Validity of the Balance Error Scoring System and the Sway Balance Application™ On Pre and Post Exercise Balance Scores

A THESIS

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THESIS APPROVAL

Graduate Athletic Training Education

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INTRODUCTION

The Balance Error Scoring System (BESS)was developed to provide clinicians with an inexpensive and objective way to assess balance outside of the laboratory.[1] The BESS measures an athlete's balance through a clinical-assessment battery and is scored by counting the errors during the tests.[1] BESS consists of three stances: single-leg, double-leg and tandem. All stances require the participant to place their hands on their hips with eyes closed for 20 seconds each.[1]

The BESS test is considered a quick, valid and reliable clinical field test that can be used for sideline evaluations of an athlete's balance after a mild head injury (MHI).[1] Considered to be the gold standard in sideline assessment, BESS is used during baseline evaluations as well and in the event of a concussion.[1]

Recently, an objective tool available for mobile devices called the Sway Balance Application™ was created to evaluate balance. This application is readily available on any device and allows for easy management of athletes scores. This test consists of five stances each lasting 10 seconds each.[2] The participant will close their eyes for each test. However, research does not show that this tool is valid for sideline assessment.

While research shows these tools are useful without exertion it is interesting to see if they are useful when an athlete may be fatigued from a practice. It is well established that fatigue affects balance, thus assessing balance immediately after a regularly scheduled practice allows for results to be more meaningful in a clinical field setting.[1,3,4]

Fatigue not only affects balance, but the body as well. Fatigue can affect a specific area of the body or the entire body. Research has shown that an immediate effect of fatigue is a reduction in the ability of muscles to apply force, which impairs balance.[5] Fatigue has shown a decrease in postural control measured through BESS total errors.[1] It is also known that fatigue above anaerobic threshold recovers within 15 minutes after practice.[5] This should be kept in mind for future studies as well for clinicians when evaluating injuries.

Several strategies have been identified to maintain balance in a variety of static and dynamic activities. These strategies are based on items that have been previously identified through research. One is proprioception, which is the afferent input of joint position sense.[6] Another is our center of gravity, referring to a point in the body which the total force of gravity is considered to act and that it projected vertically on to the support surface.[6] Therefore, the ability to balance is based on an interaction from somatosensory, vestibular and visual functions.[6] The ankle strategy restores balance through body movement centered primarily around the ankle joint when perturbation to equilibrium is small and the support surface firm.[6] The hip strategy is used when larger perturbations are experienced and the ankle strategy does not provide enough force to maintain balance and the movement is focused primarily at the hip joint.[6] The stepping or hopping strategy is used when the perturbation is large enough to displace the centre of gravity outside the person's base of support.[6]

The purpose of this study is to examine the Sway Balance Application™ as a sideline assessment tool both prior to and after exercise against an already established tool that is reliable and valid, the BESS test.

METHODS

The purpose of this research study is to test the validity the Sway Balance application™ when compared to the BESS test when evaluating balance prior to and immediately after exercise. This section will include the following subsections: research design, subjects, instrumentation, procedures, and data analysis.

<u>Specific Aims and Hypothesis</u>

1. To see if pre and post scores are different on the BESS test and the Sway Balance application™
    - Post scores after exercise on the BESS test will be higher indicating less balance than on the pre-test.
    - Post scores after exercise on the Sway Balance application™ will be lower indicating less balance than on the pre-test.
2. To see if Sway™ is a valid sideline assessment tool for balance when compared to the BESS test.
    - The Sway Balance application™ will be more valid than the BESS test when measured after activity indicating it is a better test to measure balance.

Research Design

The study was a pre and post test experimental design. The independent variables included balance as assessed by the BESS and Sway Balance Application™, perceived exertion (RPE), and demographics including age, sex, weight, and height. Under this design, participants volunteered to perform the BESS test and the Sway Balance application™ on two separate testing sessions, pre and post physical activity. The results are a generalization to Division II soccer athletes.

Subjects

Division II National Collegiate Athletic Association (NCAA) athletes (n= 79) from California University of Pennsylvania participating in women's or men's soccer will be asked to participate in this study. Prior to data collection, an informational meeting will be held with all team members to explain the research study as well as answer any questions they may have. Subjects will then read and sign an informed consent form. Confidentiality will be kept by giving each participant a subject number that was used as their identity for the duration of the study. Participants will be counterbalanced randomly according to the counterbalance chart (Appendix C6), with all even numbered subjects performing the BESS test first and all odd numbered subjects performing the Sway Balance Application™ first.

Inclusion Criteria:

- Minimum age of 18
- Member of the men's or women's intercollegiate soccer team

Exclusion Criteria:

- Any participant who had suffered an injury to the lower extremity or a head injury in the past 6 months was excluded from the study.
- Any athlete with a documented balance or neuromuscular disorder.

Instruments

This research study will utilize the following instrumentation:

- The Balanced Error Scoring System (BESS Protocol)
- Sway Balance Application™
- Borg rating perceived exertion chart
- Demographic data collection sheet (Appendix C5)

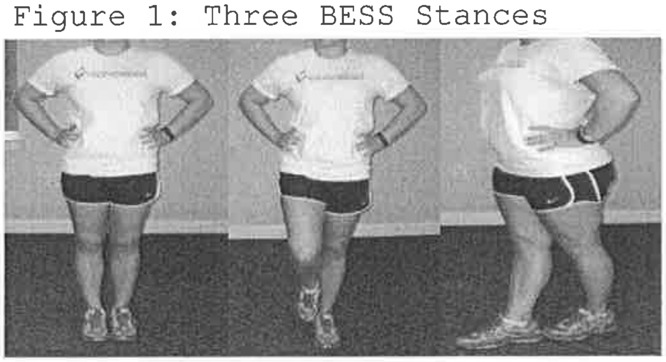
BESS Test

Balance will be measured using BESS error scores. The BESS test employs 3 stances: double-leg, single-leg, and tandem on multiple surfaces (Figure 1).[1] The surface used for soccer will be a soft surface, a turf field. A stopwatch will be used to time each 20-second test. Participants receive one error score if the subject performs any of the following during each phase of the test:[1] (1 score for each)

- lifting the hands off the iliac crests
- opening the eyes
- stepping, stumbling, or falling
- moving the hip into more than 30° of flexion or abduction
- lifting the foot
- remaining out of the test position for longer than 5 seconds

Previous research has demonstrated good inter-tester (.78 to .96) and intra-tester reliability (.87 to .98).[1] The BESS is a valid and reliable method of measuring balance. Error scores were significantly correlated with those on the EquiTest long forceplate and ranged from 0.30 to 0.78.[1] Good test-retest reliability (r= .673) of the BESS has also been reported.[1]

Figure 1: Three BESS Stances



Bipedal Single-leg Tandem

Sway Balance App

Sway Balance™ is a mobile software system, (Sway Medical LLC, Tulsa, OK), that has built in motion detectors in order to measure postural sway, specifically thoracic postural sway (Figure 2).[7] For test administration, the software system will be downloaded to iPads. The participant will be instructed to hold the mobile device against their chest, specifically the midpoint of the sternum with both hands, while performing the 5 different tests.[2] These tests include a bipedal stance, tandem stance and single leg stance positions.[7] After the participant has completed the 5 tests, a Sway score is displayed on the athlete's profile based on a 100 point scale.[7] A perfect score is 100, which means there was little to no movement during the test.[7] Past research shows a strong relationship between Sway Balance™ and the BESS test (r= 0.77) and (r= 0.87, r= 0.95) in a non-athlete population under a laboratory setting.[8,9]

Figure 2: Five Sway Balance Stances

Bipedal

Single-leg: right

Single-leg: left

Tandem: right

Tandem: left

Borg Rate of Perceived Exertion(RPE)

A 15-point Borg scale (6-20) will be used to measure ratings of perceived exertion (RPE) in an attempt to measure the amount of exertion presented by each subject pre and post practice (Figure 3). The 15-point Borg scale has been shown in previous research to be useful for evaluations of perceived exertion and for predictions of exercise intensity during sports and rehabilitation.[1]

Figure 3: Rated Perceived Exertion Scale

Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion. Look at the rating scale before and after exercise. Choose the number that best describes your level of exertion. Try to evaluate your feeling of exertion as honestly as possible. It is your own feeling of effort and exertion, not how it compares to other people's scores.

Procedure

This project will entail separate testing days. One day for BESS and one day for Sway Balance™. Upon California University of Pennsylvania's Institutional Review Board (IRB) approval, participants will be asked to participate in this study via verbal communication before or after practice. The researcher will explain the study fully to ensure the participants know the time commitment and any risks that are involved as a participant in the study. Additionally it will be explained that the participants can leave the study at any time without penalty. The exclusion criteria will be confirmed before participants enroll in the study. All participants will read and sign the informed consent form approved by the IRB, participants will receive a copy and the original will be retained by the researcher in a secure file cabinet.

Participants will report to their respective team practice facility for this study. Total study time will be approximately 30 minutes total excluding the time spent in practice. Participants will begin with the test that is reflected in the counterbalance sheet. If the BESS test is first then the participant will be instructed to stand in the first stance to be tested. The stopwatch will begin when the participant is comfortable, with their hands on their hips and eyes closed. Performance will be scored by adding 1 error point for each error committed.[10] Errors will be summed to obtain the total BESS score.[10] The participant will continue the same routine with the second and third stances. The participant will then be asked to rate his/her perceived exertion. We will record the number given. Once completed, we will instruct the participant to return after practice to perform the same test. Perceived exertion will be rated and recorded no more than 10 minutes post-exercise. A practice allows for a real-life scenario to be applied to the study. Therefore, balance testing will be close to the fatigue level experienced during a game if a head injury has occurred. Upon completion of the post-exercise test, the participant will schedule the next date to complete the other test that they have not yet performed. Participants who have the Sway Balance Application™ will be instructed to hold the device to their chest in an upright position after pressing the begin test button. The first stance will automatically begin. There are a total of 5 stances, each lasting 10 seconds. After each test the device will make a sound so that the participant can see the next stance they need to get ready for. After the 5 stances are completed participants will rate their perceived exertion and return after practice to follow the same procedure.

Data Analysis

All data will be analyzed by SPSS version 22.0 for windows at an alpha level of 0.05. The research hypotheses will be analyzed using t-tests and pearson correlations.

RESULTS

The purpose of this research study was to test the validity of the Sway Balance application™ when compared to the BESS test when evaluating balance prior to and immediately after physical activity. The following section is divided into three subsections: Demographic Information, Hypotheses Testing, and Additional Findings.

Demographic Information

Seven male collegiate soccer players participated in this study (19.7,177.44cm, 79kg).

Table 1: Subject Demographics

Age(years)	Height(cm)	Weight(kg)
19.7	177.44	79

Hypothesis Testing

The following hypotheses were tested in this study. All hypotheses were tested with a level of significance set at $\alpha \leq 0.05$. An independent t-test was used to measure pre vs. post BESS scores.

Hypothesis 1: Post scores after exercise on the BESS test will be higher indicating less balance than on the pre-test.

Conclusion: BESS pre vs. post scores showed a significant decrease in BESS performance (9.86 ± 5.01);(15.86 ± 7.88).

Hypothesis 2: Post scores after exercise on the Sway Balance application™ will be lower indicating less balance than on the pre-test.

Conclusion: Sway pre vs. post scores showed a significant increase in Sway performance, refuting my hypothesis (79.65 ± 17.64); (85.18 ± 12.52).

Table 2. Pre vs. Post BESS and Sway Balance Application™ Scores

Timing of the test	BESS	Sway Balance™
Pre	9.86 ± 5.01	79.65 ± 17.64
Post	15.86 ± 7.88	85.18 ± 12.52

Hypothesis 3: The Sway Balance application™ will be more valid than the BESS test when measured after activity indicating it is a better test to measure balance.

Conclusion: There was a negative correlation between pre scores for BESS and Sway (r= -.560, n=7, p>.05). There was a negative correlation between post scores for BESS and Sway (r=-.089, n=7, p>.05).

Table 3. Pearson correlation of BESS and Sway Balance Application™ Scores

Timing of the test	BESS and Sway Balance
Pre	r= -.560, n=7, p=.192
Post	r=-.089, n=7, p=.850

Additional Findings

An independent t-test was used to measure pre vs. post scores on the BESS and Sway Balance Application™. Pre vs. post RPE scores on the BESS test (7.86 ± 1.57); (10.86 ± 3.44). Pre vs. post RPE scores on the Sway Balance test (7.57 ± .98); (11.14 ± 2.91).

Table 4. Pre vs. Post RPE Scores on the BESS and Sway Balance Application™

Timing of the test	BESS RPE scores	Sway Balance™ RPE scores
Pre	7.86 ± 1.57	7.57 ± .98
Post	10.86 ± 3.44	11.14 ± 2.91

DISCUSSION

Discussion of Results

Sports medicine clinicians often use balance testing during the evaluation and rehabilitation of various injuries. The Balance Error Scoring System (BESS) was developed to provide clinicians with an inexpensive and objective way to assess balance outside of the laboratory.[1] BESS consists of three stances: single-leg, double-leg and tandem and is considered to be the gold standard in sideline assessment.[1] Even though this test is considered objective, some clinicians feel that counting the errors can vary from person to person. Therefore, there is a need for other tests to evaluate balance.

Recently, an objective tool available for mobile devices called the Sway Balance Application™ was created to evaluate balance. This application is readily available on any device and allows for easy management of athletes scores.[2] The cost of the Sway Balance application™ subscription that we used for this study was $500.00 for approximately 100 subject profiles and 3 users. This test consists of five stances each lasting 10 seconds each, similar to the BESS test.[2] However, research does not show that this tool is valid for sideline assessment. Therefore, we performed this study to determine if the Sway Balance application™ is a valid tool to assess balance in comparison to the BESS test when evaluating balance prior to and immediately after exercise.

A key finding of this study was a significant decrease between pre-activity and post-activity BESS scores, conversely there was a significant increase between pre and post Sway scores. Currently, there is no research in the literature examining pre vs. post scores between the BESS test and the Sway Balance application™.

Because there is no published research on these variables, it is unclear whether this is expected. Another possible reason for this finding could be the device used. The size or weight of the iPads could alter the results due to subjects holding and/or using the device incorrectly. There could be complications within the iPad devices themselves. Future research should use different devices to see if there are differences between scores.

It is of interest that BESS scores showed a significant decrease post activity. This decrease has also been seen in several studies. Wilkins et al[2] looked at a fatigue and control group before and after a 20 minute fatigue protocol. Fourteen fatigue subjects significantly increased in total errors from pretest to posttest.[2] Another study performed by Riemann et al[25] assessed sixteen participants with a mild head injury. These participants showed higher postural instability, especially on the 3 stances on a foam surface.[25] Therefore, activity has the potential to cause a decrease in postural control as measured through the BESS total error score.

A decrease in postural control due to fatigue has been concluded in numerous studies using various fatigue protocols.[11,12] Erkmen et al.[11] found that fatigue caused by a treadmill protocol decreased balance performance. They hypothesized that this may lead to slowing of the efferent signals to maintain postural control and as a result athletes are at a greater risk for musculoskeletal injuries.[11] Even though this study does not use the same fatigue protocol as the current study, it still shows that fatigue decreases balance performance. Fox et al.[12] tested thirty-six college athletes during two different balance sessions before and after exercise. The balance tests consisted of BESS, sway velocity and elliptical sway area.[12] This study found a decrease in balance performance after both anaerobic and aerobic exercise protocols using BESS, elliptical sway area, and sway velocity.[12] This study used exercise and the BESS test, which were both used in the current study. Therefore, these findings follow the current studies finding that activity causes a decrease in balance. Erkmen et al.[11] assessed balance before and after twelve male basketball players completed the Bruce Protocol until anaerobic threshold was met. This study found a decrease in balance scores for the dominant and double leg stance in basketball players.[11] The current study used a different fatigue protocol, but both studies show that activity may decrease balance scores. Through these studies it is possible that no matter the fatigue protocol, balance scores on the BESS test may decrease.

Another finding of this study was a negative correlation between pre Sway™ and BESS scores as well as between the post Sway™ and BESS scores. This finding is contrary to past research, which shows a significant inverse correlation.[2] However, past research did not include activity in their studies. Patterson et al[2] compared the BESS test and the Sway Balance application™ randomly during one session. Twenty-one non-athletes participated in this study.[2] A strong inverse correlation was found between the scores from both balance assessments.[2] Jansen et al[13] also found a significant negative correlation when comparing the BESS and the Sway Balance application™ during one session. Forty-three older adults participated in this study.[13] The current study also used both the BESS and the Sway Balance application™, but activity and an athletic population were used for the current study. Currently, research on the Sway Balance application™ has not used athletes for participants. Therefore, this could play a role in the outcome of our study. A possible reason for this could be that athletes have different physiological properties that vary from the untrained person. An athlete relies on balance daily to successfully compete, but an untrained individual would not have to use balance as much. Therefore, the increase in Sway Balance™ scores for the current study could be related to this idea.

Conclusion

In contrast to previous research, the Sway Balance application™ did not show significant inverse correlations when tested with college athletes. The Sway Balance application™ and the BESS test showed a negative correlation on both pre and post balance scores. The Sway Balance™ scores increased post-activity. However, the BESS test results did relate to previous research. Physical activity did affect balance scores on the BESS test. Due to the limitations of this study future research should be performed to examine the validity of the Sway Balance application™.

Recommendations

The findings from this study suggest that the current gold standard for sideline assessment, the BESS test, should still be used when evaluating balance in athletes. A limitation of this study was the number of subjects that participated. This could play a role in the increase in post Sway Balance application™ scores. Future research should include more subjects into the study in order to have better results. It should be noted that due to the low number of participants the findings of this study cannot be generalized for the entire population. Future research should also use an athletic population and perhaps even look at differences in scores based on the athlete's position. The Sway Balance application™ could have potential of being a valid objective assessment of balance. However, based on our findings, more research is warranted to validate this.

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APPENDICES

APPENDIX A

Review of Literature

REVIEW OF THE LITERATURE

Introduction

Sports injuries are rarely associated with balance problems, rather their association is more specific to a structure of the body.[1] However, sports often require maximal body control, where even the smallest impairment may interfere with performance without producing noticeable unsteadiness.[1] Injuries producing weakness, sensory impairment, decreased joint range of motion, or changes in neural processing can affect the ability to control one's body in space.[1]

Sports medicine clinicians often use balance testing during the evaluation and rehabilitation of various injuries.[2] These injuries can be related to orthopedic and various head injuries, including concussions.[2] Currently, concussion testing mainly relies on the athlete's truthfulness regarding symptoms.[3] Thus, objective measurements are needed to carefully evaluate the level of severity of the injury and prevent premature return to competition.[3] However, athletes often fear they will not be permitted to return to activity if they disclose such information, which can increase the risk for further damage to balance in addition to exasperating cognitive issues.[3]

Balance can be defined statically maintaining a base of support with minimal movement and the ability to perform a task while maintaining a stable position.[4] Factors that influence balance include sensory information from the eyes and ears and movement by affecting coordination, joint range of motion (ROM), and strength.[4,5] Fatigue and/or injury may also affect balance, leading to functional instability.[5] Therefore, there is a need for balance testing and there are several methods for assessing it.

The Balance Error Scoring System (BESS) was created as an objective measurement that is reliable and valid for the evaluation of a concussion and the insufficiencies as a result.[3] It allows health care professionals to evaluate balance objectively and inexpensively.[2] The BESS measures balance of a patient through different measures and is scored by counting the number of errors the athlete makes during the tests.[2] BESS uses 3 stances (double, single, and tandem) on 2 surfaces (firm, foam).[2,3]

The Sway Balance Application is another objective tool that was recently created to assess balance. This tool uses built in motion detectors in mobile devices to measure postural sway.[6] It allows health care professionals to evaluate balance objectively and quickly. The Sway Balance Application measures balance of a patient through five stances and is scored on a 100 point scale.[6,7,8] A score of 100 means the subject has perfect balance.[6,7,8]

The purpose of this literature review is to summarize the current and past research evidence regarding the effects of activity on balance scores as well as the effects of different objective measures to assess balance.

Balance Defined

Balance is defined by Knudson[9] as a person's ability to control their body position relative to some base of support and can further be defined as static and dynamic. Static balance is a stationary movement and dynamic balance is a multidirectional maximal single leg reach from a unilateral base of support.[4] Bell et al[10] states that static balance involves feedback from the somatosensory, visual, and vestibular systems to achieve steadiness.

*In reality, all postures are dynamic, involving muscle activity in order to maintain position. Even when standing still, the body is in motion, undergoing postural sway. The alignment of the body when maintaining the standing posture becomes important in controlling and maintaining the appropriate level of postural sway. To maintain a standing position, each segment of the body must be balanced with respect to the supporting segments. For this reason, there must be muscular activity in order to maintain balance. The reasons the body produces postural sway is unclear. It may have origins in the postural reflexes that aid the maintenance of upright posture. The motion of the center of gravity and the center of pressure is used as a measure of postural stability.

Bressel et al.[4] looked at the comparison of static and dynamic balance in female soccer, basketball and gymnastics athletes. First, static and dynamic balance need to be identified. Thirty-four female volunteers from a Division 1 soccer, basketball or gymnastics team participated in this study.[4] The BESS test was used to assess static balance and the Star Excursion Balance Test was used to assess dynamic balance.[4] Subjects were tested during one session in an athletic training facility. This study found that gymnasts and soccer players do not differ in terms of static and dynamic balance.[4] However, basketball players showed inferior static balance compared with gymnasts and inferior dynamic balance compared with soccer players.[4]

Broglio et al[12] reported that there are three subcomponents of the mechanism that gathers peripheral information to keep postural control.[12] Afferent information is transferred to the CNS, where different regions of the brain combine the signals and produce a motor output.[12] The basal ganglia receive the initial inputs and start a motor response based on the current position of the limbs.[12] This signal works with those of the cerebellum.[12] A final efferent signal is generated and transmitted through the brainstem to alpha motor neurons.[12] These nerves innervate the skeletal muscles that maintain postural control.[12]

Factors that Affect Balance

Sensory information obtained from the somatosensory, visual and vestibular systems and motor responses that affect coordination, joint range of motion (ROM), and strength are all factors that affect balance.[4] In continuation of this, postural control relies on many things from a variety of systems including environmental adaptation, the musculoskeletal system, a predictive central set, motor coordination, eye and head stabilization, sensory organization, and adequate limits of stability.[13] Therefore, the body works as a whole unit to maintain normal postural control as suggested by the research of Dornan et al[14], Horak et al[15] and Bressel et al.[3,14,15]

Dornan, Fernie, and Holliday[14] found that the visual system is necessary for proper postural control when somatosensory information is reduced. Horak, Nashner, and Deiner[15] revealed that somatosensory loss in the feet and ankles does not cause an increase in postural sway. They also found that in some cases subjects would use both hip musculature and ankle strategy to maintain proper balance.[15]

By exploring the different dynamics of various sports it was determined that gymnasts often practice motionless balance skills on the balance beam, similar to skills required in the BESS.[4] In contrast, basketball players rarely balance motionless skills on one leg and often attend to ball and player position cues. Soccer players often perform single-leg reaching movements outside their base of support during passing, receiving, and shooting, which may explain having better dynamic balance than basketball players. It has been theorized that because static and dynamic balance scores were not different between soccer players and gymnasts, some sensorimotor challenges may be common in these 2 sports.[4]

The ability to maintain balance through difficult situations is recognized as one of the basic motor skills. The three most critical factors affecting stability are the size of the base of support, the relation of the line of gravity to the base of support, and the height of the center of gravity. Other factors also play a role such as mass of the body, friction, segmental alignment, visual and psychological factors and physiological factors.

Maintaining a base of support when size and shape are factors is a challenging task to accomplish. In reference to size, the challenge is to keep the center of gravity over the base of support, which the wider the base the easier that is. For example, if a person is standing it is best to widen the space between the feet because this will allow equilibrium to improve due to a wider base. In regards to the shape, the base should be widened in the direction of the oncoming force.

Typically, the height of the center of gravity is located approximately at the level of the upper third of the sacrum, but only while standing. If the arms or raised or if the weight is carried above waist level, the center of gravity moves to a higher position, thus making it harder to maintain equilibrium.

When the force that the body is resisting is the downward force of gravity, the nearer the line of gravity to the center of the base of support, the greater the stability. Instability can occur when gravity shifts. This occurs when the force of gravity changes from a linear force to a rotational force, or torque.

Mass can also play a role in the body's ability to remain stable. The mass of an object is a factor in equilibrium only when motion or an external force is involved. The greater the mass, the greater the stability.

Measurements of Balance

There are several methods of measuring balance, BESS, SEBT, postural sway and time to time stabilization test to name a few.[4] BESS is an objective measure of balance using three stances for 20 seconds each with hands on hips and eyes closed.[4] The SEBT is a single leg stance while moving the opposite leg in 8 directions.[4] Postural sway is measured through a force plate, which measures balance with various stances.[4] Bressel et al[4] assessed both static and dynamic balance. Static was assessed using 3 stance variations (single leg, double, tandem) on stiff and compliant surfaces.[4] Dynamic was assessed through leg reach distances from the Star Excursion Balance test.[4]

The BESS is a clinical field test that can be used for sideline evaluations of an athlete's postural stability after an injury including mild traumatic brain injury.[2] The BESS measures an athlete's postural stability through a clinical assessment battery and is scored by counting the errors the athlete commits during the tests.[2] The BESS can be used to compare baseline scores with scores after an mild head injury. The BESS includes 3 conditions: double leg, single leg, and tandem stances on a firm surface.[2] An error is scored if the subject did any of the following: lifting the hands off the iliac crests, opening the eyes, stepping, stumbling or falling, moving the hip into more than 30° of flexion or abduction, lifting the forefoot or heel or remaining out of the test position for longer than 5 seconds.[30] Errors are calculated for each of the 3 stances and totaled for the BESS score.[2]

Force plates are often used in research as another way to assess balance. This particular method is better suited for laboratory settings due to the size and weight of the equipment. Quatman-Yates et al[16] wanted to determine if a postural sway assessment protocol using a force plate system could serve as a reliable assessment tool for adolescent athletes. Adolescent female athletes who participated in high school soccer participated in this study during their offseason. Participants were divided into an eyes open or eyes closed group. They performed 3 trials of quiet standing on the force plate with 1-2 minutes of rest between each trial. Force plate measures in this study demonstrated higher reliability coefficients for test-retest reliability with adolescent athletes.[16]

Another study by Catena et al[17] wanted to examine the effects of a concussion on gait stability when either a cognitive or motor perturbation is imposed. Fourteen individuals suffering from a concussion and fourteen matched controls performed a single task of level walking, a continuous sequential question and answer task while walking, and an obstacle crossing task.[6] They found that concussed individuals adopted a more conservative strategy to maintain gait stability and they also displayed signs of possible instability during the question and answer task. The question and answer task was most sensitive to distinguishing concussed individuals from healthy individuals, supporting the use of a similar dual-task modality in future testing after a concussion to determine a proper time for return to activity.[6]

The Sway Balance™ is a mobile software system that measures stability using the built in motion sensors of any IOS mobile device to quantify postural sway.[7] The test uses 5 different stance positions including, a bipedal stance, tandem stance and a single leg stance.[6] After the 5 positions, a score will be given.[7] As the device is pressed against the chest, a proprietary motion analysis algorithm calculates stability and provides an easy to understand value on a 100 point scale with 100 being completely stable and 0 being unstable.[7]

Fatigue Effects on the Body

Bressel et al[4] expressed the immediate effect of fatigue, which is a reduction in the ability of muscles to apply force and thus impairs balance. Another study by Erkman et al[5] stated, fatigue has an adverse effect on neuromuscular control. Muscle fatigue impairs proprioceptive acuteness due to the increase in muscle spindle discharge and disrupting afferent feedback.[5]

A study be Ageberg et al[18] looked at the effect of short-duration, sub-maximal cycle ergometry, a standardized method of inducing fatigue, on balance in single-limb stance in 24 healthy subjects. Exercise was performed on a cycle ergometer at 60 revolutions per minute.[16] Subjects worked at 60% of their HR max and stopped when HR was over 60% of their calculated HR max.[16] Subjects balanced single leg on a force plate before and after the fatigue protocol.[16] Results were higher in amplitude in the single plane, in average speed and in the number of movements exceeding 10mm from the mean value of the center of pressure in the frontal plane.[16]

Rozzi et al[19] found that in response to muscular fatigue, subjects demonstrated a decrease in the ability to detect joint motion for extension, an increase in the onset time of contraction for the medial hamstring and lateral gastrocnemius muscles in response to landing a jump, and an increase in the EMG area of the first contraction of the vastus medialis and vastus lateralis muscles when landing a jump. In addition, the increase in EMG area of the vastus lateralis after fatigue was greater for the male athletes compared with the females.[19] The study showed that knee joint laxity did not significantly increase after muscle-fatiguing exercises.[19]

Measuring Fatigue

Lab Protocols

Many protocols have been used to induce fatigue in research. Erkman et al[5] used the Bruce Protocol until anaerobic threshold was met.[5] The Bruce protocol is performed by using a treadmill, beginning at a speed of 2.74km/h and 10% gradient for 3 minutes.[5] At the second stage, the gradient is increased by 2% each time and the speed is 4.02km/h.[5] Speed and the gradient will increase in each stage.[5] The exercise protocol is ended when the subject passes the anaerobic threshold.[5] The VO_2 at the anaerobic threshold was measured by the V-slope method. VO_2, heart rate (HR) and exercise duration at the anaerobic threshold (ventilatory threshold) level were determined for each athlete.[5]

Johnston et al[20] used an isokinetic dynamometer to fatigue subjects.[20] Subjects were fatigued to less than 50% of their initial tested strength, determined by the force meter on the dynamometer.[20] Fatiguing exercise consisted of 1 minute intervals of 10 different levels, with no rest between intervals, for a total of 10 minutes of exercise.[20]

Field Protocols

Other studies used multiple protocols to assess fatigue. In this case, two different protocols were used.

The first was aerobic, the yo-yo intermittent recover test level 1. This test is a repeated 20-m shuttle run from the starting line to the turning point and then the finish line at progressively increased speeds, which is controlled by audible tones.[21] The protocol began with 4 running bouts at 10 to 13km/h over the first 160m, followed by 7 running bouts at 13.5 to 14km/h. It increased by 0.5km/h speed increments after every 8 running bouts.[21] Between these bouts, subjects had a 10 second rest period.[21] Fatigue was reached when the subject could not reach the line by the beep and the second was anaerobic, which started at level 23.1 and continued for 2 minutes.[21] On average recovery time was between 8 and 13 minutes post exercise for "very, very hard" on the RPE scale.[21]

The 7 station exertion protocol was also very popular among researchers: Station 1 was a 5-minute moderate jog at the subject's self-selected pace.[3] Station 2 was 3 minutes of sprints up and down the length of a basketball court. Station 3 was 2 minutes of push-ups. Station 4 was 2 minutes of sit-ups.[3] Station 5 was 3 minutes of 12-in (30.48-cm) step-ups.[3] Station 6 was another 3 minutes of sprints.[3] Station 7 was a 2-minute run, during which subjects were instructed to maintain the fastest pace they could for the entire 2 minutes.[3] Exertion was reached when the RPE was 15.[3] In contrast of what Fox et al found, balance recovery for this study was at 20 minutes post exercise.[3]

Wilkins et al[2] used a circuit design using the space on and around a regulation-sized basketball court.[2] The protocol consisted of 7 stations that were different from the ones listed above.[2] Stations 1 and 7 were moderate jogging stations, around the gym, of 5 and 2 minutes, respectively.[2] Stations 2 and 6 were both 3 minutes of straight-line sprint work.[2] Stations 3, 4, and 5 consisted of 2 minutes of push-ups, 2 minutes of sit-ups, and 3 minutes of 12-in (30.48-cm) step-ups.[2] Didn't define fatigue, therefore results were not optimal.[2]

Effect of Fatigue on Balance

There are several studies that show balance is affected by fatigue.[2,22,23] Fatigue produced above anaerobic threshold through exercise vanishes by about 15 minutes after the end of the exercise.[4] This is important to take into consideration when evaluating balance.[22] Wilkins et al.[2] wanted to show the effects of a whole body fatigue protocol on performance using the BESS test. The fatigue protocol consisted of 7 different stations. 14 fatigue subjects and 13 control subjects were used in this study.[2]

Balance was assessed before and immediately after the 20 minute fatigue protocol or rest period for control subjects.[2] Results showed that the fatigue group had a greater number of total errors after testing as well as had more errors than the control group. Regarding stances, fatigue affected performance on the tandem more than the double-leg or single-leg conditions.[2] Overall results showed a decrease in postural stability as a result of fatigue measured by the BESS total error score.[2]

Nardone et al[22] looked at fatigue and its effect on balance. Body sway variables were recorded by a dynamometric platform in 13 subjects, before and after two types of exercise (treadmill walking and cycle ergometer pedaling).[22] Each exercise was performed under both fatiguing and non-fatiguing conditions.[22] Results showed that treadmill walking increased body sway when the exercise was fatiguing or above anaerobic threshold.[22]

In another study, Gribble et al[23] explains that fatigue may impair the proprioceptive and kinesthetic properties of joints. Fatigue increases the threshold of muscle spindle discharge, which disrupts afferent feedback, subsequently altering joint awareness.[23] Results showed reduced knee and hip joint angles for the involved limb of those with chronic ankle instability (ICAI) occurred simultaneously with reduced reach distance as a percentage of leg length (MAXD).[23] Therefore, this indicates a relationship between performance on the star excursion balance test (SEBT) and altered neuromuscular control at the knee and hip due to ankle injury.[23] Results also showed a unilateral effect of chronic ankle instability (CAI) on performance of the SEBT, suggesting aid from a peripheral alteration in neuromuscular control.[23] The involved limb of chronic ankle instability (ICAI) group had consistently larger pre-fatigue-post-fatigue decreases in MAXD, knee flexion, and hip flexion compared with the uninjured limb (UCAI) and the healthy group (HEA).[23]

Balance as a Diagnostic tool

Due to the particulars of balance it can often be used as a diagnostic tool to assess injuries including MTBI. Currently, MTBI are evaluated based on subjective assessments, incorporating an objective measure such as balance to assess postural control may allow MTBI assessments to have more reliability.[21] Fox et al.[21] stated that balance can be an objective assessment used to evaluate Mild Traumatic Brain Injuries. A systematic review of the BESS test found that the reliability of the

BESS ranges from moderate (<0.75) to good (>0.75).[10] A high content validity in finding balance problems in concussed and fatigued populations was also found.[10] In addition, the BESS test has a good content validity for finding balance problems in functional ankle instability, ankle bracing, aging populations and people performing neuromuscular training.[10]

Halil et al[24] looked at the effects of fatigue on the balance performance using the BESS test in volleyball players. Eighteen volleyball participants from a university team volunteered to participate in this study. The BESS test was performed both before and after a fatigue protocol on both a firm and foam surface.[24] The Bruce Protocol is widely used as a fatigue protocol and consists of walking on a treadmill at 1.7mph at a 10% grade for 3 minutes, at the second stage speed was increased to 2.5mph and grade was increased by 2%, grade increased 2% and speed was increased 0.8mph each additional stage. Fatigue was assessed using a Rated Perceived Exertion (RPE) Scale and a HR monitor. All BESS scores increased after fatigue, with females scoring more errors on the posttest, foam surface and total number of errors.[24]

Riemann et al[25] investigated the efficacy of a clinical balance testing procedure for the detection of acute postural stability disruptions after a mild head injury. Sixteen subjects diagnosed with a mild head injury and sixteen matched controls were included in this study.[25] Balance was tested at 3 post-injury time intervals (days 1, 3, and 5) using two procedures: the BESS test and the NeuroCom Smart Balance Master a computerized system that allows for sensory organization testing using a dual force-plate system.[25] Both the support surface and visual surround tilt to alter sensory conditions.[25] Results showed significantly higher postural instability in the mild head injury subjects in the BESS group, with the 3 stances on a foam surface showing significant differences through day 3 post-injury.[25] Results of the NeuroCom revealed significant group differences on day 1 post-injury. Therefore, it was theorized that BESS is a valid test to use to assist clinicians in making return to play decisions in absence of force-platform equipment.

Recently a new method has emerged for assessing balance is using an accelerometer. Accelerometers are electromechanical sensors that produce an electrical output that is proportional to an acceleration input.[8] Sway balance™ is a mobile device application that uses triaxial accelerometer output to quantify postural sway during the performance of a series of tasks.[8] During each 10 second stance, deflections of the triaxial accelerometer are recorded throughout each of the tasks and units that correspond to the accelerations and are used to calculate a final balance score. Research on the Sway Balance™ shows a strong relationship between Sway Balance™ and the BESS test (r=0.77) and (r=0.87, r=0.95).[8,26] The test also shows a strong test-retest reliability, however it is suggested that a single familiarization test be used to establish a consistent baseline and remove the learning effect.[8,26] Sway Balance™ has been established as a valid software tool for objective balance testing.[8,26]

Patterson et al[6] assessed the value and validity of using software developed to access the iPod and iPhone accelerometers output and translate that to the measurement of human balance. Thirty healthy, college aged individuals volunteered for this study. Participants performed a static single leg test protocol for 10 seconds on a Biodex Balance System SD while concurrently using a mobile device with balance software. Anterior and posterior stability was recorded using both devices, described as the displacement in degrees from level and was termed the "balance score". This study found that balance scores derived from the smartphone accelerometer while using the software were consistent with balance scores obtained from a previously validated balance system.

Concussion or Mild Traumatic Brain Injury (MTBI)

In a study by McCrea et al it was stated that,"When a mild traumatic brain injury (concussion) occurs it is followed by a complex cascade of ionic, metabolic, and physiological events that can affect cerebral function for several days to weeks."[1] Broglio et al.[12] listed numerous symptoms that have shown negative affects after a concussion and within this list was postural control.[12] It is suggested that assessing balance objectively is more sensitive to post-concussion decrements than traditional paper and pencil tests.[12] A study by Cantena et al[17] concluded that concussed individuals changed their normal gait strategy in order to maintain stability. However, subjects still showed signs of instability regardless of compensatory movements.[17]

McCrea et al[1] wanted to prospectively measure immediate effects and natural recovery course relating to symptoms, cognitive functioning, and postural stability following sport-related concussion. A prospective cohort study of 1631 football players from 15 U.S. colleges were included in this study. All players underwent a pre-season baseline testing on concussion assessment measures in 1999, 2000, and 2001. Ninety-four players with concussion and fifty-six non-injured controls underwent assessment of symptoms, cognitive functioning, and postural stability immediately, 3 hours, and 1, 2, 3, 5, 7, and 90 days after injury. Scores on the Graded Symptom Checklist, Standardized Assessment of Concussion, Balance Error Scoring System, and a neuropsychological test battery were measured. Seventy-nine players with a concussion (84%) completed the protocol through day 90. Players with a concussion exhibited more severe symptoms, cognitive impairment, and balance problems immediately after concussion.[1] On average, symptoms gradually resolved by day 7, cognitive functioning improved to baseline levels within 5 to 7 days, and balance deficits dissipated within 3 to 5 days after injury.[1] Therefore, it is important to perform these measures following a concussion to ensure proper return to participation.

Summary

As it has been outlined above, balance requires support from multiple body systems in order to be achieved. Achieving balance allows our bodies to perform movement successfully because we are aware of our body in space. People achieve balance through training, either through sport or specific balance exercises. We also know that balance can be easily affected by a variety of things. Therefore, this allows balance to be a diagnostic tool. Balance can be evaluated through various means and in a timely manner. By having a baseline, balance problems can be easily diagnosed when sustaining an injury.

Concussions, specifically evaluation and treatment, are a continuing issue in athletics. Balance is often evaluated when concussions are suspected. There are many objective measures to assess balance, but no single measure has been determined to be the gold standard through research for sideline testing. Based on current evidence, the BESS test is the most widely used sideline tool and has been shown to be reliable and valid.

A significant amount of research has been conducted fatiguing specific areas of the body and then testing balance using various measures. However, few have been performed fatiguing the body as a whole and in a manner to replicate a typical athlete's practice/event. Establishing a valid sideline tool for injury assessment while an athlete may be fatigued is essential. There is not a lot of research available examining the most reliable and valid objective measure to test balance. Therefore, more research is needed to help athletic trainers provide optimal service when evaluating balance to determine an accurate diagnosis.

APPENDIX B

The Problem

STATEMENT OF THE PROBLEM

Sports medicine clinicians often use balance testing during the evaluation and rehabilitation of various injuries.[2] These injuries may be related to orthopedic injuries or head injuries including, concussion.[2] Sporting activities require maximal body control, therefore any impairment can alter performance. There are multiple factors that influence balance, which include sensory, joint range of motion and strength. On a different spectrum fatigue and injury can affect balance as well.

There are several methods for assessing balance. The BESS test seems to be the most widely used sideline test to evaluate a head injury. The BESS test is objective, inexpensive, valid and reliable.[2] However, the Sway Balance Application™ is a recent tool created to assess postural sway, but research showing its reliability and validity are lacking. Therefore, research needs to be performed to see if this tool is applicable as a sideline test for athletic trainers and other healthcare professionals.

Past research shows that fatigue decreases postural control.[21] Therefore, pre and post balance scores from each test will be evaluated in order for the research to be more applicable and to ensure reliability and validity.

The purpose of this study is to test the validity of the BESS test and the Sway Balance Application™ when evaluating balance.

Definition of Terms

The following definitions of terms will be defined for this study:

1) Muscular Fatigue- inability to generate force and has been characterized not only by a loss of force production capability, but also by localized discomfort and pain.[19]
2) Balance- a person's ability to control their body position relative to some base of support.[9]
3) Accelerometer- electromechanical sensors that produce an electrical output that is proportional to an acceleration input.[8]

Limitations of the Study

The following are possible limitations of the study:

1) Amount of time that passes between the end of practice and the post-test
2) Tests will be performed in a controlled environment

APPENDIX C

Additional Methods

APPENDIX C1

Informed Consent Form

Informed Consent Agreement

Please read this consent agreement carefully before you decide to participate in the research study.

Project Title: Validity of BESS test and the Sway Balance Application on Pre and Post Exercise Balance Scores

Purpose: The purpose of this research study is to test the validity of the BESS test and the Sway Balance app when evaluating balance pre and post exercise.

Participation: You are being asked to participate in this study because you are age 18 or over and a collegiate athlete on the Men's or Women's Soccer Team. This study will take place at Philipsburg Soccer Complex prior to an immediately after your scheduled team practice. You will be asked to perform the Balanced Error Scoring System twice (once before practice that will act as a baseline and once after practice). You will perform three stances on a firm surface (single leg, double leg, and tandem stance). Each stance will last 20 seconds long and you will place your hands on your hips and keep your eyes closed for each stance. I will use the Rated Perceived Exertion Scale before the balance test in order to rate how tired you feel. The numbers are listed from low to high and you will tell me the number that correlates with how you feel. You will also be asked to perform the Sway Balance App test twice (once before practice that will act as a baseline and once after practice). You will perform 5 stances on a firm surface. Each stance will last 10 seconds long and you will hold a device to your chest for each stance. I will use the Rated Perceived Exertion Scale again to measure how tired you feel.

Time Required: Your participation is expected to take no more than 30 minutes of your time.

Risks & Benefits: The potential risks associated with this study are minimal and may include, injury due to loss of balance. The researcher will stand near you during balance testing in case you lose your balance. If you are injured during the testing, you should go to the California University of Pennsylvania Health Center (Ground level of Carter Hall, 724-938-4232). I, the researcher have extensive first aid training and I am a state licensed healthcare professional. Any medical care required will be at your own expense. There are no direct benefits for you as the participant, but this study is expected to benefit athletic trainers and indirectly the athletes they work with. The results will be used to evaluate how balance results are affected by physical activity.

Compensation: You will receive no financial compensation for your participation.

Voluntary Participation: Please understand that participation is completely voluntary. You have the right to refuse to answer any question(s) for any reason, without penalty. You also have the right to withdraw from the research study at any time without penalty. If you want to withdraw from the study please tell the researcher. The researcher will inform the participant of any significant new findings developed during the research that may affect them and influence their willingness to continue participation. The researcher has the right to end subject participation in the study if the participant does not comply with the research procedures. All data recorded will be destroyed.

Confidentiality: Your individual privacy will be maintained throughout this study. In order to preserve the confidentiality of your responses, I have assigned a code number to your information. The list connecting your name to this number will be kept in a locked file in the research advisors campus office. The researcher and the research advisor will only have access to the records. When the study is completed and the data have been analyzed, this list will be destroyed. No identifying information will be used in any reports or publications.

Whom to Contact with Questions: If you have any questions or would like additional information about this research, please contact Meghan Almarode at 540-430-5555, ALM8551@calu.edu or the thesis research advisor Dr. Shelly DiCesaro at 724-938-5831 or dicesaro@calu.edu.

Agreement: I understand the above information and have had all of my questions about participation in this research study answered. By signing below I voluntarily agree to participate in the research study described above and verify that I am 18 years of age or older.

Signature of Participant ______________________________
Date ____________________

Printed Name of Participant ______________________________

Signature of Researcher ______________________________
Date ____________________

You will receive a copy of this form for your records.

Appendix C5

Individual Data Collection Sheet

Code #_____ Male____ Female____ Age_____

Baseline Measurement

Balanced Error Scoring System			
	Double Leg	Single Leg	Tandem Stance
# of Errors			

RPE Scale______

Code#_____ Male____ Female____ Age_____

After Moderate Activity

Balanced Error Scoring System			
	Double Leg	Single Leg	Tandem Stance
# of Errors			

RPE Scale______

Appendix C6

Participant Identification Sheet

Subject #	Pre 1	Post 1	Pre 2	Post 2
1	Sway	BESS	Sway	BESS
2	BESS	Sway	BESS	Sway
3	Sway	BESS	Sway	BESS
4	BESS	Sway	BESS	Sway
5	Sway	BESS	Sway	BESS
6	BESS	Sway	BESS	Sway
7	Sway	BESS	Sway	BESS

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ABSTRACT

TITLE: Validity of the Balance Error Scoring System and the Sway Balance Application™ On Pre and Post Exercise Balance Scores

RESEARCHER: Meghan Almarode, LAT, ATC, NASM-PES

ADVISOR: Shelly DiCesaro, PhD

REASEARCH TYPE: Master's Thesis

PURPOSE: The purpose of this study was to test the validity of the Sway Balance Application™ in comparison to the Balanced Error Scoring System test when evaluating balance prior to and immediately after exercise.

DESIGN: Pre and post experimental design.

PARTICIPANTS: A total of 7 male collegiate soccer players participated in this study. Volunteers were from the Men's soccer team at California University of Pennsylvania.

METHODS: Volunteers read and signed the informed consent form. Following this, participants completed two separate sessions of balance testing, one for the BESS test and one for the Sway Balance application™. The order of the tests was determined by the counterbalance chart. Tests were completed pre and post physical activity.

FINDINGS: Pre and post scores showed a significant decrease in BESS scores. However, there was a significant increase in Sway Balance performance between pre and post scores. There was a negative correlation for pre scores between BESS and Sway. There was a negative correlation for post scores between BESS and Sway.

CONCLUSION: Based on the findings of this study, athletic trainers need to be aware of the

effects of activity when evaluating mild head injuries or balance.