2006

Comparison of Static Stability (Postural Sway) and Dynamic Stability (TTS) Methods of Measurement

Jamie Rammelsberg

BARRY UNIVERSITY

SCHOOL OF HUMAN PERFORMANCE AND LEISURE SCIENCES

COMPARISON OF STATIC STABILITY (POSTURAL SWAY) AND DYNAMIC STABILITY (TTS) METHODS OF MEASUREMENT

BY

JAMIE RAMMELSBERG ATC/LAT

A thesis submitted to the
Department of Sport and Exercise Science
In partial fulfillment of the
Requirements for the Degree of
Master of Science in
Movement Science
Specialization in Athletic Training

Miami Shores, Florida
2006

Chapter One

Introduction

Statement of Problem

Joint proprioception is generally recognized among certified athletic trainers and therapists as a key component of injury prevention and rehabilitation following an injury.[1-3] Joint proprioception can be measured directly through the use of force plates with time to stabilization (TTS) and postural sway, Biodex machines for joint position sense (JPS), and through the star excursion balance test (SEBT). The SEBT is dynamic in nature, which may help for applicability to the athletic world, but it does not take into consideration participants leg length, height, flexibility, or stiffness of the muscles in the lower extremity. Force plates determine any slight pressure changes on the plantar aspect of the foot as it is moved through different ranges of motion while the body is standing.[4] TTS is a test that involves jumping or stepping down onto the force plate and measuring the time until a stable state is reached.[5-7] While this test is dynamic in nature as are sports, the stable state that one must reach is individual to each participant and a baseline for deficit has yet to be established. Postural sway is a measurement of how far off of the midline a body sways while standing still.[1,8] The use of postural sway and center of pressure measurements has been established as reliable and valid and exact deficits have been determined through the use of this test. Biodex machines can be employed to measure the joint's position awareness in an open and closed kinetic chain environment.[7,9,10] While the Biodex has been shown to find significant results when extreme deficits are present, it would be helpful to find a test that may be more sensitive at finding altered joint stability. Though useful to the rehabilitation of athletes, the use of these methods can be time consuming to the athletes when wanting to get back onto the field for play. Therefore, many certified athletic trainers put the athletes through proprioceptive training along with strength and agility drills, and then release them to play when they can prove that they are functional with the joint of the injury.[11,12] However, it may be possible to determine a quick and effective test which may prevent athletes and patients from going back to activity too soon.

Proprioception of any joint consists of the joint's reaction time, muscular balance, and general positioning awareness so that the body will be able to tell when it is off balance. If the body has a strong proprioceptive base, then one will be able to correct any problems before it falls, an ankle is sprained, or a knee gives out. Time to stabilization, JPS, SEBT, and postural sway all measure different aspects of proprioception following injury which can then be used to determine return to play, and they can also be used prior to the season to determine if there may be a predisposition to injury present within the joint.[13,14] While there are multiple tests to determine the proprioception of a joint of the lower extremity, studies are lacking when it comes to comparing these tests to determine what may be best in finding deficits in the clinical setting for return to play.

Purpose of Study

The purpose of the study was to compare static stability and dynamic stability through measuring postural sway and time to stabilization. While past research shows that both of these methods are able to detect deficits in joint stability and states that time to stabilization may be more sensitive and therefore a better test than postural sway, there is no data to support this conclusion due to a lack of comparison studies.

Hypothesis

Research Hypothesis One: Any amount of deviance from normal postural sway will also show up as a deviance in TTS.

Research Hypothesis Two: There will not be an increase in TTS time without a deviance in postural sway.

Null Hypothesis: There will be no significant correlation between postural sway and TTS.

Operational Definitions

Balance: “involves the integration of muscular, neurological, and biomechanical information” to maintain a stable stance over a base of support.[15]

Dynamic Stability: ability to maintain balance while the body is in motion.

Joint Position Sense (JPS): This is a non-weight bearing test measures variations in joint angle in regards to a testing position.

Postural Sway: Test that measures the amount of movement a person possesses while standing still on one leg with their eyes closed.

Proprioception: ability to determine the position of a joint in space through use of receptors within the muscles, ligaments, and joint capsules.

Star Excursion Balance Test (SEBT): This is a dynamic test that measures how far in various directions one can reach with the contra-lateral foot while balancing on the test limb.

Static Stability: the ability to maintain balance with as little corrections as possible while standing still.

Time to Stabilization (TTS): Test that measures one’s ability to return to a stable state following a jump or step down onto a force plate.

Assumptions

It is to be assumed that the participants were truthful on the questionnaire pertaining to previous and current injuries in regards to the lower limb and head. It was also assumed that the participants would try their best on all tests in the study. It was assumed that the distance between the step and the force plate would be the measured the same for each participant. When running the testing procedures, it was assumed that each participant would be given the same set of instructions on how to perform each test and that they were monitored to ensure proper execution.

Delimitations

Participants were undergraduate, graduate, or faculty and staff at Barry University ages 18 and up. Participants reserved the right to withdraw from the study if they felt uncomfortable, unable to do the tests, or felt as though they might harm themselves.

Limitations

The study did not control for participant’s athletic participation or ability and their exercise levels were not taken into consideration.

Significance

The study will help enable certified athletic trainers and physical therapists to choose a prescreening and return to play test for lower limb stability. By enabling these professions to view comparison tests they may better choose tests that will work for their athletes, patients, and in clinics. Since TTS and postural sway are both recognized as methods for measuring proprioception and deficits while eliminating variables such as height, flexibility, and subject ability, comparison studies between these two measurements may help to shed light on differences between them and to better show the advantages and disadvantages of both tests. With a highly usable and reliable test, predisposition to injury may come to light enabling correction before injury. It may also help to establish a better return to play criteria to be used along with current functional return to play testing that could prevent athletes going back to activity too soon and putting themselves at risk. One example of where this would help is return to play following a lateral ankle sprain. They are one of the most frequent injuries in sports and the recurrence rate may be as high as 60 percent.[12,16] By using quantifiable tests, this reoccurrence may become more preventable.[17] While it is recognized by certified athletic trainers and physical therapists alike that deficits in balance may predispose one to injury, very few put these measurements to use during preseason. It is also a common concern that athletes and patients may be returning to activity too soon thus leading to further injury and reinjury. With including stability tests in preseason screening, this may identify possible predisposition to injury, and also serve as a guideline for return to play. This would then help to put athletes, athletic trainers, and coaches’ minds at ease that a full recovery has taken place.

Chapter Two

Literature Review

Introduction

For many years, athletic trainers and researchers alike have struggled to establish clinical and laboratory orthopedic tests that are reliable and valid.[6] Once tests are established, it provides a baseline for all professions to follow so that documentation is in the same form. There is also a possibility of the tests being used to identify those who may be predisposed to injury, and for return to play guidelines following injury.[13,14] For the lower extremity, many tests exist that are both dynamic and static in nature. A few of these tests include joint position sense, the star excursion balance test, static stance, and time to stabilization.

Research shows that functional joint stability may arise from a relationship between static and dynamic components thus leading to research in both areas.[18,19] Static Balance is any balance that takes place while the body is not in motion. When standing in place, the body naturally is in constant motion. This motion increases when standing on one foot or when their eyes are closed.[1,8,17] Natural motion while standing still includes 12 degrees of sway forward and backward, anterior and posterior, and 16 degrees of sway from side to side, medial and lateral.[20] Any motion above this is considered abnormal and is a deficit in static sway. Measurement of this can be done through three dimensional video analyses looking at the motion that takes place in the participants' hips, knees, and ankles. Measurement can also take place with the use of a force plate which shows the center of pressure as it moves through the base of the foot. This center of pressure relates to the body's ground reaction force in response to the body moving to maintain balance.[21]

Dynamic balance is any balance that takes place while the body is in motion.[21] this happens when keeping balance landing from a jump, staying on ones' feet with when cutting and changing direction, and during abrupt starts and stops. Quantifying dynamic stability can be done using the Star Excursion Balance Test, and Time to Stabilization.[5,6,8] Both of these tests require the participants to perform an additional task along with balancing and thus may be more functional than a static test. While the SEBT measures how far away from the center of gravity one can reach before falling, thus their stability while in motion, the TTS looks at how long it takes one to regain balance following an activity such as a jump or a step down.

When a person is standing upright, their ability to evaluate joint position, movement, and speed are critical factors for maintaining balance.[10,17] If there are deficits in the joint such as joint position sense deficits, muscle strength deficits, delayed peroneal reaction time, balance deficits, altered peroneal nerve function, or decreased dorsiflexion range of motion, than an injury may be more likely to occur.[6,22] It is also stated that loss of stability may be the primary cause of joint injury.[23] The deficits within the joint's movement and position is reliant upon the joint capsule, the ligaments within the joint, and the tendons in the area offering feedback on the joint's pressure and tension.[8] These aspects have been quantified through measures of postural control in both the dynamic and the static conditions.[19,24] One such method is to assess for postural sway. Postural sway is the body's ability to maintain balance over a stable base of support. While there are studies that show postural sway values are sensitive enough to distinguish differences between participants who are injured and who are healthy,[1,7,17] it has also been said that static conditions may fail to show postural control deficits due to the ease of the test.[8,25] Because of this, dynamic measures would be more challenging and possibly more effective for detecting deficits in participants with instability in the lower extremity.[6,26] It is well documented through these static and dynamic tests that athletes who have poor postural stability run an increased risk for sustaining an ankle injury than those who have normal postural stability measurements.[1,8,17,25,27-28] Due to this, finding a sensitive test that is valid and reliable could be used in finding those at risk, and with proper intervention, possibly be prevented. Bracing and taping during research has shown to improve the accuracy of joint position sense, static sway, and dynamic postural control. These were tested on a Biodex for joint position sense, single leg stance for postural sway, and single leg jumping onto a force plate for dynamic testing.[1] A closer look at each of the tests gives further insight as to how each one could be used and the plus and minuses of each.

Joint Position Sense

Ankle sprains result in a decrease in muscle strength, altered or deficient proprioception within the joint, and an increase in laxity. The altered sense of proprioception is stated to be due to damaged mechanoreceptors within the joint.[7] These mechanoreceptors are necessary for properly positioning the foot just before heel strike which is said to be the most common point in gait for ankle sprains.[7] Joint position sense (JPS) testing is one method of quantifying proprioceptive deficits.

Joint position sense is based on the theory that sense of position is mainly signaled by slowly adapting skin receptors and muscle spindles.[10] The threshold of JPS testing is usually less than two degrees. Anything greater than this in results shows a deficit in position sense and possibly a predisposition to recurrent ankle sprains[9] The JPS is tested on a Biodex system which allows for minimal movement at the joint to be measured. The participants are placed in approximately 100 degrees of hip flexion, and 120 degrees of knee flexion. In this position, the ankle can be measured in plantar flexion, dorsiflexion, inversion, and eversion.[7] A testing protocol described by Brown et. al. had the participants close their eyes, then their ankle was passively brought to a test angle at a random speed between two and twenty degrees per second. The position was held for 15 seconds while the participant was told to remember the position of their foot. After the ankle was moved twice to the testing angle at 20 degrees per second, it was then passively moved at 2 degrees per second. The participants had the instruction that when they felt as though their ankle reached the testing angle, they should stop the platform from moving and push the hold button on the machine. This angle was then measured for absolute errors from the testing angle. Each participant went through three test trials and test angles were taken at 10 percent and 90 percent of the participant’s range of motion to account for differences in flexibility.[7] While the injured ankle had a greater difference of scores in JPS than the uninjured during this study, the results were not significant.[7]

A study performed by Konradsen et.al. passively moved the ankle five degrees at a speed of $0.3s^{-1}$ and were then asked if they had felt as though they had moved. JPS in this study had better results after the participants had warmed up for twenty minutes.[9]

Participants in this study were found to be significantly less likely to detect this slow movement if they had chronic ankle instability. Significant results were easier to detect when the injury being tested was acute, or when rehabilitation did not take place following the injury. Konradsen's study failed to take into consideration whether or not the participants had deficits prior to their injuries, were a result of repeated injury, or from a single injury. However, this study did reveal that instability deficits can be detected up to six weeks post injury without rehabilitation intervention and occurs mostly in the plantar flexion range.[9]

Another study by Forestier et.al. matched reference angles of contra-lateral ankles pre and post fatigue.[10] The greatest amount of error in this study was detected at 20 degrees of dorsiflexion and 10 degrees of plantar flexion. This study did not take into consideration the speed and angle of movement taking place at the ankle.[10] Due to the strict testing procedures and control equipment needed for JPS measurements, it is not feasible to do as a clinical test and is therefor usually only used in research.[9]

While there have been many different studies done on JPS, that have found deficits, they have resulted in insignificant findings. The study by Konradsen, while it did show significant results, it found significance in healthy ankles with relationship to pre and post warming up and with chronic ankle instability.[9] While

JPS may work in finding extreme deficits, a stability test that is more sensitive may be better for predisposition to injury detection and for setting return to play criteria.

Star Excursion Balance Test

The star excursion balance test (SEBT) is one form of dynamic testing for the lower extremity. In this test, the participant balances on the leg being tested in the middle of a star on the floor. They are then instructed to touch different rays of the star with the opposite foot while maintaining balance. The examiner records the amount of errors, such as falls or tap downs, and the reach distance is recorded. Research by Olmstead et.al. shows that the further a person can reach without losing their balance the better they are able to keep their center of gravity over the base of support and therefore have better stability.[8] The SEBT appears to be sensitive enough when detecting reach deficits in athletes with unilateral ankle instability. The dynamic nature of this test along with the limited equipment needed to run the procedure, make this a cost-effective tool for assessing lower extremity functional deficits.[8]

One criticism of Olmstead’s study was that the height and leg length of the participants was not taken into consideration. The reach length could possibly be highly varied between a person who is five-foot tall and someone who is six-foot tall. The other draw back of the study was that while it found significant values for deficits, it wasn't compared to static postural stance or dynamic tests on the force plate to correlate between decreased postural control and decreased reach distance.[8]

The SEBT appears to be a valid clinical tool by looking at past research. This test does however rely highly on the examiner's measurements and record keeping skills. While the SEBT is cost effective, it lacks in the ability to take precise measurements. The test also presents a lack of ability for comparison between participants due to height differences. The SEBT may work well for certified athletic trainers in the high school setting with little access to equipment, a more accurate reading of stability may be more beneficial for a university or clinical setting.

Static Postural Sway

Postural stability is commonly measured through static postural sway. This is a measurement of the person's ability to remain as still as possible while maintaining balance over a stable base of support.[1,8] This is often tested through variations of the Rhomberg test. An increase in postural sway is recognized as a risk factor for ankle sprains and an increased risk of injury.[1,8,17,25,28] The single leg stance for postural sway is often measured on a force plate for evaluations of injuries to lower extremities.[7,8,13,17,25,27,29]

This method looks at the center of pressure one exerts through the base of support while maintaining a static balance.[13] Since the body is always in a state of continuous motion, one must adjust themselves to keep their center of gravity over their base of support thus causing the movement in the center of pressure.[8] While maintaining this balance, the joint's position and movement added to the visual and vestibular inputs acts to control one's posture.[8] Those with impaired balance have been found to have larger and faster center of pressure movements on the force plate. As the center of pressure increases in velocity, it becomes more difficult or even impossible for one to correct the movement and maintain balance.[17] Laughton et. al. established norms for this center of pressure movement in both the young and the elderly population. For young participants, it has been established that a standard deviation of 1.01in the anterior posterior direction and 0.79 in the medial lateral direction. Standard deviations for the elderly population are 1.08 anterior posterior and 1.33 medial lateral.[30] Participants with standard deviations over these norms are recognized as having a functional deficit.

Results from Brown et. al. and Ageberg et. al. reported that postural control studies showing that static postural sway measurements are more sensitive in the frontal plane than in the sagital plane.[7,25] Yet another study showed significant results in both the frontal and the sagital plane when comparing injured to uninjured limbs.[17] It has been found that exercise and muscular fatigue does not have an effect on postural control but that only large changes can be detected through this method and not small changes in score.[25] A study by Hertel et. al. showed significant results two weeks post injury when comparing injured limb to non injured, however the results became insignificant four weeks following the injury.[17]

The static test for postural stability, while on the force plate, is a variation of the Rhomberg test and can vary in difficulty.[27] The simpler tasks involved balancing on two feet with the eyes open, and the hardest task would be to balance on one foot with the eyes closed.[8,27] Variations between studies includes the amount of time the participant is required to balance. While Hertel et.al. found significant results after 2 weeks but not after four, the participants only balanced for five seconds.[17] The study by Ageberg et.al. had participants balance for 25 seconds and found more sensitive results in the frontal plane, but had no significant results when comparing limbs.[25] Finally, a study by Riemann et.al. had participants balance for 12 seconds while holding a single stance posture with their eyes closed and hands on their hips.[27] Because of the differences in testing procedures between stance style and time balanced along with comparison studies to other forms of testing, this area of research is lacking and inconclusive.

Due to the static postural sway test showing significant results in many various settings and studies, its use by certified athletic trainers and physical therapists shows great promise. While past studies have been inconclusive towards finding the best protocol, further research in this area would help to determine the best balance time and testing positions to create the protocol able to yield the greatest results. Once the optimal protocol is obtained, then true comparison testing can begin between various measures of stability.

Time to Stabilization

Time to stabilization (TTS) is a functional measurement of stability describing the participant's ability to maintain minimal postural sway when transitioning from a dynamic to a static state.[5,6,31] Due to activities being dynamic in nature, research led from stable measurements towards more dynamic measurements. The goal of this was to get a measurement that is quantifiable and that more closely mimics activity. If a measurement is found to significantly detect deficits and be dynamic in nature, than it may prove to be a better test to use for stability purposes. While TTS has been found to show deficits, there are still draw backs to the procedure resulting in one more stability test with lack of clarification. Time to stabilization is a testing procedure that incorporates both sensory and mechanical systems to complete the task.[5,26] Because it uses both of these systems, it holds the ability to measure participant's skill level of regaining balance on landings as well as predict predisposition to injury.[13,14] TTS has become more recently used in testing procedures because it more closely recreates the forces and posture demands that often occur during activity[27] and therefore is thought that it might be a more functional test than other measures.[26] Another plus side of this test is that it takes the participant's attention away from the task of maintaining balance and places the focus on performing the jump thus leading to a possible more accurate score for balancing.[27]

There is not however a consistent basis for comparison in TTS scores due to variations in methods of analysis and protocol procedures.[6] The three protocols for performing TTS are the step down protocol, the hop protocol, and the jump protocol. While the jump protocol has shown to have a higher degree of difficulty than the other two, the step protocol was reported to be easier than the hop protocol making it the easiest on participants to perform. When looking at joint stiffness and joint laxity in participants, there was no significant difference between the step down and the jump down protocols however the TTS scores were greater during the step down protocol regardless of how the data was analyzed.[6]

The jump protocol has participants start 70 cm away from the force plate and jump half of their max vertical jump. Each participant then lands on the leg being tested in the center of the force plate and balances for 20 seconds.[7,14] The hop protocol involves hopping off of a platform and landing on the leg being tested. The studies utilizing the hop protocol used different platform heights, one being 40 cm and one being 15 cm high. The participants balanced for 3 seconds and 20 seconds respectively.[29,27] Participants' TTS score is found by the amount of time it takes for them to return to their stable baseline.[31] When hopping from 40 cm, Caulfield and Garrett found no significant difference between functionally instable ankles and control participants in reaction forces, medial lateral sway, or anterior posterior sway.[29] Finally, the step down protocol involves stepping down from a 20 cm platform onto the force plate, stabilizing as quickly as possible, and holding for 20 seconds.[6] All three protocols have the participants landing on a single leg with the participants hands on their hips and looking straight ahead.[6,27,29]

TTS has been tested in many different settings. When comparing TTS scores before and after anesthesia in healthy participants, the results were not significant showing that mechanoreceptors in the joint do not make a big enough contribution to be quantified in this way.[27] TTS has also been tested before and after cryotherapy treatment in healthy participants. The results of this study also emitted no significant results showing that cold treatments do not impair dynamic stability.[26] A study by Wikstrom, Powers, and Tillman tested TTS on healthy participants following different settings of lower extremity fatigue again with no significant results.[5] Finally, a study by Caulfield and Garrett looking purely at the peak ground reaction forces occurring in TTS with the jump protocol also came up insignificant.[29]

While studies using TTS for examining between injured and uninjured lower extremities showed significant results, other testing settings have come up with insignificant results. This research, along with the previous types of measuring posture, is lacking in comparison between stability measurements to determine the protocol that will produce the most significant, easiest to read and compare results. TTS measurements are also flawed in that the forces being measured are in 3 different directions giving three different measures of postural stability. TTS does not provide a link between these measurements, meaning that all directions need to be looked at individually and can not be looked at as a whole.[31] also, while comparing scores between healthy and unhealthy participants, it must be taken into consideration that baseline measurements for the groups may be different due to possible different levels of stability. This potentially leads to unequal group comparisons.[31]

While the TTS measurement also appears to be an optimal test for quantifying lower extremity stability, it seems to apply only when comparing injured to uninjured. Using this test to screen for predisposition to injury while seeming a good idea due to the dynamic nature, may not work out in practice. This is due to TTS measure how long it takes participants to get back to baseline measurements. If they already possess a deficit and therefore possible predisposition, then their baseline is compromised. A comparison of this technique against other stability tests would help to show if TTS will work for prescreening situations.

Conclusion

Athletic trainers and therapists alike strive to get injured athletes and patients back to activities of daily living and sports as soon as possible following return to play criteria. These criteria include the amount of strength and range of motion that are present within the injured area as well as the proprioceptive abilities to help prevent further injury. Measurements of proprioception are hard to obtain due to the many different tests available to use and there is some confusion about which test significantly correlates to functional stability. This also makes comparison of data between tests difficult since the measurements of the various tests are in different units and while measuring proprioception, they are measuring different components of proprioception.

While JPS can detect deficits within two degrees of movement, this is a stable, non-weight bearing measurement and is very unlike daily and sport activity. The amount of time required to run the JPS along with the strict testing procedures and control equipment needed, makes this test usable in the research setting only and not for use in clinics and athletic training rooms.

The SEBT, while able to measure stability in a dynamic nature and is not costly in terms of equipment needed, it relies on the examiner’s record keeping, and the participants height and leg length must be taken into consideration when comparing participants to each other. These measurements are also difficult to compare to results of the static postural sway and TTS.

When comparing static postural sway results with results from other sway tests, one must be sure the protocols are similar. Due to the varying ability of difficulty in this test, different protocols are likely to result in very different outcomes. Due to the differences in time and stance style, static postural sway research is lacking and inconclusive. However, due to the test being measured by a force plate, it does allow for easier comparison with the TTS test due to the use of the same equipment.

TTS measurements, while the thought behind the test is that it is a more functional test than the other stability tests, studies lack to compare this type of measurement to others. While this is a dynamic test that enables the participants to concentrate on something other than balancing, there are also three procedures for this test resulting in hard to compare data. There are also different methods of analysis for the raw data obtained through TTS leading to another problem when it comes to clinical comparisons.

Each testing scenario has its flaws and plus sides, yet studies fail to compare between types of tests leading clinicians to wonder which test will work the best for detecting return to play criteria to prevent further injury and also any predisposition to injury that may be present. Due to these findings, research should begin to compare tools of measurements along with different scenarios to enable athletic trainers and physical therapists to be better informed when it comes to which test is better to use in the clinical setting.

Chapter three

Methods

Participants

Thirty participants were invited to participate through the use of flyers placed throughout the Human Performance and Leisure Sciences building at Barry University. To ensure a mix of participants in age, sex, and activity level, flyers were also placed outside Barry University's main cafeteria. This was to help to promote recruitment of students who were not athletes as well as faculty and staff of the university. Participants were required to give about twenty minutes of their time and they had no current acute ankle, knee, or hip sprain within the last three weeks, or a concussion within the last six months. Participants were asked to volunteer for the study if they meet these criteria. The participants had to be eighteen years old or older. All participants were then assigned a number that was also be placed on their questionnaire and orthopedic tests. The participants remained anonymous throughout the study and afterwards as well. All data collected will be kept locked in a private safe for five years following the study.

Instruments

An AMTI 4507 force plate and AMTI SGA6-4 amplifier was used to evaluate postural sway and TTS. The gains on the amplifier were set at 4000 and were zeroed out to level readings on the force plate in all planes of measurement. All data was analyzed using the Vicon Peak Motus version 8.0. Data was be collected at 600 Hz and smoothed using Fourier filter with optimal limits chosen using the Jackson Knee Optimal method. The Step made by Sports Step Inc. was used for the step in the TTS procedure and was placed 20 centimeters high and three inches in front of the force plate.

Procedure

Set-up

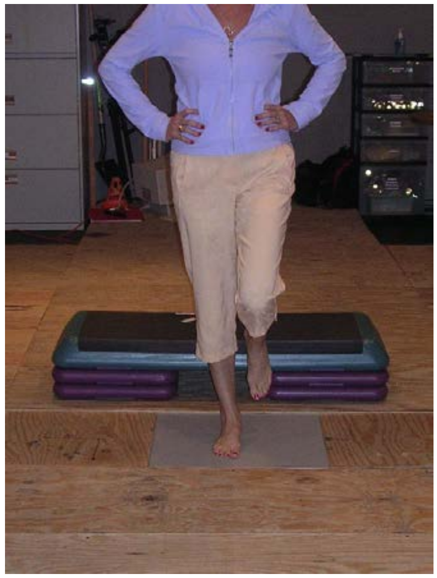
When participants first reported for the study, they were asked to sign a consent form (see Appendix B), a HIPPA from (see Appendix C), and they were informed of the purpose of the study and risks associated with participation. The participants were also informed that they had the option to remove themselves from the study if they became uncomfortable or felt as though they could not continue. Participants then filled out a questionnaire (see Appendix D) pertaining to previous lower extremity injuries and concussions. This questionnaire was used to reduce the amount of risk present to the participant. They were also tested bilaterally for ankle and knee laxity through anterior drawer tests by a certified athletic trainer. The same certified athletic trainer handled all participants' orthopedic tests throughout the study. Participants were not allowed to partake in the study if it was discovered that they were within six months post concussion, were suffering from an acute ankle, knee, or hip sprain, or if they presented with any ankle or knee laxity.

For all participants, the step used in the TTS measurement was set 3 inches away from the force plate and 20 cm off the ground. Before any data was collected through Vicon Peak Motus the amplifier was zeroed out to level readings on the force plate in all planes of measurement.

Performance

Each participant was instructed how to perform the postural sway stance and the step off drill for TTS. They were asked to perform each testing procedure three times per foot. The postural sway procedure required the participants to stand with their shoes off with one foot in the middle of the force plate with their hands on their hips. The contra-lateral leg was to be flexed slightly at the hip and the knee to hold the foot off the ground. It should not have been supported by the balance limb (see Figure 1). Participants were asked to balance for 10 seconds in this stance with their eyes closed. This was done three times per limb. The average of the three trails was used for analysis.

Figure 1: Force Plate Stance



The procedure for the TTS test included having the participant start standing on the step placed in front of the force plate with their hands on their hips. The starting position is shown in Figure 2. They were then asked to step forward off of the step on command and land in the center of the force plate on the limb being tested. Once the participant landed, they were instructed to balance as soon as possible and hold the position until told to relax. They held the same position as described in the postural sway but were allowed to keep their eyes open. Participants balanced for 10 seconds after landing from the step down. This procedure was done three times per limb. The average of the three trials was used for data analysis.

Figure 2: TTS Start Position

Data Reduction

Participants were considered stable in the TTS test when they reach ±0.25 standard deviations of their overall series mean. This was analyzed in both the anterior posterior direction and the medial lateral direction. Data collected during postural sway for center of pressure was analyzed by the standard deviation of total mean position of the center of pressure in both anterior/posterior movement and medial/lateral movement as measured in millimeters.

Force Plate Analysis

A Pearson Correlation was run to look at the amount of correlation between the standard deviation of sway on the left limb and TTS on the left limb. This also compared the standard deviation of sway on the right limb with TTS on the right limb. A high correlation between TTS and sway would show that the two tests of stability are related to each other in their measurements.

Design Analysis

Variables

Independent variables:

Independent variables for the study were the testing limbs. This includes both the left and the right lower extremities.

Dependent variables:

The study consists of four dependent variables. There are two variables for the postural sway procedure and two for the time to stabilization procedure.

The two dependent variables in the study for postural sway, through the standard deviation of center of pressure, are the anterior/posterior direction and the medial/lateral direction.

Time to stabilization dependent variables are also the anterior/posterior and medial/lateral directions.

Chapter Four

Analysis of Data

Demographics

The total number of participants for the study was twenty-one. The break down of the demographics is shown in Table 1. Of the total population, 90% of the participants had experienced a previous injury. 62% of the participants had previously injured their left lower extremity while 71% of them had previous injuries to the right limb. Of all of these injuries, only 4 of them were within the last year and only two of those participants felt as though they were still problematic. Nine of the participants were male and the other twelve were female.

Of the males that participated, one of them was left foot dominate, five of the males had injured both extremities while a total of seven had previously injured their left lower extremity, and seven of them had previously injured their right lower extremity. The age range for the male participants was 19 to 38.

The female participants in the study ranged from 19 to 30 years of age. Two of the females were left foot dominated while the remaining ten females were right foot dominated. Four of the females had injured both the left and the right lower extremities, but a total of six of the female participants had previously injured their left lower extremity while eight of the females had previously injured their right lower extremity.

Table 1. Demographics

Demographics	Injured Left Foot	Injured Right Foot	Dominate Foot	Mean Age	Total
Male	7	7	1 Left	28.5	9
Female	6	8	2 Left	24.5	12

Table 1A Group Results

	StD	Mean	Min	Max
COP AP	0.00488	0.01592	0.007999	0.030934
COP ML	0.00721	0.0149	0.006733	0.041672
TTS AP	0.286785	3.325071	2.254	3.607
TTS ML	2.7465	2.757976	1.967	4.37

Results

The data Collected matches previous research in that TTS measurements, although a norm has not yet been established, tend to take around three seconds. This is supported by the research done by Wikstrom et. al. [6] The COP measurements taken in this study was done through the use of ground reaction forces. Norms have been established for COP measurements by Laughton et.al. to be 3.54 in the AP direction and 2.26 in the ML direction.[30] This norm was found by using the standard deviation of the velocity of movement however and therefore a different type of measurement than the one performed in this study.

A correlation analysis was run using SPSS to determine if the two methods of measuring stability were in anyway related. The data collected supports the null hypothesis in that there is no significant correlation between COP and TTS in either the anterior posterior (AP) or medial lateral (ML) directions. The correlation charts are shown in Table 2 and Table 3 for balancing on the left foot and the right foot respectively and the correlations that this study viewed are highlighted for easier viewing.

Table 2. Balancing on the left foot

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP				
TTS ML	0.084429	1		
COP AP	-0.0454	0.027518	1	
COP ML	0.13729	0.074968	0.923214	1

Table 2A

	Mean	StD	Min	Max
TTS AP	3.360095	0.198687	2.579	3.558
TTS ML	2.689381	0.295488	2.118	3.335
COP AP	0.016082	0.005631	0.007999	0.03093
COP ML	0.014044	0.006107	0.006733	0.02827

Table 3. Balancing on the right foot

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	0.117444	1		
COP AP	-0.10614	-0.13111	1	
COP ML	0.121398	0.133662	0.664842	1

Table 3A.

	Mean	StD	Min	Max
TTS AP	3.29695	0.363563	2.254	3.607
TTS ML	2.8502	0.484824	1.967	4.37
COP AP	0.15833	0.004226	0.009802	0.02574
COP ML	0.015964	0.008397	0.007311	0.04167

When correlating the COP AP to TTS AP and the COP ML to TTS ML, it is seen that the chances of correlation are r=-0.045 and r=0.075 respectively for the left foot and r=-0.106 and r=0.133 for the right foot. This correlation supports the idea by Wikstrom that one measurement cannot be used in place of the other in that they are not highly correlated.[6]

Further breakdown of the data for correlation took place to view females with and without previous lower extremity injuries while balancing on both the left (Table Four and Table Five) and the right feet (Table Six and Table Seven). While some of the highest correlations of the study are seen when correlating females, this only takes place in the ML direction and is not significant enough to suggest repeated predictability.

Table 4. Females balancing on the left with injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	-0.23515	1		
COP AP	0.438036	-0.3454	1	
COP ML	0.307733	-0.3059	0.292045	1

Table 5. Females balancing on the left without injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	0.636607	1		
COP AP	-0.04111	0.686598	1	
COP ML	0.219582	0.789424	0.956338	1

Table 4A.

	Mean	StD	Min	Max
TTS AP	3.40916	0.09520	3.254	3.499
TTS ML	2.7598	0.3275	2.118	3.05
COP AP	0.0146	0.0065	0.0079	0.0249
COP ML	0.0135	0.0088	0.0067	0.028

Table 5A.

	Mean	StD	Min	Max
TTS AP	3.417	0.1021	3.332	3.558
TTS ML	2.658	0.1899	2.43	2.904
COP AP	0.0151	0.004	0.0086	0.02
COP ML	0.0122	0.0032	0.0086	0.0181

Table 6. Females balancing on the right with injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	-0.0653	1		
COP AP	-0.05076	0.35441	1	
COP ML	0.113642	0.27661	0.963333	1

Table 7. Females balancing on the right without injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	-0.3882	1		
COP AP	-0.5975	-0.4449	1	
COP ML	-0.4438	-0.6345	0.853072	1

Table 6A.

	Mean	StD	Min	Max
TTS AP	3.30457	0.3417	2.541	3.518
TTS ML	2.569	0.3916	1.967	3.161
COP AP	0.0147	0.0028	0.011	0.0203
COP ML	0.0117	0.0034	0.0073	0.0177

Table 7A.

	Mean	StD	Min	Max
TTS AP	3.0856	0.0724	2.254	3.58
TTS ML	3.0743	0.2702	2.777	3.305
COP AP	0.0154	0.0041	0.0121	0.0201
COP ML	0.018	0.0112	0.0113	0.031

The study did not contain enough male participants to perform correlations for without injury, but the correlations on the injured extremities were similar to the females. When comparing injured to non injured and not controlling for sex, balancing on the left with no injury (Table 8) shows a r=-0.645 and r=-0.66 correlation in the AP and Ml directions respectively. This correlation drastically drops however when balancing on the left foot with injury is correlated (Table 9). The correlation then becomes 3.4% and 17.9% in the AP and Ml directions. Results are similar when looking at balancing on the right foot.

Table 8. Balancing on the left without injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	-0.0655	1		
COP AP	-0.6459	-0.5619	1	
COP ML	-0.5520	-0.6602	0.865552	1

Table 8A.

	Mean	StD	Min	Max
TTS AP	3.397	0.0936	3.33	3.558
TTS ML	2.608	0.2305	2.203	2.904
COP AP	0.015	0.0037	0.0086	0.02
COP ML	0.013	0.0032	0.0086	0.018

Table 9. Balancing on the left with injury

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	0.154707	1		
COP AP	0.034424	0.156661	1	
COP ML	0.234979	0.179811	0.938966	1

Table 9A.

	Mean	StD	Min	Max
TTS AP	3.3439	0.252713	2.579	3.505
TTS ML	2.713	0.328319	2.118	3.335
COP AP	0.016446	0.006913	0.007999	0.030934
COP ML	0.015106	0.007505	0.006733	0.02827

When correlating sex and ignoring injury, significance is even lower. With the highest correlation being males in the AP direction on their right foot at r=0.69, the same participants on the opposite limb yields only a r=0.15 correlation in the AP direction.

The only correlation that at first looks significant was found when looking at balancing on the left foot by participants who were left foot dominated (Table 10). R=0.96, p>.05. Due to the high p value however, this was non significant.

Table 10. Left foot dom. balancing on the left limb

	TTS AP	*TTS ML*	*COP AP*	*COP ML*
TTS AP	1			
TTS ML	-0.63678	1		
COP AP	0.959746	-0.8277	1	
COP ML	0.971328	-0.4352	0.865454	1

Table 10A.

	Mean	StD	Min	Max
TTS AP	3.371667	0.112855	3.284	3.499
TTS ML	2.947	0.336399	2.737	3.335
COP AP	0.017118	0.002569	0.014586	0.019723
COP ML	0.015554	0.004703	0.012719	0.020982

When looking at the skewness of the TTS in the AP position, and COP in the ML direction, they were both skewed by more than one. The data was transformed using Tukey's ladder for transformations to have the data best fit a normal curve. Once the data was transformed, correlations were rerun using the new data resulting in the same outcomes.

Qualitatively looking at the COP movement shows that the largest of the excursions took place in the second half of balancing. Since none of the participants' TTS took longer than 4.37 seconds, COP data was truncated to 4.5 seconds instead of the full 10 seconds of balancing with the eyes closed. When running correlations in this instance, there were still no significant findings in any circumstance.

Chapter Five

Discussion

There are many factors that affect a person's stability in the lower extremity. These include but are not limited to injury, training, strength within the joint and the limbs, input from the vestibular cochlea, and the amount that one depends upon visual cues. Determining a proper measurement to assess someone's stability is constantly being researched and there are varying ways of measuring factors of stability. This research focused on two methods that are often used in measuring stability but that have little room for human error. While the star excursion balance test can adequately measure ones range of functional motion, it can also be altered by the amount of flexibility a person has or the tightness of their muscles. Joint position sense is a way of measuring how accurately one can determine where their joint is in space. This may then possibly measure if they can sense when their body is out of alignment. However, this is a non weight-bearing test that measures joint receptor ability, which is only one of the many factors that contributes to stability.

Postural sway measurement through COP movement has been shown to be able to determine when one may be at increased risk of injury. There are studies however that show that postural sway measurements may not be sensitive enough for highly trained individuals.[8,25] There are also multiple ways of performing the test ranging from easy to hard. The hardest testing scenario was used in this study to ensure a challenging test that would possibly more accurately test the stability of the lower extremity. While the standard deviation of the center of pressure was used to determine each participant's amount of sway and stability, correlating the results with their time to stabilization was non-conclusive. Center of pressure movement can also be looked at in other ways however. The total amount of movement can be analyzed, or the velocity of movement can be considered. Due to the nature of the time to stabilization test measuring how quickly one stabilizes, future research may need to correlate the velocity of the center of pressure movement to the person's time to stabilization. This would determine if one test is really more efficient at finding instability than the other. This would then compare speed to time, or when looking at how quickly the velocity returns to neutral, comparing time to time.

Time to stabilization measurements were taken by using the step down method. While this was chosen due to its perceived ease in performing, other testing procedures may have elicited different results. It has previously been found by Riemann et. al. that the step down method may be perceived as being too easy and therefore resulting in the participants not trying as hard to balance resulting in longer time to stabilization scores.[27] When explaining to the participants how to perform the protocol, they were told to step down. Watching the participants perform the protocol showed that many of them employed a double base of support when they first stepped onto the force plate. This allowed them to use both limbs for stabilization during initial contact where describing the protocol as a drop down onto the force plate may have resulted in never using a double stance. While this slight time of double stance may have helped the participants to gain stability measurements quicker due to being able to use both limbs for a short period of time, it is also possible that it lengthened each participant's time to stabilization. This could be due to the additional weight shift when the limb being held in the air was picked up off of the step. Also, due to the task not being perceived as difficult, participants may not have attempted to balance as quickly as they could due to them not feeling as though they were off balance. Using the hop or the jump methods for finding TTS would result in different measurements therefore possibly changing the correlation. Using the most difficult COP test scenario with the most difficult TTS, being the jump protocol, may be a better way to compare these two methods of measuring lower extremity stability. This would be due to both tests being challenging enough that participants would have to try their hardest or else possibly fall.

Time to stabilization is a measurement of how long it takes someone to reach a stable state.[31] If their stability is compromised and they are all over the force plate naturally, then measuring TTS may actually result in a shorter time due to it not taking as long to reach a large movement state than it would be to reach a small amount of movement state. Due to this, future research may need to measure ones COP deviation first, to determine if they already have a compromised stability. If the stability is compromised, then running the participant through TTS could possibly result in inconclusive data, where as, if the participant had a COP deviation within normal limits, than the TTS that they posses would hold a stronger meaning.

While there are multiple factors that contribute to one's stability and balance, the visual input can highly alter the ability to maintain balance. The COP deviation testing protocol was done with the eyes closed due to previous research stating that postural sway with the eyes open may be too easy resulting in a test that isn't sensitive enough. This eliminated any visual cues that the participant would have been able to aid in balancing. The TTS protocol however, was performed with the eyes open. This allowed the participants to use both vestibular and visual cues to aid in balancing. TTS protocols, are dynamic in nature, and would be risky if performed without visual cues and therefore future studies in comparisons may need to employ COP tasks that keep visual input intact.

Injury detection and rehabilitation are crucial to the field of athletic training and physical therapy. Due to this, these multiple measurements of stability have come about and been used to help determine predisposition and functional ability. While COP and TTS have both been found to detect stability, finding the most beneficial test for different environments has been taxing in the research field. While a large number of the participants in this study have had previous injury, only four of them felt as though they were still symptomatic. Everyone else in the study felt as though they had been fully rehabilitated and that they were no longer symptomatic. Past research has shown differences between injured and uninjured people however they may need to consider the participants perception of the injury as well.

Future Ideas

There are many other influences that may alter the results of both TTS testing and COP measurements. This includes shoe wear, taping and bracing, exercise, strengthening programs, age, and possibly gender. Wearing shoes not only can give the ankle joint a little extra support, it also provides extra sensory input. Not only does the participant feel the weight they are distributing on the bottom of their foot, but they can now also feel any movement that takes place by the rubbing of the shoes on the sides and top of their foot. This is also true in taping and bracing. Even after the effectiveness of the tight tape wears off, it still is capable of providing these extra sensations. Another factor of shoes is looking at athletes who wear tennis shoes versus cleats. Where there is a possibility that athletes wearing cleats have less stability since they are limited on the amount of their foot that is in contact with the ground, there is also the possibility that athletes who are trained and used to wearing cleats may have higher stability due to training on less support.

While looking at less support in cleats, comparing sports could also prove beneficial. Not only do different sports train differently, they also train on different surfaces. Testing to see if athletes who train on uneven surfaces, such as soccer and cross country, possess more or less stability than athletes who train on flat reliable surfaces, such as basketball and volleyball may help to give an idea of possibly where rehabilitation should take place. Testing within the sports can take place using COP, TTS, or balancing on foam in either of the situations.

While Wikstrom et. al. showed that there was no difference in TTS pre and post fatigue,[5] an exercise program may alter the outcome. Training in a dynamic state may result in the body relying on dynamics for their stability. This could be tested through testing participants pre-exercise, putting them through dynamic training sessions, testing their TTS during the study, and then again post the workout sessions. While some improvement in TTS would be expected with dynamic training, determining if there was improvement in COP could show if training had a crossover effect between dynamic and static states.

Along with fatigue and exercise, there is also fatigue in testing that should be considered. While this study alternated limbs being testing, since it was done three times per leg, there could have been a learning effect which would give the subjects an apparent higher stability, or there could have been fatigue due to the repeated actions of those who were unable to accomplish successful trails. Some of the participants were able to do three trails successfully while others attempted the testing protocols eight times per leg which would result in possible less stability. To help accommodate this, this study took the average of the three successful trials, but future studies could look into the effect of testing once, three times, and over time to determine the most accurate way to take the measurements for both TTS and for COP.

Lastly, looking at age groups or activity levels could make a large difference in stability. The young and the elderly have been shown to possess less balance and therefore possibly less stability, activity level of the individual would still play a large part in COP and TTS times. Comparing active and inactive elderly or active children to inactive children could show the additional benefits of the effects of exercise and activity. While these two age groups of people have been shown to possess altered balance due to developmental reasons, comparing highly trained young adults to inactive persons in their age groups may even better show the effects of training. This would take out developmental issues and enable more of a focus on long term training effects.

Conclusion

Accepting the null hypothesis that there was no significant correlation between postural sway and TTS leads to the conclusion that using a dynamic measurement should only be used to measure dynamic motion. Likewise, static measurements can only be used to measure the amount of static stability that a person possesses. This may show that athletic trainers, since they deal with dynamic, athletic environments, should use dynamic testing, rehabilitation, and measuring. Physical therapists however, when dealing with the elderly, inactive, and concussed, may need to focus more on COP deviation measurements. Since TTS can only measure the amount of time it takes to get back to each person's static stability point, working static along with dynamic could be the best way to get complete results. While this study showed that the two can not predict the other, looking to see if more static stability equals a longer TTS score, a shorter score, or if they truly are unrelated is needed.

Athletic trainers typically begin rehabilitation with static exercises, progress to more difficult static, lead into dynamic exercises, and end with sport specific training. This is to get the athlete back to their sport as soon as possible without an increased risk of further injury. Knowing the difference between the static and dynamic stability measurements, preseason training should begin by including a dynamic stability test. This could help to determine those at an increased potential risk of injury, but also would give a base line for return to play if injury occurred later in the season. COP measurements could also be taken preseason, but should be used as a baseline post concussion to measure the amount of sensory input from the vestibular cochlear system. While both of these tests have significant use in the field of athletic training, selecting when each would be appropriate is key.

While this study shows that dynamic tests should be used for things that are dynamic in nature, it only considered one form of dynamic testing. The star excursion balance test (SEBT), while it relies on range of motion and flexibility along with stability, is a less expensive dynamic test and therefore more readily accessible in the athletic training room. If the SEBT can detect and predict the same dynamic instability the TTS possesses, then the field of athletic training would have an inexpensive test that would be reliable. More research needs to be done in this area to compare the various dynamic tests to possibly determine the most efficient.

References

1. Mattacola CG, Dwyer MK. Rehabilitation of the Ankle After Acute Sprain or Chronic Instability. *Journal of Athletic Training*. 2002;37(4):413-429.

2. Refshauge KM, KilbreathSL, Raymond J. Deficits in detection of inversion and eversion movements amoung subjects with recurrent ankle sprains. *Journal of Orthopeadic Sports Physical Therapy*. 2003;33(4):166-176.

3. Stasinopoulos D. Comparison of three preventative methods in order to reduce the incidence of ankle inversion sprains among female volleyball players. *British Journal of Sports Medicine*. 2004;38(2):182-185.

4. Caulfield B, Garrett M. Changes in Ground Reaction Force During Jump Landing in Subjects with Functional Instability of the ankle Joint. *Clinical Biomechanics*. 2004;19(6):617-621.

5. Wikstrom EA, Powers ME, Tillmam MD. Dynamic Stabilization Time After Isokinetic and Functional Fatigue. *J Ath Train*. 2004;39(3):247-253.

6. Wikstrom EA, Tillman MD, Borsa PA. Detection of Dynamic Stability Deficits in Subjects with Functional Ankle Instability. *Med Sci Sports Exercise*. 2005;37(2):169-175.

7. Brown C, Ross S, Mynark R, Guskiewicz K. Assessing Functional Ankle Instability With Joint Position Sense, Time to Stabilization, and Electromyography. *J Sport Rehabil*. 2004;13:122-134.

8. Olmstead LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the Star Excursion Balance Tests in Detecting Reach Deficits in Subjects with Chronic Ankle Instability. *Journal of Athletic Training*. 2002;37(4):501-506.

9. Konradsen L. Factors Contributing to Chronic Ankle Instability: Kinesthesia and Joint Position Sense. *Journal of Athletic Training*. 2002;37(4):381-385.

10. Forestier N, Teasdale N, Nougier V. Alteration of the Position Sense at the Ankle Induced by Muscular Fatigue in Humans. *Med Sci Sports Exerc*. 2002;34(1):117-122.

11. Eils E, Rosenbaum D. A Multi-Station Proprioceptive Exercise Program in Patients with ankle Instability. *Med Sci Sports Exercise*. 2001;33(12):1991-1998.

12. Hertel J. Functional Anatomy, Pathomechanics, and Pathophysiology of Lateral Ankle Instability. *J Ath Train*. 2002;37(4):364-375.

13. Tillman MD, Chow JW. Applications of Force-Plate Technology. *Athletic Therapy Today*. 2001;7(5):50-51.

14. Ross SE, Guskiewicz KM. Time to Stabilization: A method for Analyzing Dynamic Postural Stability. *Athletic Therapy Today*. 2003;8(3):37-39.

15. Arnheim DD, Prentice WE. Principles of Athletic Training, Tenth Edition. McGraw-Hill; 2000:386.

16. Hiller CE, Refshauge KM, Beard DJ. Sensorimotor Control is Impaired in Dancers with Functional Ankle Instability. *The American Journal of Sports Medicine*. 2004;23:216-223.

17. Hertel J, Buckley WE, Denegar CR. Serial Testing of Postural Control After Acute Lateral Ankle Sprain. *J Ath Train*. 2001;36(4):363-368.

18. Riemann BL, DeMont RG, Ryu K, Lephart SM. The Effects of Sex, Joint Angle, and the Gastrocnemius Muscle on Passive Ankle Joint Complex Stiffness. *Journal of Athletic Training*. 2001;36(4):369-375.

19. Evans T, Hertel J, Sebastianelli W. Bilateral Deficits in Postural Control Following Lateral Ankle sprain. *Foot and Ankle International*. 2004;11:833-839.

20. Bandy WD, Sanders B. Therapeutic Exercise; Techniques for Intervention. Lippincott Williams & Wilkins; 2001:240.

21. Riemann B. Is There a Link Between Chronic Ankle Instability and Postural Instability? *J Athl Train*. 2002;37(4):386-393.

22. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and Muscle Strength in Subjects with a History of Ankle Sprains and Chronic Instability. *Journal of Athletic Training*. 2002;37(4):487-493.

23. Docherty CL, Arnold BL, Zinder SM, Granata K, Gansneder BM. Relationship Between Two Proprioceptive Measures and Stiffness at the Ankle. *Journal of Electromyography and Kinesiology*. 2004;14(3):317-324.

24. Gribble PA, Hertel J, Denegar CR, Buckley WE. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. *Journal of Athletic Training*. 2004;39(4):321-329.

25. Ageberg E, Roberts D, Holmstrom E, Friden T. Balance in Single-Limb Stance in Healthy Subjects: Reliability of Testing Procedure and The Effect of Short-Duration Sub-Maximal Cycling. *BMC Musculoskeletal Disorders*. 2003;4:14.

26. Miniello S, Dover G, Powers M, Tillman M, Wikstrom E. Lower Leg Cold Immersion Does Not Impair Dynamic Stability in Healthy Women. *J Sport Rehabil*. 2005;14:234-247.

27. Riemann BL, Myers JB, Stone DA, Lephart SM. Effect of Lateral Ankle Ligament Anesthesia on Single-Leg Stance Stability. *Med Sci Sport Exerc*. 2004;36(3):388-396.

28. Beynnon BD, Murphy DF, Alosa DM. Predictive Factors for Lateral Ankle Sprains: A Literature Review. *J Ath Train*. 2002;37(4):376-380.

29. Caulfield B, Garrett M. Changes in Ground Reaction Force During Jump Landing in Subjects with Functional Instability of the Ankle Joint. *Clinical Biomechanics*. 2004;19:617-621.

30. Laughton CA, Slavin M, Katdare K, Nolan L, Bean JF, Kerrigan DC, Phillips E, Lipsitz LA, Collins JJ. Aging, Muscle Activity, and Balance Control: Physiologic Changes Associated with Balance Impairment. *Gait and Posture*. 2003;18(2):101-108.

31. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A New Force-Plate Technology Measure of Dynamic Postural Stability: The Dynamic Postural Stability Index. *Journal of Athletic Training. 2005;*40(4):305-309.

Appendices

Appendix A

Comparison of Static Stability (Postural Sway) and Dynamic Stability (TTS) Methods of Measurement

Jamie Rammelsberg

Introduction: Determining the most beneficial test to detect predisposition to injury is crucial to the field of athletic training. While there are many tests to determine stability, this study focuses on time to stabilization and center of pressure postural sway to determine if they are interchangeable.
Subjects: Twenty-one subjects volunteered for the study. This consisted of 9 males and 12 females ranging in age from 19-38.
Measurements: Time to stabilization and center of pressure measurements were taken while balancing for 10 seconds. This was done three times per limb in each setting.
Statistical Analysis: The standard of center of pressure in both the AP and ML direction was used for data correlation. The amount of time it took each participant to stabilize in both the AP and ML directions was also used for correlating.
Results: There were no significant findings in any testing scenario. The use of static measurements can not be used to predict the amount of dynamic stability a person possesses.

Introduction

A major concern of athletic trainers is the prevention of injury. One way this can be done is through detection of factors that may put athletes at a predisposition. While the amount of stability that one possesses can highly effect injury rate, quantifying this stability has been difficult due to the various ways stability can be measured. Two main ways of measuring stability is through dynamic motion or through static measurements. While they have both been found to possess the ability to detect deficits, determining when to use each type has still to be determined. Dynamic stability can be measured through the star excursion balance test (SEBT) or through time to stabilization (TTS) and static stability is measured through postural sway.

The SEBT consists of balancing on one limb and reaching as far as possible in various directions with the opposite foot. The theory behind this is that the more stability a person possesses, the further they can reach before losing balance. While this test is inexpensive and easy to run, it relies heavily on the participant’s level of flexibility, range of motion in the joint, and muscle stiffness, not just stability.

Time to stabilization, while a relatively new method of measuring dynamic stability, does not rely on flexibility, activity level, or range of motion. It does have the fall back however, that due to its relatively newness, there are various protocols for running the test and the most effective way has not yet been determined. One of these protocols involves stepping off of a step onto a force plate and balancing as quickly as possible, one involves a drop off from the step, and the third protocol requires a jump onto the force plate. While the jump protocol is the most dynamic in nature, it is also perceived as the hardest to perform. The step down protocol was determined to be the easiest test to perform, it also resulted in participants taking a long time to stabilize than when performing the other two scenarios.[6]

Static stability is a person's ability to maintain balance while standing still. This is typically done through measuring the center of pressure of one's postural sway. This does not measure the movement of one's center of gravity, but rather their reaction to the movement of their center of gravity. Typically this is view as a standard deviation measurement of the total movement, but can also be looked at as total movement that occurs, or the velocity of the movement. While there are many ways of looking at the data that is collected during COP, there is also various protocols for collecting COP. The easiest test for the participant to perform consists of standing with a double base support, feet shoulder width apart, and eyes open. The hardest performance is done while standing on one leg with the eyes closed. While COP measurements have been shown to reveal possible predisposition to injury,[1,8,17,25,28] there is also concern that the test may not be sensitive enough to detect deficits in highly trained individuals. Due to having multiple ways of measuring stability, comparing them to each other to determine when each test would be most beneficial to use is a must.

Subjects

Twenty-one subjects volunteered for the study. There was a total of 9 males and 12 females. The age range of all participants was 19-38. Ninety percent of the participants had previously sustained injury. Sixty-two percent of the total participants had previous injury to their left lower extremity, and 71% had previous injury to their right. Out of the 21 participants, four of the injuries were within the past year, and only two of the injured participants still felt symptomatic.

Measurements

After volunteering for the study, participants answered a questionnaire and were tested for joint laxity in both the knees and the hip to ensure that testing would not put them at an increased risk for injury. They were then informed of how to do the step down protocol for TTS and allowed to practice, as well as informed as to how to perform the COP test. The participants were read instructions so that each participant received the same instruction. COP testing consisted of standing on the test limb in the middle of the force plate. When the participants were informed to begin, they would then pick up the opposite limb, and balance without the leg in the air resting on the testing limb. They were instructed to keep their hands on their hips and their eyes closed. This position was held for ten seconds. The test was performed on each leg three times. Time to stabilization was performed by stepping off of a 20cm high step onto the force plate and balancing immediately on the testing limb. Again, hands were to be kept on the hips, but the eyes stayed open for this testing procedure. Again the balancing was done for 10 seconds and three times per foot. The starting limb and testing protocol were randomized for all subjects.

Statistical Analysis

Center of pressure data was processed using Peak Motus for each trail of each participant for the standard deviation in both the anterior posterior (AP) direction and the medial lateral (ML) direction. The average of the three standard deviations in each direction was then taken for the participants' score in that direction. Time to stabilization data was processed using Peak Motus as well. The ground reaction forces were then placed into Excel where a formula was applied to determine the amount of time it took each participant to stabilize in each trail in both the AP and ML directions. These times were then averaged to use for correlation.

Results

The data was correlated to see if TTS in the AP direction was related to COP in the AP direction and like wise, if TTS ML was related to COP ML. Scenarios that were included in the study looked at which side the participants were balancing on, correlations by sex, by injury history, and by sex by injury. Sex by balancing leg and dominate leg by balancing leg was also compared. All correlations resulted in no significant findings.

Discussion

The lack of correlations in the data shows that measuring one's static stability cannot be used to predict dynamic stability when using the method in this study. Likewise, the dynamic measurement of stability used in this study cannot be used to predict one's static stability. Comparing a center of pressure measurement performed with eyes open may result in different outcomes due to the time to stabilization protocol using visual cues. Also, using a more difficult TTS protocol to compare with the most difficult COP may provide different data results. Other factors that may prove to be beneficial for comparisons would be looking at the total distance of the movement in COP and looking at the velocity of COP. While looking at the velocity of the excursions during COP, one could also look at how quickly a participant regains control after a large excursion takes place.

Appendix B

Informed Consent Form

Your participation in a research project is requested. The title of the study is Comparison of Static Stability (Postural Sway) and Dynamic Stability (TTS) Methods of Measurement. The research is being conducted by Jamie Rammelsberg ATC/L, a thesis student in the Human Performance and Leisure Sciences department at Barry University, and is seeking information that will be useful in the field of athletic training. The aims of the research are to determine which method of measurement for stability is most likely to yield positive results. In accordance with these aims, the following procedures will be used: participants will be asked to balance on a force plate to the best of their ability while data is being collected, and then to step off of a step onto the force plate and balance to the best of their ability. We anticipate the number of participants to be 30.

If you decide to participate in this research, you will be asked to do the following: answer a short survey asking about past injuries and be evaluated by a certified athletic trainer for any current injuries of the lower extremity. We will use your survey results to minimize any risk to you and any information you choose to supply will not be shared with anyone outside of the research group. Once this is done, you will then be asked to balance on one foot for ten seconds, then step off a seven-inch step and balance for ten seconds. This will be done on both legs three times. The total amount of time you will be asked to contribute is 20 minutes.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you drop out at anytime during the study, without consequence.

The risks of involvement in this study are minimal and include possible spraining of ankle, and falling. Should you feel as though you might fall, you may discontinue from balancing and stand on two feet. Although there are no direct benefits to you, your participation in this study may help our understanding of balance and the most beneficial way to measure stability.

As a research participant, information you provide will be held in confidence to the extent permitted by law. Any published results of the research will refer to group averages only and no names will be used in the study. If individuals are referred to, only the assigned participant number will be mentioned. Data will be kept in a locked file in the researcher’s office. Your signed consent form will be kept separate from the data. All data will be destroyed after 5 years.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Jamie Rammelsberg, at 614-519-0431, my supervisor, Dr. Shapiro, at 305-899-3574, or the Institutional Review Board point of contact, Mrs. Nildy Polanco, at 305-899-3020. If you are satisfied with the information provided and are willing to participate in this research, please signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Jamie Rammelsberg and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

____________________ ________

Signature of Participant Date

____________________ ________

Researcher Date

Appendix C

Barry University Institutional Review Board Office
11300 NE 2nd Avenue, LaVoie Hall, Miami Shores, FL 33161-6695
(305) 899-3020
HIPPA RESEARCH AUTHORIZATION
TO USE AND DISCLOSE HEALTH INFORMATION

IRB Protocol Number: 06-02-17
Principal Investigator: Jamie Rammelsberg

IRB Approval Date:
PI Department: Human Performance and Leisure Sciences

Protocol Start Date: 04-01-2006
Protocol End Date: 06-30-2006

HIPAA Research Authorization Form
AUTHORIZATION TO USE AND DISCLOSE HEALTH INFORMATION

Study Name: Comparison of Static Stability (Postural Sway) and Dynamic Stability (TTS) Methods of Measurement

I agree to permit Barry University and any of my doctors or other health care providers (together "Providers"), and

Jamie Rammelsberg
Principal investigator

And her collaborators and staff (together "Researchers"), to obtain, use and disclose health information about me as described below.

1. **The health information that may be used and disclosed includes:**
    - All information collected during the research described in the informed consent form for the study:

Comparison of Static Stability (Postural Sway) and Dynamic Stability (TS) Methods of Measurement

    - ("the Research"); and
    - Health information in my medical records that is relevant to the research that I disclose.
2. **The providers may disclose health information in my medical records to:**
    - The Researchers;
    - Representatives of government agencies, review boards, and other persons who watch over the safety, effectiveness, and conduct of research.
    - The sponsor of the research,

Dr. Sue Shapiro
Sponsor

    - And it's agents and contractors (together "sponsor"); and
3. **The Researcheres may use and share my health information:**
    - Among themselves, with the
    - Sponsor, and with other participating researchers to conduct the research; and
    - As permitted by the Informed Consent Form.
4. **The Sponsor may use and share my health information as permitted by the Informed Consent Form.**

Participant Signature ______________________ Date __________

Appendix D
Questionnaire

Any information you supply here will stay anonymous throughout the study and will only be shared with the researcher, Jamie Rammelsberg, and the sponsor, Dr. Sue Shapiro.

1. How old are you?		___________	
2. Have you ever had an ankle injury?		Yes	No
If so, which side?	Right	Left	Both
How long ago was the last injury?		___________	
Does the injury still cause you problems?		Yes	No
Did you do any rehabilitation for the injury?		Yes	No
Do you feel you were fully rehabilitated?		Yes	No
3. Have you ever had a knee injury?		Yes	No
If so, which side?	Right	Left	Both
How long ago was the last injury?		___________	
Does the injury still cause you problems?		Yes	No
Did you do any rehabilitation for the injury?		Yes	No
Do you feel you were fully rehabilitated?		Yes	No
4. Have you ever had a hip injury?		Yes	No
If so, which side?	Right	Left	Both
How long ago was the last injury?		___________	
Does the injury still cause you problems?		Yes	No
Did you do any rehabilitation for the injury?		Yes	No
Do you feel you were fully rehabilitated?		Yes	No
5. Have you ever had a Concussion?		Yes	No
Did this happen within the last 6 months?		Yes	No
6. Which is your dominant foot?		Left	Right
Which foot do you kick with?		Left	Right
Which foot do you step forward with first?		Left	Right

Orthopedic Tests

Do Not Write Bellow This Line

Left Hip			Right Hip		
Pain	Yes	No	Pain	Yes	No
Left Knee			Right Knee		
Laxity	Yes	No	Laxity	Yes	No
Pain	Yes	No	Pain	Yes	No
Left Ankle			Right Ankle		
Laxity	Yes	No	Laxity	Yes	No
Pain	Yes	No	Pain	Yes	No

Weight in kilograms ___________