protocols at recovery time interval 3.**

APPENDIX B:

IRB Consent Form

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Participants
Social Behavioral Form

IRB Study # 06-0424
Consent Form Version Date: 9/1/2006

Title of Study: The Effect of Aerobic and Anaerobic Exertion Protocols on Postural Control

Principal Investigator: Zachary Fox LAT,ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 919-962-7187
Email Address: zfoxatc@email.unc.edu
Co-Investigators: Kevin M. Guskiewicz, PhD, ATC
Jason P. Mihalik, MS, CAT(C), ATC
Claudio L. Battaglini, PhD
J. Troy Blackburn, PhD, ATC

Faculty Advisor: Kevin M. Guskiewicz, PhD, ATC
Study Contact telephone number: 619-701-096
Study Contact email: zfoxatc@email.unc.edu

<u>What are some general things you should know about research studies?</u>

You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above any questions you have about this study at any time.

<u>What is the purpose of this study?</u>

The purpose of this research study is to learn about the effects of an anaerobic and aerobic fatigue protocol on postural control in healthy college-aged athletes. A secondary purpose of this study will be to establish a recovery time course from each fatigue protocol in which postural control returns to baseline measures.

The Balance Error Scoring System (BESS) is a clinical test that athletic trainers use to determine postural control following a mild head injury. Scores are obtained at rest during pre-physical examinations at the beginning of the season. These scores are used as a baseline to compare the scores taken following a sustained head injury. We still do not know the effects of fatigue on the BESS and need to understand better the recovery time course for postural control measures to return to baseline following fatigue.

You are being asked to be in the study because you are a NCAA Division I athlete between the ages of 18-25 years who participates in a high contact sport in which the incidence of mild head injuries are greater than those sports that are low contact.

Are there any reasons you should not be in this study?

You should not be in this study if you have any pre-existing lower extremity injuries that may put you at further risk of injury, have a known visual, vestibular, or balance disorder, or sustained a mild head injury within the last three months. Additionally, if you have undergone balance testing in the last three months or have a learning disability, you will be excluded from this study.

How many people will take part in this study?

If you decide to be in this study, you will be one of approximately 30 people in this research study.

How long will your part in this study last?

You will be required to meet on two separate occasions, both being 3-7 days apart from one another. The first session will include an orientation and baseline measures of postural control, followed by one of the exercise protocols. This session will last approximately 70 minutes. The second session will include the opposing exercise protocol and will last approximately 45 minutes.

What will happen if you take part in the study?

If you agree to take part in this study, you will report to the Motor Control Research Laboratory located on the second floor of Fetzer Gymnasium (Room 123) for the first of two testing sessions. When you arrive, a brief orientation of the research study will be given and baseline BESS scores and forceplate measures will be obtained. The BESS is a series of 6 different balance tasks and will be performed while on a forceplate. Standing on a forceplate is no different than standing on a hard surface (i.e., floor). These 6 tasks will be performed one time each in the following order: double leg stance on a stable surface, single leg stance on a stable surface, tandem stance on a stable surface, double leg stance on a foam surface, single leg stance on a foam surface, tandem stance on a foam surface. Each task will be performed for 20 seconds, with a 15 second rest period between tasks. You will repeat the BESS test procedure three separate times, and your third-trial score will be determined as your baseline. The reason for repeated testing trails is to limit a learning effect from occurring in subsequent trials.

Following the first session, you will report back to the Motor Control Research Laboratory within 3-7 days to perform the alternate exercise protocol. Participants will be counterbalanced in the order of aerobic/anaerobic protocols for the purpose of neutralizing learning effects between test order. An explanation of the testing procedure as well as a video of the exercise protocol will be given. The exercise protocols will take place in Fetzer Gymnasiums. You will be required to wear shorts, a t-shirt, and athletic tennis shoes while performing the protocol. Before the exercise protocol, you will carry out a warm-up and stretching period consisting of the first four running intervals followed by a standardized low back and lower extremity stretching program. Upon completion of the exercise protocol, you will be escorted back to the Motor Control Research Lab where you will begin the BESS test. There will be three minutes between the end of the protocol and the first BESS testing. You will then be tested at eight minutes, thirteen minutes, and eighteen minutes post exertion in order to establish a recovery timeline. Heart rate and RPE will be recorded at each testing interval.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You may also expect to benefit by participating in this study by gaining a better idea of how well your balance is and by how much your balance may be altered by the effects of fatigue

What are the possible risks or discomforts involved from being in this study?

When performing the balance tasks for the BESS, there is a minimal risk that you may lose your balance and have to catch yourself to avoid stumbling or falling. There is also a minimal possibility of feeling some delayed onset muscle soreness (DOMS) following the exertion protocol: this muscle soreness is what athletes experience when they work out for the first time in a long time. This soreness usually resolves between 24-48 hours and does not affect your activities of daily living.

How will your privacy be protected?

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

Measures will be taken to ensure that your privacy is maintained. Standard protocol will be used with the video tapes in order to protect the privacy of the participants. Following each lab session, all records and all the video tapes will be stored in a locked filing cabinet in the Motor Control Research Laboratory. Only the primary and co-investigators will have access to these tapes. The door to the Motor Control Research Laboratory will remain locked at all times when not in use. After transcription, the tapes will remain locked in the filing cabinet for three years

What will happen if you are injured by this research?

All research involves a chance that something bad may happen to you. This includes the risk of personal injury. In spite of all safety measures being taken during this research study, the possibility for injury remains. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?

There will be no costs for being in the study

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

____ ________________

Signature of Research Participant Date

____

Printed Name of Research Participant

____ ________________

Signature of Person Obtaining Consent Date

____

Printed Name of Person Obtaining Consent

APPENDIX C:
SPSS Statistical Output

RQ:2 BESS AEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	BESS_BL
2	BESS_AER_T3
3	BESS_AER_T8
4	BESS_AER_T13
5	BESS_AER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
BESS_BL	4.8889	2.29008	36
BESS_AER_T3	10.0278	3.18466	36
BESS_AER_T8	7.3333	3.14416	36
BESS_AER_T13	5.5278	2.39626	36
BESS_AER_T18	5.1389	2.69553	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.820	6.644	9	.675

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.915	1.000	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	665.944	4	166.486	56.675
	Greenhouse-Geisser	665.944	3.660	181.940	56.675
	Huynh-Feldt	665.944	4.000	166.486	56.675
	Lower-bound	665.944	1.000	665.944	56.675
Error(time)	Sphericity Assumed	411.256	140	2.938	
	Greenhouse-Geisser	411.256	128.108	3.210	
	Huynh-Feldt	411.256	140.000	2.938	
	Lower-bound	411.256	35.000	11.750	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.618	226.701	1.000
	Greenhouse-Geisser	.000	.618	207.445	1.000
	Huynh-Feldt	.000	.618	226.701	1.000
	Lower-bound	.000	.618	56.675	1.000
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	4.889	.382	4.114	5.664
2	10.028	.531	8.950	11.105
3	7.333	.524	6.270	8.397
4	5.528	.399	4.717	6.339
5	5.139	.449	4.227	6.051

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-5.139*	.437	.000	-6.447	-3.830
	3	-2.444*	.415	.000	-3.687	-1.201
	4	-.639	.352	.783	-1.694	.416
	5	-.250	.353	1.000	-1.307	.807
2	1	5.139*	.437	.000	3.830	6.447
	3	2.694*	.456	.000	1.329	4.060
	4	4.500*	.399	.000	3.303	5.697
	5	4.889*	.419	.000	3.633	6.145
3	1	2.444*	.415	.000	1.201	3.687
	2	-2.694*	.456	.000	-4.060	-1.329
	4	1.806*	.438	.002	.494	3.118
	5	2.194*	.425	.000	.921	3.468
4	1	.639	.352	.783	-.416	1.694
	2	-4.500*	.399	.000	-5.697	-3.303
	3	-1.806*	.438	.002	-3.118	-.494
	5	.389	.324	1.000	-.583	1.361
5	1	.250	.353	1.000	-.807	1.307
	2	-4.889*	.419	.000	-6.145	-3.633
	3	-2.194*	.425	.000	-3.468	-.921
	4	-.389	.324	1.000	-1.361	.583

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.837	40.937[b]	4.000	32.000	.000
Wilks' lambda	.163	40.937[b]	4.000	32.000	.000
Hotelling's trace	5.117	40.937[b]	4.000	32.000	.000
Roy's largest root	5.117	40.937[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.837	163.748	1.000
Wilks' lambda	.837	163.748	1.000
Hotelling's trace	.837	163.748	1.000
Roy's largest root	.837	163.748	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 1: BESS ANAEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	BESS_BL
2	BESS_ ANAER_T3
3	BESS_ ANAER_T8
4	BESS_ ANAER_T13
5	BESS_ ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
BESS_BL	4.8889	2.29008	36
BESS_ANAER_T3	8.0833	3.10184	36
BESS_ANAER_T8	6.3333	2.74643	36
BESS_ANAER_T13	5.8889	2.20101	36
BESS_ANAER_T18	4.6944	2.17544	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.698	12.010	9	.213

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse -Geisser	Huynh-Feldt	Lower-bound
time	.827	.923	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	266.411	4	66.603	24.157
	Greenhouse-Geisser	266.411	3.307	80.568	24.157
	Huynh-Feldt	266.411	3.693	72.141	24.157
	Lower-bound	266.411	1.000	266.411	24.157
Error(time)	Sphericity Assumed	385.989	140	2.757	
	Greenhouse-Geisser	385.989	115.734	3.335	
	Huynh-Feldt	385.989	129.252	2.986	
	Lower-bound	385.989	35.000	11.028	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.408	96.629	1.000
	Greenhouse-Geisser	.000	.408	79.880	1.000
	Huynh-Feldt	.000	.408	89.210	1.000
	Lower-bound	.000	.408	24.157	.998
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	4.889	.382	4.114	5.664
2	8.083	.517	7.034	9.133
3	6.333	.458	5.404	7.263
4	5.889	.367	5.144	6.634
5	4.694	.363	3.958	5.431

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-3.194*	.504	.000	-4.703	-1.685
	3	-1.444*	.428	.018	-2.727	-.162
	4	-1.000	.378	.121	-2.132	.132
	5	.194	.365	1.000	-.898	1.287
2	1	3.194*	.504	.000	1.685	4.703
	3	1.750*	.357	.000	.680	2.820
	4	2.194*	.380	.000	1.057	3.332
	5	3.389*	.407	.000	2.170	4.608
3	1	1.444*	.428	.018	.162	2.727
	2	-1.750*	.357	.000	-2.820	-.680
	4	.444	.353	1.000	-.613	1.502
	5	1.639*	.393	.002	.462	2.815
4	1	1.000	.378	.121	-.132	2.132
	2	-2.194*	.380	.000	-3.332	-1.057
	3	-.444	.353	1.000	-1.502	.613
	5	1.194*	.321	.007	.233	2.155
5	1	-.194	.365	1.000	-1.287	.898
	2	-3.389*	.407	.000	-4.608	-2.170
	3	-1.639*	.393	.002	-2.815	-.462
	4	-1.194*	.321	.007	-2.155	-.233

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.669	16.156[b]	4.000	32.000	.000
Wilks' lambda	.331	16.156[b]	4.000	32.000	.000
Hotelling's trace	2.020	16.156[b]	4.000	32.000	.000
Roy's largest root	2.020	16.156[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.669	64.625	1.000
Wilks' lambda	.669	64.625	1.000
Hotelling's trace	.669	64.625	1.000
Roy's largest root	.669	64.625	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 2: ELLIPSE AREA AEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	EA_AVG_BL
2	EA_AVG_AER_T3
3	EA_AVG_AER_T8
4	EA_AVG_AER_T13
5	EA_AVG_AER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
EA_AVG_BL	49.1433	17.56245	36
EA_AVG_AER_T3	80.1018	28.22888	36
EA_AVG_AER_T8	61.8152	27.44424	36
EA_AVG_AER_T13	55.2455	21.83856	36
EA_AVG_AER_T18	51.6974	22.29299	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.577	18.380	9	.031

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse -Geisser	Huynh-Feldt	Lower-bound
time	.787	.873	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	22175.509	4	5543.877	15.546
	Greenhouse-Geisser	22175.509	3.146	7048.326	15.546
	Huynh-Feldt	22175.509	3.493	6348.657	15.546
	Lower-bound	22175.509	1.000	22175.509	15.546
Error(time)	Sphericity Assumed	49926.503	140	356.618	
	Greenhouse-Geisser	49926.503	110.117	453.394	
	Huynh-Feldt	49926.503	122.253	408.387	
	Lower-bound	49926.503	35.000	1426.472	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.308	62.183	1.000
	Greenhouse-Geisser	.000	.308	48.910	1.000
	Huynh-Feldt	.000	.308	54.300	1.000
	Lower-bound	.000	.308	15.546	.969
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	49.143	2.927	43.201	55.086
2	80.102	4.705	70.550	89.653
3	61.815	4.574	52.529	71.101
4	55.245	3.640	47.856	62.635
5	51.697	3.715	44.155	59.240

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-30.958*	4.438	.000	-44.254	-17.663
	3	-12.672	4.895	.139	-27.337	1.993
	4	-6.102	4.065	1.000	-18.280	6.076
	5	-2.554	3.282	1.000	-12.386	7.278
2	1	30.958*	4.438	.000	17.663	44.254
	3	18.287*	5.842	.035	.784	35.789
	4	24.856*	4.175	.000	12.349	37.364
	5	28.404*	4.573	.000	14.705	42.104
3	1	12.672	4.895	.139	-1.993	27.337
	2	-18.287*	5.842	.035	-35.789	-.784
	4	6.570	5.121	1.000	-8.774	21.913
	5	10.118	4.018	.165	-1.919	22.155
4	1	6.102	4.065	1.000	-6.076	18.280
	2	-24.856*	4.175	.000	-37.364	-12.349
	3	-6.570	5.121	1.000	-21.913	8.774
	5	3.548	3.514	1.000	-6.980	14.076
5	1	2.554	3.282	1.000	-7.278	12.386
	2	-28.404*	4.573	.000	-42.104	-14.705
	3	-10.118	4.018	.165	-22.155	1.919
	4	-3.548	3.514	1.000	-14.076	6.980

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.635	13.942[b]	4.000	32.000	.000
Wilks' lambda	.365	13.942[b]	4.000	32.000	.000
Hotelling's trace	1.743	13.942[b]	4.000	32.000	.000
Roy's largest root	1.743	13.942[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.635	55.769	1.000
Wilks' lambda	.635	55.769	1.000
Hotelling's trace	.635	55.769	1.000
Roy's largest root	.635	55.769	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 1: ELLIPSE AREA ANAEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	EA_AVG_BL
2	EA_AVG_ANAER_T3
3	EA_AVG_ANAER_T8
4	EA_AVG_ANAER_T13
5	EA_AVG_ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
EA_AVG_BL	49.1433	17.56245	36
EA_AVG_ANAER_T3	72.8240	31.97710	36
EA_AVG_ANAER_T8	62.4551	30.88725	36
EA_AVG_ANAER_T13	56.5385	21.68732	36
EA_AVG_ANAER_T18	47.8025	22.17562	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.620	15.994	9	.067

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

	Epsilon[a]		
Within Subjects Effect	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.826	.922	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	15258.954	4	3814.738	11.927
	Greenhouse-Geisser	15258.954	3.303	4619.443	11.927
	Huynh-Feldt	15258.954	3.689	4136.841	11.927
	Lower-bound	15258.954	1.000	15258.954	11.927
Error(time)	Sphericity Assumed	44778.741	140	319.848	
	Greenhouse-Geisser	44778.741	115.612	387.319	
	Huynh-Feldt	44778.741	129.099	346.855	
	Lower-bound	44778.741	35.000	1279.393	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.254	47.707	1.000
	Greenhouse-Geisser	.000	.254	39.396	1.000
	Huynh-Feldt	.000	.254	43.992	1.000
	Lower-bound	.001	.254	11.927	.919
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	49.143	2.927	43.201	55.086
2	72.824	5.330	62.004	83.643
3	62.455	5.148	52.004	72.906
4	56.538	3.615	49.201	63.876
5	47.802	3.696	40.299	55.306

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-23.681*	4.647	.000	-37.602	-9.759
	3	-13.312	4.900	.102	-27.993	1.369
	4	-7.395	3.591	.470	-18.154	3.363
	5	1.341	3.574	1.000	-9.368	12.050
2	1	23.681*	4.647	.000	9.759	37.602
	3	10.369	4.592	.303	-3.390	24.128
	4	16.285*	4.863	.020	1.714	30.857
	5	25.022*	4.550	.000	11.389	38.654
3	1	13.312	4.900	.102	-1.369	27.993
	2	-10.369	4.592	.303	-24.128	3.390
	4	5.917	4.255	1.000	-6.831	18.665
	5	14.653*	3.522	.002	4.100	25.205
4	1	7.395	3.591	.470	-3.363	18.154
	2	-16.285*	4.863	.020	-30.857	-1.714
	3	-5.917	4.255	1.000	-18.665	6.831
	5	8.736	3.235	.106	-.955	18.427
5	1	-1.341	3.574	1.000	-12.050	9.368
	2	-25.022*	4.550	.000	-38.654	-11.389
	3	-14.653*	3.522	.002	-25.205	-4.100
	4	-8.736	3.235	.106	-18.427	.955

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.540	9.405[b]	4.000	32.000	.000
Wilks' lambda	.460	9.405[b]	4.000	32.000	.000
Hotelling's trace	1.176	9.405[b]	4.000	32.000	.000
Roy's largest root	1.176	9.405[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.540	37.621	.998
Wilks' lambda	.540	37.621	.998
Hotelling's trace	.540	37.621	.998
Roy's largest root	.540	37.621	.998

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 2: SWAY VELOCITY AEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	SV_AVG_BL
2	SV_AVG_AER_T3
3	SV_AVG_AER_T8
4	SV_AVG_AER_T13
5	SV_AVG_AER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
SV_AVG_BL	8.1471	2.07514	36
SV_AVG_AER_T3	10.1773	2.41094	36
SV_AVG_AER_T8	9.0645	2.58791	36
SV_AVG_AER_T13	8.3892	2.29703	36
SV_AVG_AER_T18	8.1118	2.28500	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.624	15.748	9	.073

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse -Geisser	Huynh-Feldt	Lower-bound
time	.822	.918	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	109.198	4	27.300	35.692
	Greenhouse-Geisser	109.198	3.289	33.197	35.692
	Huynh-Feldt	109.198	3.671	29.744	35.692
	Lower-bound	109.198	1.000	109.198	35.692
Error(time)	Sphericity Assumed	107.081	140	.765	
	Greenhouse-Geisser	107.081	115.128	.930	
	Huynh-Feldt	107.081	128.493	.833	
	Lower-bound	107.081	35.000	3.059	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.505	142.768	1.000
	Greenhouse-Geisser	.000	.505	117.404	1.000
	Huynh-Feldt	.000	.505	131.033	1.000
	Lower-bound	.000	.505	35.692	1.000
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	8.147	.346	7.445	8.849
2	10.177	.402	9.362	10.993
3	9.064	.431	8.189	9.940
4	8.389	.383	7.612	9.166
5	8.112	.381	7.339	8.885

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.030*	.222	.000	-2.696	-1.365
	3	-.917*	.237	.004	-1.626	-.209
	4	-.242	.205	1.000	-.856	.372
	5	.035	.173	1.000	-.482	.552
2	1	2.030*	.222	.000	1.365	2.696
	3	1.113*	.252	.001	.359	1.867
	4	1.788*	.230	.000	1.099	2.478
	5	2.066*	.214	.000	1.425	2.706
3	1	.917*	.237	.004	.209	1.626
	2	-1.113*	.252	.001	-1.867	-.359
	4	.675*	.183	.008	.127	1.223
	5	.953*	.166	.000	.456	1.450
4	1	.242	.205	1.000	-.372	.856
	2	-1.788*	.230	.000	-2.478	-1.099
	3	-.675*	.183	.008	-1.223	-.127
	5	.277	.157	.862	-.193	.748
5	1	-.035	.173	1.000	-.552	.482
	2	-2.066*	.214	.000	-2.706	-1.425
	3	-.953*	.166	.000	-1.450	-.456
	4	-.277	.157	.862	-.748	.193

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.785	29.142[b]	4.000	32.000	.000
Wilks' lambda	.215	29.142[b]	4.000	32.000	.000
Hotelling's trace	3.643	29.142[b]	4.000	32.000	.000
Roy's largest root	3.643	29.142[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.785	116.569	1.000
Wilks' lambda	.785	116.569	1.000
Hotelling's trace	.785	116.569	1.000
Roy's largest root	.785	116.569	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 1: SWAY VELOCITY ANAEROBIC

Within-Subjects Factors

Measure: MEASURE_1

time	Dependent Variable
1	SV_AVG_BL
2	SV_AVG_ANAER_T3
3	SV_AVG_ANAER_T8
4	SV_AVG_ANAER_T13
5	SV_AVG_ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
SV_AVG_BL	8.1471	2.07514	36
SV_AVG_ANAER_T3	9.4707	2.60893	36
SV_AVG_ANAER_T8	9.0025	2.84527	36
SV_AVG_ANAER_T13	8.4652	2.42820	36
SV_AVG_ANAER_T18	7.8912	2.17836	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
time	.391	31.389	9	.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse -Geisser	Huynh-Feldt	Lower-bound
time	.709	.778	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
time	Sphericity Assumed	59.244	4	14.811	11.947
	Greenhouse-Geisser	59.244	2.834	20.902	11.947
	Huynh-Feldt	59.244	3.110	19.049	11.947
	Lower-bound	59.244	1.000	59.244	11.947
Error(time)	Sphericity Assumed	173.567	140	1.240	
	Greenhouse-Geisser	173.567	99.204	1.750	
	Huynh-Feldt	173.567	108.854	1.595	
	Lower-bound	173.567	35.000	4.959	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
time	Sphericity Assumed	.000	.254	47.786	1.000
	Greenhouse-Geisser	.000	.254	33.861	.999
	Huynh-Feldt	.000	.254	37.155	1.000
	Lower-bound	.001	.254	11.947	.919
Error(time)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

a. Computed using alpha = .05

Estimated Marginal Means

time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	8.147	.346	7.445	8.849
2	9.471	.435	8.588	10.353
3	9.002	.474	8.040	9.965
4	8.465	.405	7.644	9.287
5	7.891	.363	7.154	8.628

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.324*	.259	.000	-2.099	-.548
	3	-.855	.299	.071	-1.752	.041
	4	-.318	.203	1.000	-.925	.289
	5	.256	.165	1.000	-.238	.750
2	1	1.324*	.259	.000	.548	2.099
	3	.468	.335	1.000	-.534	1.470
	4	1.005*	.255	.004	.240	1.771
	5	1.580*	.248	.000	.836	2.323
3	1	.855	.299	.071	-.041	1.752
	2	-.468	.335	1.000	-1.470	.534
	4	.537	.342	1.000	-.486	1.561
	5	1.111*	.284	.004	.259	1.963
4	1	.318	.203	1.000	-.289	.925
	2	-1.005*	.255	.004	-1.771	-.240
	3	-.537	.342	1.000	-1.561	.486
	5	.574*	.166	.014	.077	1.072
5	1	-.256	.165	1.000	-.750	.238
	2	-1.580*	.248	.000	-2.323	-.836
	3	-1.111*	.284	.004	-1.963	-.259
	4	-.574*	.166	.014	-1.072	-.077

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.601	12.061[b]	4.000	32.000	.000
Wilks' lambda	.399	12.061[b]	4.000	32.000	.000
Hotelling's trace	1.508	12.061[b]	4.000	32.000	.000
Roy's largest root	1.508	12.061[b]	4.000	32.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.601	48.242	1.000
Wilks' lambda	.601	48.242	1.000
Hotelling's trace	.601	48.242	1.000
Roy's largest root	.601	48.242	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

RQ 3: 2x4 RM ANOVA using BESS

Within-Subjects Factors

Measure: MEASURE_1

protocol	time	Dependent Variable
1	1	BESS_AER_T3
	2	BESS_AER_T8
	3	BESS_AER_T13
	4	BESS_AER_T18
2	1	BESS_ANAER_T3
	2	BESS_ANAER_T8
	3	BESS_ANAER_T13
	4	BESS_ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
BESS_AER_T3	10.0278	3.18466	36
BESS_AER_T8	7.3333	3.14416	36
BESS_AER_T13	5.5278	2.39626	36
BESS_AER_T18	5.1389	2.69553	36
BESS_ANAER_T3	8.0833	3.10184	36
BESS_ANAER_T8	6.3333	2.74643	36
BESS_ANAER_T13	5.8889	2.20101	36
BESS_ANAER_T18	4.6944	2.17544	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
protocol	1.000	.000	0	.
time	.549	20.233	5	.001
protocol * time	.763	9.119	5	.105

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
protocol	1.000	1.000	1.000
time	.767	.824	.333
protocol * time	.845	.916	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: protocol+time+protocol*time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
protocol	Sphericity Assumed	41.253	1	41.253
	Greenhouse-Geisser	41.253	1.000	41.253
	Huynh-Feldt	41.253	1.000	41.253
	Lower-bound	41.253	1.000	41.253
Error(protocol)	Sphericity Assumed	241.122	35	6.889
	Greenhouse-Geisser	241.122	35.000	6.889
	Huynh-Feldt	241.122	35.000	6.889
	Lower-bound	241.122	35.000	6.889
time	Sphericity Assumed	699.094	3	233.031
	Greenhouse-Geisser	699.094	2.300	303.990
	Huynh-Feldt	699.094	2.471	282.962
	Lower-bound	699.094	1.000	699.094
Error(time)	Sphericity Assumed	253.031	105	2.410
	Greenhouse-Geisser	253.031	80.491	3.144
	Huynh-Feldt	253.031	86.472	2.926
	Lower-bound	253.031	35.000	7.229
protocol * time	Sphericity Assumed	50.705	3	16.902
	Greenhouse-Geisser	50.705	2.535	20.004
	Huynh-Feldt	50.705	2.749	18.444
	Lower-bound	50.705	1.000	50.705
Error(protocol*time)	Sphericity Assumed	326.420	105	3.109
	Greenhouse-Geisser	326.420	88.717	3.679
	Huynh-Feldt	326.420	96.220	3.392
	Lower-bound	326.420	35.000	9.326

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		F	Sig.	Partial Eta Squared
protocol	Sphericity Assumed	5.988	.020	.146
	Greenhouse-Geisser	5.988	.020	.146
	Huynh-Feldt	5.988	.020	.146
	Lower-bound	5.988	.020	.146
Error(protocol)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
time	Sphericity Assumed	96.701	.000	.734
	Greenhouse-Geisser	96.701	.000	.734
	Huynh-Feldt	96.701	.000	.734
	Lower-bound	96.701	.000	.734
Error(time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
protocol * time	Sphericity Assumed	5.437	.002	.134
	Greenhouse-Geisser	5.437	.003	.134
	Huynh-Feldt	5.437	.002	.134
	Lower-bound	5.437	.026	.134
Error(protocol*time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Noncent. Parameter	Observed Power[a]
protocol	Sphericity Assumed	5.988	.663
	Greenhouse-Geisser	5.988	.663
	Huynh-Feldt	5.988	.663
	Lower-bound	5.988	.663
Error(protocol)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
time	Sphericity Assumed	290.102	1.000
	Greenhouse-Geisser	222.385	1.000
	Huynh-Feldt	238.911	1.000
	Lower-bound	96.701	1.000
Error(time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
protocol * time	Sphericity Assumed	16.310	.930
	Greenhouse-Geisser	13.781	.894
	Huynh-Feldt	14.947	.912
	Lower-bound	5.437	.621
Error(protocol*time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

a. Computed using alpha = .05

Estimated Marginal Means

1. protocol

Estimates

Measure: MEASURE_1

protocol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	7.007	.407	6.181	7.833
2	6.250	.367	5.505	6.995

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	Mean Difference (I-J)	Std. Error	Sig.[a]
1	2	.757*	.309	.020
2	1	-.757*	.309	.020

Based on estimated marginal means

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	.129	1.385
2	1	-1.385	-.129

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.146	5.988[b]	1.000	35.000	.020
Wilks' lambda	.854	5.988[b]	1.000	35.000	.020
Hotelling's trace	.171	5.988[b]	1.000	35.000	.020
Roy's largest root	.171	5.988[b]	1.000	35.000	.020

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.146	5.988	.663
Wilks' lambda	.146	5.988	.663
Hotelling's trace	.146	5.988	.663
Roy's largest root	.146	5.988	.663

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

2. time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	9.056	.472	8.098	10.013
2	6.833	.414	5.993	7.674
3	5.708	.321	5.056	6.361
4	4.917	.328	4.250	5.583

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	2.222*	.265	.000	1.482	2.962
	3	3.347*	.313	.000	2.472	4.222
	4	4.139*	.300	.000	3.300	4.978
2	1	-2.222*	.265	.000	-2.962	-1.482
	3	1.125*	.267	.001	.379	1.871
	4	1.917*	.183	.000	1.405	2.429
3	1	-3.347*	.313	.000	-4.222	-2.472
	2	-1.125*	.267	.001	-1.871	-.379
	4	.792*	.198	.002	.239	1.344
4	1	-4.139*	.300	.000	-4.978	-3.300
	2	-1.917*	.183	.000	-2.429	-1.405
	3	-.792*	.198	.002	-1.344	-.239

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.857	65.958[b]	3.000	33.000	.000
Wilks' lambda	.143	65.958[b]	3.000	33.000	.000
Hotelling's trace	5.996	65.958[b]	3.000	33.000	.000
Roy's largest root	5.996	65.958[b]	3.000	33.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.857	197.874	1.000
Wilks' lambda	.857	197.874	1.000
Hotelling's trace	.857	197.874	1.000
Roy's largest root	.857	197.874	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

3. protocol * time

Measure: MEASURE_1

				95% Confidence Interval	
protocol	time	Mean	Std. Error	Lower Bound	Upper Bound
1	1	10.028	.531	8.950	11.105
	2	7.333	.524	6.270	8.397
	3	5.528	.399	4.717	6.339
	4	5.139	.449	4.227	6.051
2	1	8.083	.517	7.034	9.133
	2	6.333	.458	5.404	7.263
	3	5.889	.367	5.144	6.634
	4	4.694	.363	3.958	5.431

RQ 3: 2X4 RM ANOVA using ELLIPSE AREA

Within-Subjects Factors

Measure: MEASURE_1

protocol	time	Dependent Variable
1	1	EA_AVG_AER_T3
	2	EA_AVG_AER_T8
	3	EA_AVG_AER_T13
	4	EA_AVG_AER_T18
2	1	EA_AVG_ANAER_T3
	2	EA_AVG_ANAER_T8
	3	EA_AVG_ANAER_T13
	4	EA_AVG_ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
EA_AVG_AER_T3	80.1018	28.22888	36
EA_AVG_AER_T8	61.8152	27.44424	36
EA_AVG_AER_T13	55.2455	21.83856	36
EA_AVG_AER_T18	51.6974	22.29299	36
EA_AVG_ANAER_T3	72.8240	31.97710	36
EA_AVG_ANAER_T8	62.4551	30.88725	36
EA_AVG_ANAER_T13	56.5385	21.68732	36
EA_AVG_ANAER_T18	47.8025	22.17562	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
protocol	1.000	.000	0	.
time	.786	8.134	5	.149
protocol * time	.634	15.388	5	.009

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
protocol	1.000	1.000	1.000
time	.868	.944	.333
protocol * time	.785	.845	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: protocol+time+protocol*time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
protocol	Sphericity Assumed	384.184	1	384.184
	Greenhouse-Geisser	384.184	1.000	384.184
	Huynh-Feldt	384.184	1.000	384.184
	Lower-bound	384.184	1.000	384.184
Error(protocol)	Sphericity Assumed	18178.275	35	519.379
	Greenhouse-Geisser	18178.275	35.000	519.379
	Huynh-Feldt	18178.275	35.000	519.379
	Lower-bound	18178.275	35.000	519.379
time	Sphericity Assumed	28298.210	3	9432.737
	Greenhouse-Geisser	28298.210	2.605	10864.473
	Huynh-Feldt	28298.210	2.833	9989.694
	Lower-bound	28298.210	1.000	28298.210
Error(time)	Sphericity Assumed	34505.230	105	328.621
	Greenhouse-Geisser	34505.230	91.163	378.501
	Huynh-Feldt	34505.230	99.146	348.025
	Lower-bound	34505.230	35.000	985.864
protocol * time	Sphericity Assumed	879.742	3	293.247
	Greenhouse-Geisser	879.742	2.355	373.601
	Huynh-Feldt	879.742	2.535	346.972
	Lower-bound	879.742	1.000	879.742
Error(protocol*time)	Sphericity Assumed	39078.723	105	372.178
	Greenhouse-Geisser	39078.723	82.417	474.160
	Huynh-Feldt	39078.723	88.742	440.364
	Lower-bound	39078.723	35.000	1116.535

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		F	Sig.	Partial Eta Squared
protocol	Sphericity Assumed	.740	.396	.021
	Greenhouse-Geisser	.740	.396	.021
	Huynh-Feldt	.740	.396	.021
	Lower-bound	.740	.396	.021
Error(protocol)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
time	Sphericity Assumed	28.704	.000	.451
	Greenhouse-Geisser	28.704	.000	.451
	Huynh-Feldt	28.704	.000	.451
	Lower-bound	28.704	.000	.451
Error(time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
protocol * time	Sphericity Assumed	.788	.503	.022
	Greenhouse-Geisser	.788	.477	.022
	Huynh-Feldt	.788	.485	.022
	Lower-bound	.788	.381	.022
Error(protocol*time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Noncent. Parameter	Observed Power[a]
protocol	Sphericity Assumed	.740	.133
	Greenhouse-Geisser	.740	.133
	Huynh-Feldt	.740	.133
	Lower-bound	.740	.133
Error(protocol)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
time	Sphericity Assumed	86.112	1.000
	Greenhouse-Geisser	74.764	1.000
	Huynh-Feldt	81.311	1.000
	Lower-bound	28.704	.999
Error(time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
protocol * time	Sphericity Assumed	2.364	.215
	Greenhouse-Geisser	1.855	.192
	Huynh-Feldt	1.998	.199
	Lower-bound	.788	.139
Error(protocol*time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

a. Computed using alpha = .05

Estimated Marginal Means

1. protocol

Estimates

Measure: MEASURE_1

protocol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	62.215	3.095	55.932	68.498
2	59.905	3.709	52.376	67.434

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	Mean Difference (I-J)	Std. Error	Sig.[a]
1	2	2.310	2.686	.396
2	1	-2.310	2.686	.396

Based on estimated marginal means

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-3.143	7.762
2	1	-7.762	3.143

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.021	.740[b]	1.000	35.000	.396
Wilks' lambda	.979	.740[b]	1.000	35.000	.396
Hotelling's trace	.021	.740[b]	1.000	35.000	.396
Roy's largest root	.021	.740[b]	1.000	35.000	.396

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.021	.740	.133
Wilks' lambda	.021	.740	.133
Hotelling's trace	.021	.740	.133
Roy's largest root	.021	.740	.133

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

2. time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	76.463	4.341	67.650	85.276
2	62.135	3.804	54.412	69.858
3	55.892	3.064	49.672	62.112
4	49.750	3.232	43.189	56.311

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	14.328*	3.412	.001	4.785	23.871
	3	20.571*	3.442	.000	10.944	30.197
	4	26.713*	3.279	.000	17.544	35.882
2	1	-14.328*	3.412	.001	-23.871	-4.785
	3	6.243	2.904	.231	-1.877	14.363
	4	12.385*	2.592	.000	5.136	19.634
3	1	-20.571*	3.442	.000	-30.197	-10.944
	2	-6.243	2.904	.231	-14.363	1.877
	4	6.142	2.319	.072	-.344	12.628
4	1	-26.713*	3.279	.000	-35.882	-17.544
	2	-12.385*	2.592	.000	-19.634	-5.136
	3	-6.142	2.319	.072	-12.628	.344

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.669	22.273[b]	3.000	33.000	.000
Wilks' lambda	.331	22.273[b]	3.000	33.000	.000
Hotelling's trace	2.025	22.273[b]	3.000	33.000	.000
Roy's largest root	2.025	22.273[b]	3.000	33.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.669	66.820	1.000
Wilks' lambda	.669	66.820	1.000
Hotelling's trace	.669	66.820	1.000
Roy's largest root	.669	66.820	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

3. protocol * time

Measure: MEASURE_1

protocol	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	80.102	4.705	70.550	89.653
	2	61.815	4.574	52.529	71.101
	3	55.245	3.640	47.856	62.635
	4	51.697	3.715	44.155	59.240
2	1	72.824	5.330	62.004	83.643
	2	62.455	5.148	52.004	72.906
	3	56.538	3.615	49.201	63.876
	4	47.802	3.696	40.299	55.306

RQ 3: 2x4 RM ANOVA using SWAY VELOCITY

Within-Subjects Factors

Measure: MEASURE_1

protocol	time	Dependent Variable
1	1	SV_AVG_AER_T3
	2	SV_AVG_AER_T8
	3	SV_AVG_AER_T13
	4	SV_AVG_AER_T18
2	1	SV_AVG_ANAER_T3
	2	SV_AVG_ANAER_T8
	3	SV_AVG_ANAER_T13
	4	SV_AVG_ANAER_T18

Descriptive Statistics

	Mean	Std. Deviation	N
SV_AVG_AER_T3	10.1773	2.41094	36
SV_AVG_AER_T8	9.0645	2.58791	36
SV_AVG_AER_T13	8.3892	2.29703	36
SV_AVG_AER_T18	8.1118	2.28500	36
SV_AVG_ANAER_T3	9.4707	2.60893	36
SV_AVG_ANAER_T8	9.0025	2.84527	36
SV_AVG_ANAER_T13	8.4652	2.42820	36
SV_AVG_ANAER_T18	7.8912	2.17836	36

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
protocol	1.000	.000	0	.
time	.701	11.979	5	.035
protocol * time	.553	20.002	5	.001

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
protocol	1.000	1.000	1.000
time	.844	.915	.333
protocol * time	.782	.842	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: protocol+time+protocol*time

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
protocol	Sphericity Assumed	3.753	1	3.753
	Greenhouse-Geisser	3.753	1.000	3.753
	Huynh-Feldt	3.753	1.000	3.753
	Lower-bound	3.753	1.000	3.753
Error(protocol)	Sphericity Assumed	96.943	35	2.770
	Greenhouse-Geisser	96.943	35.000	2.770
	Huynh-Feldt	96.943	35.000	2.770
	Lower-bound	96.943	35.000	2.770
time	Sphericity Assumed	135.206	3	45.069
	Greenhouse-Geisser	135.206	2.532	53.389
	Huynh-Feldt	135.206	2.746	49.230
	Lower-bound	135.206	1.000	135.206
Error(time)	Sphericity Assumed	109.136	105	1.039
	Greenhouse-Geisser	109.136	88.637	1.231
	Huynh-Feldt	109.136	96.125	1.135
	Lower-bound	109.136	35.000	3.118
protocol * time	Sphericity Assumed	6.285	3	2.095
	Greenhouse-Geisser	6.285	2.346	2.679
	Huynh-Feldt	6.285	2.525	2.489
	Lower-bound	6.285	1.000	6.285
Error(protocol*time)	Sphericity Assumed	115.065	105	1.096
	Greenhouse-Geisser	115.065	82.100	1.402
	Huynh-Feldt	115.065	88.368	1.302
	Lower-bound	115.065	35.000	3.288

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		F	Sig.	Partial Eta Squared
protocol	Sphericity Assumed	1.355	.252	.037
	Greenhouse-Geisser	1.355	.252	.037
	Huynh-Feldt	1.355	.252	.037
	Lower-bound	1.355	.252	.037
Error(protocol)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
time	Sphericity Assumed	43.361	.000	.553
	Greenhouse-Geisser	43.361	.000	.553
	Huynh-Feldt	43.361	.000	.553
	Lower-bound	43.361	.000	.553
Error(time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			
protocol * time	Sphericity Assumed	1.912	.132	.052
	Greenhouse-Geisser	1.912	.147	.052
	Huynh-Feldt	1.912	.143	.052
	Lower-bound	1.912	.176	.052
Error(protocol*time)	Sphericity Assumed			
	Greenhouse-Geisser			
	Huynh-Feldt			
	Lower-bound			

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Noncent. Parameter	Observed Power[a]
protocol	Sphericity Assumed	1.355	.205
	Greenhouse-Geisser	1.355	.205
	Huynh-Feldt	1.355	.205
	Lower-bound	1.355	.205
Error(protocol)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
time	Sphericity Assumed	130.082	1.000
	Greenhouse-Geisser	109.810	1.000
	Huynh-Feldt	119.086	1.000
	Lower-bound	43.361	1.000
Error(time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		
protocol * time	Sphericity Assumed	5.735	.482
	Greenhouse-Geisser	4.484	.420
	Huynh-Feldt	4.827	.437
	Lower-bound	1.912	.270
Error(protocol*time)	Sphericity Assumed		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Lower-bound		

a. Computed using alpha = .05

Estimated Marginal Means

1. protocol

Estimates

Measure: MEASURE_1

protocol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	8.936	.380	8.165	9.707
2	8.707	.385	7.925	9.489

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	Mean Difference (I-J)	Std. Error	Sig.[a]
1	2	.228	.196	.252
2	1	-.228	.196	.252

Based on estimated marginal means

Pairwise Comparisons

Measure: MEASURE_1

(I) protocol	(J) protocol	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.170	.627
2	1	-.627	.170

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.037	1.355[b]	1.000	35.000	.252
Wilks' lambda	.963	1.355[b]	1.000	35.000	.252
Hotelling's trace	.039	1.355[b]	1.000	35.000	.252
Roy's largest root	.039	1.355[b]	1.000	35.000	.252

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.037	1.355	.205
Wilks' lambda	.037	1.355	.205
Hotelling's trace	.037	1.355	.205
Roy's largest root	.037	1.355	.205

Each F tests the multivariate effect of protocol. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

2. time

Estimates

Measure: MEASURE_1

time	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	9.824	.388	9.037	10.611
2	9.033	.411	8.200	9.867
3	8.427	.378	7.659	9.195
4	8.001	.358	7.275	8.728

Pairwise Comparisons

Measure: MEASURE_1

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.791*	.198	.002	.237	1.344
	3	1.397*	.173	.000	.914	1.879
	4	1.823*	.155	.000	1.389	2.257
2	1	-.791*	.198	.002	-1.344	-.237
	3	.606*	.199	.027	.049	1.164
	4	1.032*	.156	.000	.595	1.469
3	1	-1.397*	.173	.000	-1.879	-.914
	2	-.606*	.199	.027	-1.164	-.049
	4	.426*	.127	.011	.072	.780
4	1	-1.823*	.155	.000	-2.257	-1.389
	2	-1.032*	.156	.000	-1.469	-.595
	3	-.426*	.127	.011	-.780	-.072

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.818	49.600[b]	3.000	33.000	.000
Wilks' lambda	.182	49.600[b]	3.000	33.000	.000
Hotelling's trace	4.509	49.600[b]	3.000	33.000	.000
Roy's largest root	4.509	49.600[b]	3.000	33.000	.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Multivariate Tests

	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Pillai's trace	.818	148.800	1.000
Wilks' lambda	.818	148.800	1.000
Hotelling's trace	.818	148.800	1.000
Roy's largest root	.818	148.800	1.000

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

b. Exact statistic

3. protocol * time

Measure: MEASURE_1

protocol	time	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	10.177	.402	9.362	10.993
	2	9.064	.431	8.189	9.940
	3	8.389	.383	7.612	9.166
	4	8.112	.381	7.339	8.885
2	1	9.471	.435	8.588	10.353
	2	9.002	.474	8.040	9.965
	3	8.465	.405	7.644	9.287
	4	7.891	.363	7.154	8.628

HEART RATE Descriptives

Descriptive Statistics

	N	Mean	Std. Deviation
BL_HRaer	36	77.11	10.270
post_I_HRaer	36	191.25	7.595
post_3_HRaer	36	124.08	11.111
post_8_HRaer	36	113.11	12.578
post_13_HRaer	36	107.86	12.248
post_18_HRaer	36	105.61	11.542
BL_HRana	36	77.64	10.232
post_I_HRana	36	180.11	9.483
post_3_HRana	36	114.89	14.330
post_8_HRana	36	104.36	15.601
post_13_HRana	36	102.06	13.548
post_18_HRana	36	100.11	14.471
Valid N (listwise)	36		

RPE Descriptives

Descriptive Statistics

	N	Mean	Std. Deviation
BL_RPEaer	36	6.28	.454
post_I_RPEaer	36	18.25	.874
post_3_RPEaer	36	13.64	1.693
post_8_RPEaer	36	10.89	1.687
post_13_RPEaer	36	9.17	1.682
post_18_RPEaer	36	7.69	1.215
BL_RPEana	36	6.28	.454
post_I_RPEana	36	17.58	1.131
post_3_RPEana	36	12.81	1.818
post_8_RPEana	36	10.31	1.910
post_13_RPEana	36	8.64	1.676
post_18_RPEana	36	7.53	1.230
Valid N (listwise)	36		

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