

A COMPARISON STUDY: BALANCE ERROR SCORING SYSTEM USING REAL-TIME
AND SLOW-MOTION VIDEO PLAYBACK

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Education with a major in Exercise Science.

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ABSTRACT

The Balance Error Scoring System (BESS) is a subjective clinical balance assessment frequently used by various healthcare providers. The test consists of three different stances (feet together, tandem, and single leg) that are each 20 seconds long. An administrator carefully observes and records the number of pre-defined balance or stability errors committed by the test subject. However, it is unclear if test administrators are able to observe all errors committed by the subject in real-time.

PURPOSE: The purpose of this study was to analyze the difference in scoring a balance assessment with the assistance of video playback and slow-motion playback to identify if errors were all noted.

METHODS: 66 NCAA Division I athletes ages 19.68 ± 1.27 years old were scored in person and recorded on video for slow-motion access while performing two series of BESS trials by an experienced BESS rater. Age, sex, orthopedic injuries, past concussions, height, and weight were also recorded. Errors were recorded using the BESS Error Criteria (BEC) with a maximum score of 10 errors and Total Errors Scored (TES) the accumulative errors scored in 20 seconds.

RESULTS: Significant differences between means in both measures scored in real-time and slow-motion playback (TES: 6.0 ± 4.3 and 6.8 ± 5.2 ; BEC: 6.0 ± 4.3 and 6.7 ± 4.9 errors, respectively) were reported.

CONCLUSION: Results of this study suggest that experienced BESS raters capture more balance errors when viewed in slow-motion. However, Cohen's *d* effect size (TES: 0.2 and BEC: 0.1) suggests that clinically this is not meaningful, therefore; healthcare providers should still score BESS in real time.

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LIST OF ABBREVIATIONS

ACSM	American College of Sports Medicine
AP	Anterior-posterior
BEC	BESS errors criteria
BESS	Balance Error Scoring System
ML	Medial-lateral
MS	Multiple sclerosis
MTBI	Mild traumatic brain injury
NATA	National Athletic Trainer's Association
NCAA	National Collegiate Athletic Association
OA	Overall
SOT	Sensory Organization Test
TES	Total errors scored

CHAPTER 1

INTRODUCTION

Balance is an equivocal component for both activities of daily living and athletic performance (A. V. Patel, Mihalik, Notebaert, Guskiewicz, & Prentice, 2007; Patterson, Amick, Thummar, & Rogers, 2014). Balance is defined as the ability to maintain postural equilibrium, the act of maintaining the body to a state of static or dynamic control (Cavanaugh, Guskiewicz, & Stergiou, 2005). Without balance the human body can struggle with maintaining control over the coordination and operation of musculoskeletal and central nervous system complexes usually causing injury (Allum & Honegger, 1998). The assessment of balance has evolved over the years with the advancement of technology. Balance assessments can now be categorized into qualitative and quantitative data depending on the type of method used to attain the data.

The most commonly used method in the athletics is subjective evaluations such as Romberg, BESS, and modified BESS. These assessments fundamentally utilize a test administrators knowledge and experience to observe balance (Bell, Guskiewicz, Clark, & Padua, 2011). Although these tests are validated and shown to be reliable by volumes of research (Guskiewicz, 2003; Guskiewicz & Broglio, 2011; Hunt, Ferrara, Bornstein, & Baumgartner, 2009; Iverson & Koehle, 2013), should the test administrator not be an experienced rater, flaws can be found in the data collected. This potential differential has led over the years to the development of technological approaches to the observation and analysis of balance assessments.

As both subjective and objective measures have been proven to be very reliable for determining postural control (Furman et al., 2013; Hunt et al., 2009), it is then that accessibility becomes an issue. Because the cost and size of most objective analysis tools can be prohibitive,

most athletic facilities are unable to purchase these items for use in balance assessments. However, objective methodology, found more commonly in the clinical and laboratory setting, can quantify how well a person is able to balance using technology to calculate scores (Patterson et al., 2014).

This is further corroborated as video recordings have made their way into game day rituals in numerous athletic settings. The world of sports started viewing questionable calls using instant replay during athletic events in the 1960s to help legitimize and quantify sport as a fairer playing field (Vass, 2008). In instant replay, contested decisions made by officials on the field are reviewed by freezing videotaped frames and slowing down the play which in turn confirms or invalidates an official's call on the playing field (Vannatta, 2011). Though debate arose around questions regarding prolongation of the game, how it might affect the history of a sport, or how it could ruin relationships between coaches, athletes, and officials (Kuenster, 2008; MacMahon, Starkes, & Deakin, 2007; Vass, 2008). It was acknowledged by Vannatta (2011) that recording athletic events allows for an extra eye on the field to help identify errors. So then, perhaps this concept could be used in balance assessment?

1.1 Statement of Problem

Currently, balance assessment is used to identify errors from a static stance while balancing. Previous researchers have reviewed errors of balance after physical activity to test fatigue rates, post-mild traumatic brain injury, vestibular disease and other various pathologies, as well as healthy individuals (Furman et al., 2013; Hunt et al., 2009; Susco, Valovich McLeod, Gansneder, & Shultz, 2004; Weber et al., 2013). However, it has never been proven if a greater or fewer number of errors can be detected through implanting techniques which allow for slow-motion

observation. It may be important to examine whether more or less errors can be captured by a test administrator if all tests were recorded using a similar device to instant replay.

The central questions asked in this study:

1. Is there a difference in errors identified when scoring BESS stances through video playback between two different analysis speeds (real-time vs slow-motion) in twenty seconds?
2. Is the current process of balance assessment in sports identifying all errors?

1.2 Purpose

The overall purpose of this study was to observe if there is a difference in the number of errors detected between assessing BESS via recordings in real-time playback and slow-motion playback.

1.3 Significance of the Study

Research studies investigated the overall performance of BESS evaluations in various conditions (Distefano, Casa, et al., 2013; Finnoff, Peterson, Hollman, & Smith, 2009; Furman et al., 2013; Hunt et al., 2009; Iverson & Koehle, 2013; Susco et al., 2004; Valovich McLeod et al., 2004; Weber et al., 2013). In the studies identified, all results were videotaped and later scored by either multiple test-raters (Iverson & Koehle, 2013) or a single rater (Furman et al., 2013; Hunt et al., 2009; Weber et al., 2013), but none of them specified if outcomes differ using the recordings. Although these articles were informative, observational testing such as BESS can be subjective due to the fact that errors can be justified if not captured on tape. This valuable insight

helped to guide further investigation on how well video recordings pair-up to real life observation and whether slow-motion observation can identify greater errors. The findings from this study will provide information to healthcare providers in multiple fields of practice to better assess balance.

1.4 Research Hypothesis

It was hypothesized that more errors would be observed by the test administrator when scoring BESS trials in slow-motion video analysis verses real-time recordings.

1.5 Assumptions

Assumptions of this study are as follows:

- 1.) The subjects were assumed to be free of any recent musculoskeletal lower extremity injury, vestibular, somatosensory or visual disorders due to their affect on balance assessment.
- 2.) It can be assumed that each participant has previously been familiarized with BESS as a baseline requirement during physicals for NCAA's.
- 3.) It is assumed that none of the participants were suffering from fatigue because each test took place approximately 2-hours post-practice.
- 4.) It can be assumed that when a participant moves out of the trial position they will receive an error for each movement as long as the errors do not occur simultaneously.
- 5.) The participants were assumed to have attempted each trial stance to the best of his/her ability.

1.6 Limitations

Not knowing how far the camera was set-up from each participant in previous studies was a limitation of this study. The unknown parameters for the testing atmosphere makes identifying how well errors can be seen difficult to compare results to other studies. In this study approximately 15 feet was chosen to place the camera from the participant. The second limitation of this study was using a modified BESS protocol with the hands placed on the sternum instead of on the iliac crests of the hips. BESS protocol calls for hands to be placed on the hips to help maintain center of gravity. Due to simultaneously recording a secondary assessment the hand placement was modified. An iPod Touch using SWAY mobile application was held on the sternum of each subject testing five stances. The procedures for this test can be reviewed in Methods 3. 4. The third limitation in this study was testing the participants immediately after their familiarization and without a second trial. Other studies have given each participant approximately 20 minutes between tests to eliminate any fatigue, but due to time constraints and with using video playback we found this to be unnecessary. In addition to not allowing a rest period between trials, this study tested each participant approximately two hours post-practice. Track and Field athletes practice ranges from the type of events each athlete is involved in and can vary in time making testing this athletic population post-practice a limitation.

1.7 Delimitations

The results of this study are limited to healthy, athletic, college-aged men and women. A modified BESS protocol was used in the procedures of this study. Therefore, studies using other methods of BESS may not produce the same results.

1.8 Definitions

1. Balance: the ability to maintain the body's center of gravity within its base of support in both dynamic and static movements (Guskiewicz, 2011; Kleffelaar, Roe, Sandvik, Hellstrom, & Soberg, 2013)
2. Learning Effects: improved performance for specific activity over time (Pagnacco, Carrick, Pascolo, Rossi, & Oggero, 2012).
3. Objective Assessment: use of rubrics and/or technology to analyze performance with a strict quantitative measure (Riemann, Guskiewicz, & Shields, 1999).
4. Postural Stability: the ability to maintain control in a specific position while refraining internal and external gravitational perturbations of the body (Cavanaugh et al., 2005; Woolley, Rubin, Kantner, & Armstrong, 1993).
5. Real-Time: 60 frames per second
6. Slow Motion Replay: 24 frames per second; generated by slowing the frame rate of the playback of the recorded event. Causes a single frame to be repeated several times. Slow-motion replay sequences can be modeled as a repetitive pattern of a non-zero number of still frames being followed by a non-zero number of short frames.
7. Somatosensory System: stimuli within the central nervous system that detect proprioception and cutaneous pressure receptors from the supporting surface on which a person is standing to assist with balance (Horak & Nashner, 1986; Massion, 1994; Nashner, Black, & Wall, 1982)
8. Subjective Assessment: the use of a test administrator to judge a performance based on qualitative benchmarks (Riemann et al., 1999).

9. Vestibular System: stimuli within the central nervous system that detect inputs linear and angular postural sway that cause accelerations of the head (Horak & Nashner, 1986; Johansson & Magnusson, 1991; Massion, 1994; Nashner et al., 1982)

CHAPTER 2

REVIEW OF LITERATURE

2.1 Physiology Behind Balance

The central nervous system (CNS) depends upon sensory input from three primary sources in order to maintain position and motion of the body: somatosensory, visual, and vestibular systems (Johansson & Magnusson, 1991; Massion, 1994; M. Patel, Fransson, Johansson, & Magnusson, 2011; Riemann et al., 1999). The somatosensory system is made up of proprioceptors and mechanoreceptors that process information from ligaments, joint capsules, and musculotendinous tissues located in the human extremities (Horak, Nashner, & Diener, 1990; Riemann et al., 1999; Shumway-Cook & Horak, 1986). Visual sensory input helps humans distinguish the depth of proprioception allowing the body to adapt to surroundings. The inner ear translates balance information to the vestibular system in order to maintain equilibrium. (Furman et al., 2013) If one of these systems were not able to function properly and send information to the CNS, sensory re-weighting would occur causing the remaining body mechanisms to compensate (Allum & Honegger, 1998).

2.1.1 Somatosensory

External forces send stimuli to the body via the somatosensory system. The most common stimuli activated during balance are the tactile, or more specifically, the proprioceptive stimuli. Tactile stimuli excites when physical contact is made, such as found when a person stands on a force platform, firm surface or foam pad during a balance assessment. However, proprioceptive stimuli are also excited through internal forces depending upon the sway of the

human body. When the body receives such tactile stimuli internal receptors in turn stimulate the proprioception in the body to correct a person's posture. Horak et al., (1989) hypothesized that the sensory receptors in the ankle and feet joints are vital for assisting in the stabilization of posture when they compared surface displacement results from subjects suffering foot and ankle anesthesia to a control group (Horak et al., 1990). Further, Massion referenced the work of Di Fabio and Anderson from 1993 that also confirms somatosensory control starts at the feet and lower legs to help stabilize postural sway (Massion, 1994).

2.1.2 Vestibular

The vestibular system engages to correct unnecessary sway so as to re-orient the body to static stance, but it cannot work alone. Thus, Martin (1965) found that the vestibular sense works in cohesion with the proprioception found in the somatosensory system to support the overall stability of the body, especially if visual surfaces are unknown to the human.

2.1.3 Visual

Visual control is dependent on the distance between the feet in any stance. The further apart the feet are during an upright stance the more responsible for controlling balance the somatosensory system becomes (Massion, 1994). In addition, if the eyes are closed, a stimulus sends feedback to the brain to identify how a person is positioned while standing.

2.2 Strategy to assessing balance

Proper assessment of balance relies heavily on the ability of the test administrator or objective tool to capture errors committed by the subject. During this process the human body

makes certain observable postural corrections while balancing that are controlled via the central nervous system.

2.2.1 Postural Reaction

The human body uses postural reactions to correct the signals sent from the sensory system to regain proper balance. Horak and Nashner (1986) studied how the body strategically activates muscles in the hip and ankle to overcome disturbances when restoring balance. (Horak & Nashner, 1986; Massion, 1994)

2.2.2 Postural Sway

Postural sway is controlled by the vestibular system, which receives stimuli from internal and external forces. The correction of postural sway is how the body attempts to regain equilibrium and balance as it interacts with the proprioception of the various surfaces a person is standing on. A study completed by Nashner et al. (1981) attempted to verify whether the vestibular system was the only input responsible for abnormal balance measures. Subjects with vestibular disorders and healthy controls had their EMG recorded while performing balance tasks. Results showed that the influence of visual and somatosensory inputs could not be completely suppressed. This suggests that when it appears that only vestibular input is stimulated the proprioception and visual inputs still interact but at a slower rate (Nashner et al., 1982).

2.3 Video Recordings

Recent advances in digital video recordings have made automated video analysis a lot more tangible and cost-effective for almost any person. Digital video recordings can now be done with

the use of cell phones and templates to record anything from a baby crying to NFL games. The world continues to thrive off of the advances in technology to capture every waking moment of life.

2.6.1 Instant Replay

Instant replay is defined as the ability to re-watch a portion of a video for closer analysis (Pan, 2001). However, different types of instant replay exist in both commercial and television broadcast of videos. The type of play back differs depending upon the editing effect set on the camera. Standard cameras can have repeated frames in slow-motion playback because they record motion at normal speeds. Higher speed super motion cameras are able to play back film at normal speeds without any repeated frames (Kobla, DeMenthon, & Doermann, 1999). Therefore, many disputes have been made in sports about how well instant replay truly works to analyze a play outside of the official's eyes.

2.6.1.1 Are there errors not seen with the regular eye?

The complexity of decision-making in sports can be a hasty task with a lot of pressure. Recording athletic events increases the number of perspectives on the play if a dispute arises during a game instant replay can be utilized to objectify the call on the play to validate or correct the infraction. Officials have to be aware of more than one movement during an athletic event to ensure the correct call is made (Vannatta, 2011). Some examples of this are: self awareness on the field to not obstruct a play, watching the ball as it leaves the players hands before the buzzer or making sure the athletes feet are in-field during a catch. Therefore, it can be important to

utilize a replay official to either pause a single frame or watch slow-motion replay to ensure the proper call is made.

2.4 Tools and Assessments of Balance

Healthcare providers have integrated balance assessment into their practice for decades in order to evaluate various pathologies and return to activity decisions. Through the years, balance assessment has developed into a vital component of vestibular disease evaluation; currently, it is being implemented as a principle tool assisting healthcare providers in making more sound decisions regarding return to play protocols in the athletic setting. In order to have good postural stability or balance the central nervous system's somatosensory, visual, and vestibular control must work in cohesion. Several assessments have been created to identify whether balance is affected by somatosensory, vestibular, visual, or neuromuscular damage. Varied methods exist for the analysis of these systems to more readily diagnose postural deficits. These clinically subjective, qualitative tests are commonly used due to their accessibility; therefore one must keep in mind that more objective, quantitative standards are found in laboratories that can afford the higher-technology which most accurately assess balance.

2.4.1 Romberg

The first ever assessment of balance was created by Mortiz Heinrich Romberg, the founder of modern neurology who developed the Romberg Test in 1853. The Romberg Test was initially used for examining the posterior column for a condition known as *tabes dorsalis neurosyphilis*, which attacks a human's equilibrium or state of balance causing ataxia and motor dysfunction. It was the discovery of this disease that aided in the implementation of the

Romberg Sign. Mortiz observed patients standing with feet parallel and together with eyes closed (Figure 2.1) for thirty seconds, looking for any sway or other indication of somatosensory impairments, before diagnosing (Housman et al., 2014; Riemann et al., 1999). A positive Romberg's test is indicated when a patient loses their balance due to possible lesions on the neurons (Cohen, Mulavara, Peters, Sangi-Haghpeykar, & Bloomberg, 2013).

The Romberg test has since become the foundation of numerous modified balance tests used by healthcare providers, varying only in technology usage, to assess errors performed while balancing (Riemann et al., 1999). Other modifications that have developed over the decades for assessing balance integrity include different stances (double-limb, tandem, and single limb) and sensory conditions (eyes closed versus eyes open), which a patient must maintain while balancing (Cavanaugh et al., 2005).

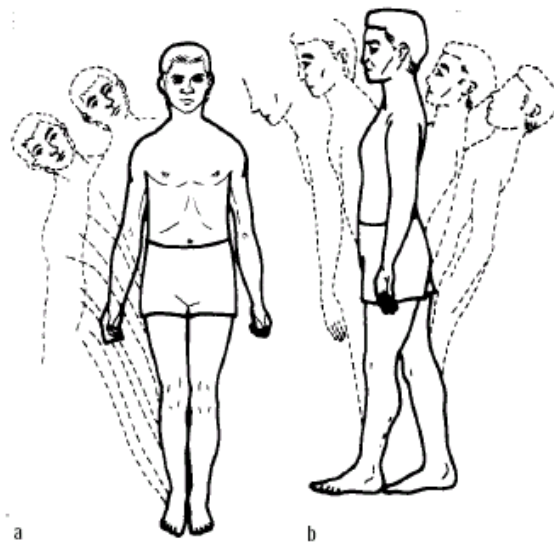


Figure 2.1. Original Romberg Test with positive signs

2.4.2 BESS

The Balance Error Scoring System (BESS) was developed at the University of North Carolina at Chapel Hill Sports Medicine Research Laboratory in 1999. The premise of developing this specific balance assessment was to provide a cost- and time-effective method to aid healthcare providers in evaluating static, postural stability with mild traumatic brain injury (MTBI) (Guskiewicz, Ross, & Marshall, 2001; Harmon et al., 2013; Sheehan, Lafave, & Katz, 2011).

BESS protocol requires a test administrator to observe three stances (narrow double leg stance, single leg stance, and tandem stance) twice for twenty seconds on two different surfaces - a firm level surface floor and medium density foam pad. Double-leg stance is performed with feet parallel touching side by side. Single leg stance is stabilized on the non-dominant foot with approximately 30 degrees hip flexion and 45 degrees knee flexion. The non-dominant leg is defined by asking the patient which leg they would use to kick a ball with; it is then the opposite leg of the preferred kicking leg. In the tandem stance, the subject is standing heel to toe with non-dominant leg in back; it is important that the heel of the dominant foot be touching the toes of the non-dominant foot. Figure 2.2 demonstrates where hands should be placed on the hips for each of the stances, and that eyes be closed.

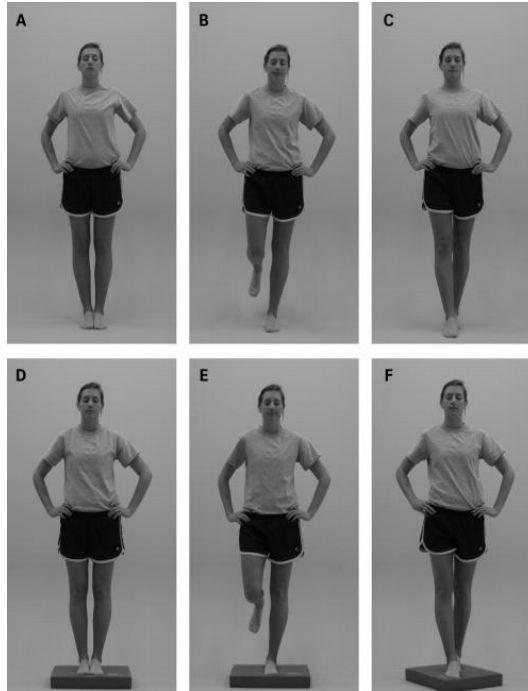


Figure 2.2. Balance Error Scoring System (Burk, Munkasy, Joyner, & Buckley, 2013)
A.) double-leg stance; B.) single-leg stance (standing on the nondominant leg); C.) tandem stance; D.) double-leg foam stance; E.) single-leg foam stance; F.) tandem foam stance

Once the subject has assumed the appropriate stance, with hands on the hips and eyes closed, the evaluation can begin (Fox, Mihalik, Blackburn, Battaglini, & Guskiewicz, 2008; Guskiewicz, 2001; Guskiewicz, Perrin, & Gansneder, 1996). Each trial is scored by a test administrator who is counting the number of deviations from the proper stance accumulated by the subject being tested. Errors that are credited for point deduction consist of: moving hands off the iliac crests (hips), opening the eyes, stepping, stumbling or falling, abduction or flexion of the hip/s beyond 30 degrees, lifting the forefoot (toes of the foot) or heel/s off of the testing surface, and remaining out of the proper testing position for greater than five seconds. Should a subject commit more than one error simultaneously only one error can be recorded; with a maximum score of 60 points being accounted for when both firm and foam surfaces are used (Harmon et al., 2013).

A growing concern amongst healthcare professionals has been regarding the acute effects of fatigue on the body during BESS performance, especially since most providers use BESS to make game and practice time decisions (Arliani et al., 2013; Fox et al., 2008; A. V. Patel et al., 2007). A question most providers ask is, Is there an appropriate amount of time to wait for the body to recover after physical activity? To address this issue, Wilkins et al. (2004) tested a group of twenty-seven NCAA Division I male athletes for their overall BESS scores; but not before a familiarization procedure took place to allow them to be acquainted with all the equipment used in the testing. These athletes proceeded to participate in a seven-station circuit where their rating of perceived exertion was measured during the protocol. After they completed their circuit workout they were required to immediately go through BESS protocol for assessment of fatigue. Findings in this study showed that fatigue clearly affects the total overall performance of post-test BESS. It also revealed that fatigue affected the tandem stance performance the most (Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004).

A few years later, another group of researchers performed a similar study wanting to look at how long it takes the body to recover from the effects of physical activity before returning to normal values (Fox et al., 2008). Again, collegiate male athletes were used in this study, but instead of using a seven-station circuit, only one exercise was used and was immediately followed by a post-test BESS assessment consisting of an initial three-minute post-exercise evaluation with subsequent intervals set five minutes apart. From this they were able to determine that balance recovery occurs approximately thirteen minutes after physical exercise has ceased (Fox et al., 2008).

Practice or learned effects of BESS have also been in question for years (Diamantopoulos, Clifford, & Birchall, 2003; Valovich McLeod et al., 2004), specifically, when

used in post-concussion protocols due to the repetitive testing over multiple days. One study was done where subjects were observed to analyze effects from learning curves while standing on foam; however, the results showed no learning effect outside of the first time subjects who had a learning period in the staging protocol, and there was no change in use of time constraints used as the subjects were being tested (Pagnacco et al., 2012).

Another study, by Valovich and colleagues (2003), tested a group of high school athletes using the baseline criterion. Findings indicated that following a concussion, the participants returned to baseline within five to seven days post-injury. Furthermore, the subjects actually committed progressively less errors each day the test was administered (Valovich, Perrin, & Gansneder, 2003). Additionally Burk et al. (2013), observed changes over a 90-day period in college-aged women who participated in recreational sports and those results revealed significant differences in the pre- and post-season overall BESS scores (Burk et al., 2013). These analyses could possibly contradict the aforementioned study where the group of Division I athletes in 2001 were unable to return to baseline scores within 3-5 days post-injury due to neuropsychological symptoms (Guskiewicz et al., 2001), but since an athlete who suffers injuries is eager to return to their vigorous activity, it makes the healthcare provider's evaluation of utmost importance. Therefore, it may be vital to reassess an athlete's baseline tests over the course of their athletic career as the body adapts to better postural control and MTBI recovery. Balance is an integral assessment tool when evaluating MTBI, also known as concussions, as it stresses the central nervous system and senses (McCroly et al., 2009). Hence, it is vital that when BESS is used to return anyone back to normal activities, especially physical activity, that baseline score be established in order to compare any post-concussive assessment (Ferrara, McCrea, Peterson, & Guskiewicz, 2001; Guskiewicz, 2011).

In reviewing the original BESS protocol, it was not specified whether or not the testing environment played a role in the overall outcomes. In 2007, Onate et al., tested a group of collegiate baseball players, with no history of head injury or neurological problems, in the dugout and in the baseball locker room to identify if environment influenced scoring. The results of this study showed that testing environment is a factor in overall score, with more errors being scored in the studies performed in the dugout. Consequently, it is highly recommended that baseline assessments be conducted in a comparable environment to the follow-up assessments (Onate, Beck, & Van Lunen, 2007). This may be a difficult task for many healthcare providers working with an athletic population, but this article highlights that a clinical type environment can be simulated within the team's locker rooms that are normally near the playing fields.

Test administrators' subjective judgment to decipher how much movement is made during each BESS stance for an error to be counted as stated in the protocol criteria has been mentioned by various researchers to be an objective measure (Finnoff et al., 2009; Guskiewicz et al., 1996; Riemann & Guskiewicz, 2000b; Riemann et al., 1999). Significant correlation between force platform and BESS assessment in Riemann et al. (1999) was found.

Multiple studies have been conducted to evaluate the reliability of BESS in assessing balance in subjects suffering from fatigue (Distefano, Casa, et al., 2013; Susco et al., 2004), dehydration (A. V. Patel et al., 2007), MTBI, and other pathologies previously mentioned (Distefano, Casa, et al., 2013; King et al., 2013; Valovich et al., 2003; Weber et al., 2013; Wilkins et al., 2004). Studies have also researched the impact of various environments on the measure of BESS assessment outcomes leading to changings in healthcare protocols when using this evaluation (Furman et al., 2013; Onate et al., 2007). Due to the research previously published, normative data and inter- intra-rater results have been developed to better compare the

overall results of BESS (Hunt et al., 2009; Iverson, Kaarto, & Koehle, 2008; Iverson & Koehle, 2013). However, none of the studies have sought to evaluate if all errors are observed in real-time motion.

Table 2.1 BESS Articles using video scoring

Authors	Study Conditions	Patients Exercise	Patients Control	Age Group	Setting	Test Raters	Results
Burk et al. 2013	NCAA D-1	39	17	18-22 Females	quiet room	2	P=0.003 between PRE and POST performance
Distefano et al. 2012	hypohydration, hyperhydration, fatigue	12	0	18-39 Males	laboratory	1	P=0.002 Hypohydrated resulted in higher BESS scores compared to euhydrated temperate and hot environments.
Finnoff et al. 2009	athletes	30	0	N/A	clinic	3	Total BESS scores are not reliable Subcategories are reliable
Furman et al. 2013	concussed; high school	43	27	14-17 girls & boys	clinic	1	Significant concussion group differences p<0.01
Hunt et al. 2009	high school athletics	78	0	13-19 boys	clinic	1	intraclass reliability coefficient increases if DL stance is removed
Iverson et al. 2013	preventative health screen for adults	1,236	0	20-69 men and women	clinic	2+	739 men & 497 women small correlation between BESS scores and age
Patel et al. 2007	dehydration, euhydration	24	0	17-25 Males	clinic	1	dehydration did not affect BESS
Sheehan et al. 2011	young children	46	0	9-10	clinic	4	raw scores rather than UNC scores has higher reliability.
Susco et al. 2004	recreational athletes	80	20	18-24	clinic	1	time had an effect on all conditions except double firm and double foam, which remained unchanged with exertion. 36 were recorded.
Valovich McLeod et al. 2004	young athletes	50	0	9-14	laboratory	1	significant learning effects were found on days five and 60
Weber et al. 2013	NCAA D-1 wrestlers	32	0	18-22	athletic training facility	1	errors increased from baseline to post practice

2.4.3 Modified BESS

BESS is a cost-effective, low-technology and portable balance assessment. However there is discrepancy, mentioned above, as relates to subjects having a learning effect while standing on a medium density foam cushion with eyes closed and whether it correlates realistically to the playing field for sport evaluations. As questions arose, a modified BESS was created composed of only three stances (narrow double leg stance, single leg stance, and tandem stance) instead of the original six. The foam cushion is also eliminated in the modified BESS. However, scoring is still counted in the same manner as the original BESS and each subject still has to remain in the testing position for twenty-seconds with hands on their hips and eyes closed (Clark, Saxion, Cameron, & Gerber, 2010; King et al., 2013). Two studies were done to determine if alterations to the BESS would improve the ability to correctly assess a person with postural control deficits. King et al. (2013) and Clark et al. (2010) found that there were no differences in overall outcome in the absence of the foam cushion.

2.4.4 Sensory Organization Test

Sensory Organization Test (SOT) is an objective, high-tech, computerized sensory system used to identify dynamic posturography using the principles of Romberg and developed in Clackamas, OR by NeuroCom International. Force platforms are used diagnostically in this assessment to evaluate the postural sway. The computerized platforms pick up forces from the feet and joints as pressure shifts to their particular center of gravity. Protocol standards are set up for six elements lasting 20-seconds each (Mulavara, Cohen, Peters, Sangi-Haghpeykar, & Bloomberg, 2013). Each condition is performed three times to accumulate a score that successfully isolates every sensory system. “Sway referencing” controls the visual and

proprioceptive support to stress the central nervous system's adaptive responses to sensory conflict situations as they are introduced. The SOT achieves this by moving the surrounding visual walls and flooring while the subject's eyes are either open or closed (J. K. Register-Mihalik, Mihalik, & Guskiewicz, 2008; Resch, May, Tomporowski, & Ferrara, 2011; Riemann et al., 1999).

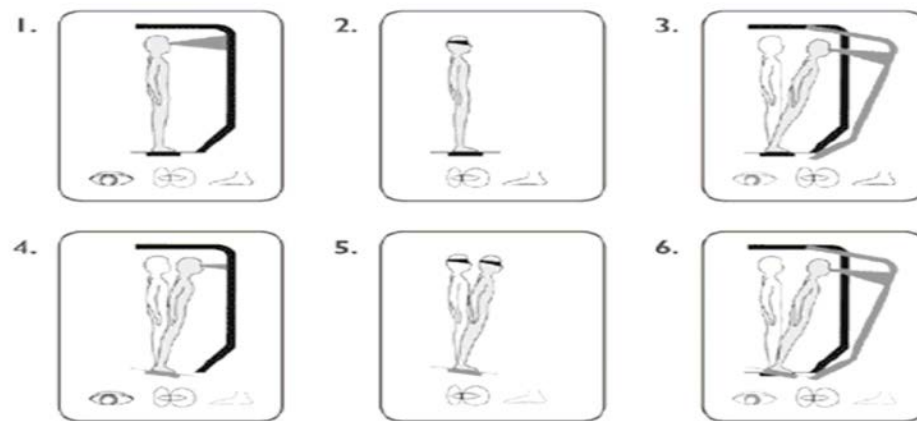


Figure 2.3. Six conditions of SOT

Condition 1.) Eyes open with fixed surface and visual surroundings; Condition 2.) Eyes closed with fixed surface; Condition 3.) Eyes open with fixed surface and sway-referenced visual surroundings; Condition 4.) Eyes open with sway-reference surface and fixed visual surroundings; Condition 5.) Eyes closed with sway-referenced surface; Condition 6.) Eyes open with sway-referenced surface and visual surroundings (Trinidad et al., 2013)

A comprehensive report is then computed to determine the equilibrium score, sensory analysis which consists of somatosensory, visual, vestibular ratios, and a strategy analysis. The overall score represents the three sets of the six conditions weighted average. Somatosensory ratio comparison is Condition 2 to Condition 1; visual ratio comparison is Condition 4 to Condition 1; vestibular ratio comparison is Condition 5 to Condition 1. Each composite score represents the body's ability to maintain balance within the framework of the sensory system being isolated, therefore a high score denotes better performance, also known as less postural sway (Guskiewicz, 2011; J. K. Register-Mihalik et al., 2008).

Access to SOT technology is limited due to its cost and has brought to the forefront the need to establish whether or not complex expensive automation is necessary to appropriately assess balance and obtain measurements for postural deficits. As a consequence, several studies surfaced to assess balance using both the SOT system and BESS. In 2000, Riemann & Guskiewicz conducted a three-day study to identify any correlation between force platform assessment in the BESS and the outcomes analyzed by SOT. By the end of their study clinical BESS evaluations mirrored those results acquired with the use of SOT technology. Though the group was unable to determine if a learned effect had developed in the subjects over the course of the day to day assessments (Riemann & Guskiewicz, 2000a).

2.4.5 Biodex

Another quantitative balance assessment tool that can be found in laboratories and clinics is the Biodex Stability System (Biodex Medical Systems Inc., Shirley, New York). It evaluates both neuromuscular and balance control with a platform that moves up to 20° surface tilt in a 360° range of motion. As this device measures multiple directions of postural tilt from the ankle and foot, various settings of resistance ranging from 1 (the least stable) to 8 (the most stable) can be introduced. The platform works in correlation with computer software allowing this tool to be a quantitative objective measure instead of the clinically common subjective and qualitative measures like BESS (Aydoğ, Aydoğ, Cakci, & Doral, 2006).

In 1998 a group of researchers examined proprioceptive deficiencies within the AP (anterior-posterior) postural tilt and ML (medial-lateral) measurement zones in hopes to create normative data for balance on the Biodex. The experiment's findings revealed that AP scores

contribute approximately 95% of the OA (overall) score and combining of the AP and ML scores account for the overall score (Arnold & Schmitz, 1998).

Evaluating how anthropometric measurements can affect balance is another way the Biodex system can be utilized. Body composition varies in every individual, but does it truly affect how well a person can balance. Greve et al. gathered height, weight, and body mass index of forty subjects to answer this question. The results presented in this study revealed a significant correlation between body mass index and postural instability. Knowing that body mass can affect postural control means this tool can then be successfully used together with anthropometrics to help return people back to normative values (Greve, Cuğ, Dülgeroğlu, Brech, & Alonso, 2013).

2.4.6 Accelerometers

In contrast to the qualitative measures mentioned above, accelerometers have recently become the latest balance assessment tool utilized. They provide accurate, inexpensive, quantitative measures for both clinical and laboratory environments. Accelerometers can be found in consumer devices such as iPhones and iPads, making the accessibility of this tool tangible to use in multiple settings. Accelerometers found in Apple Inc. products are nano-accelerometers that measure the instantaneous acceleration of an object compared to gravity at any given time, in a free-fall reference frame (Patterson et al., 2014). SWAY Medical Corporation of Tulsa, Oklahoma created a mobile phone application, *SWAY Balance*, that can be downloaded on all Apple Inc. products to assess balance. This mobile app gives descriptive pictures and explanations of postural stances used on the device. Figure 2.4 is an example of how the test is self-administered.

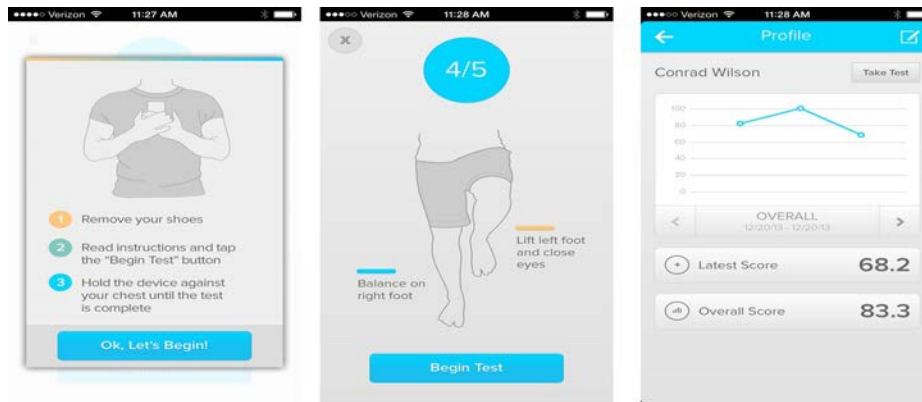


Figure 2.4. SWAY Balance Mobile Application (Patterson et al., 2014)

Patterson et al. (2014) did a pilot study to compare the use of this specific accelerometer mobile application to the Biodex Stability System mentioned earlier. The protocol for this assessment tool is outlined on each page of the application so that the subject being tested can read and verify what they have heard is correct. This allows for less errors to occur and helps create a more objective measure for healthcare providers. There are five stances used in this assessment and all stances are performed on a hard surface. This study used Athlete’s Single Leg Test protocol for 10 seconds on the Biodex system while the subject was concurrently holding the mobile device on the sternum of their chest. Results of this study showed that this tool significantly correlated with the Biodex outcomes making smartphone accelerometers an affordable and transportable tool to use for balance assessment (Patterson et al., 2014).

2.5 Validity and Reliability in the Test

American College of Sports Medicine (ACSM), National Athletic Trainer’s Association (NATA) and American Medical Society for Sports Medicine have all identified BESS to be the preferred and recommended balance assessment tool for all head injury protocols. In 2008, a group of healthcare professionals gathered in Zurich to discuss the importance of best practice

standards for mild traumatic brain injuries, including the evaluation of postural balance (Harmon et al., 2013). However, the majority of data substantiating BESS outcome scores and test-retest reliability developed after the 2008 conference revealing that BESS only has a low to moderate reliability index (Hunt et al., 2009).

As was pointed out earlier, BESS results correlate with those of other measures of postural stability assessments such as Romberg sign, Sensory Organization Test and Sway; and even though learning effects have been found with consecutive testing days (Riemann et al., 1999; Valovich et al., 2003), significant variance and reliability have not been found to be issues in multiple studies when double-leg stance is used to assess overall balance, especially if appropriate recovery time is not achieved (Riemann et al., 1999; Susco et al., 2004; Valovich McLeod et al., 2004). Moreover, when double-leg stance is eliminated from a coefficient equation there is a higher reliability ($r = 0.71$), but the reliability may still be insufficient. In order to increase reliability scores to a satisfactory level, BESS trials must be repeated on each individual person approximately three times (Finnoff et al., 2009; Hunt et al., 2009).

Normative data for various age groups using BESS to diagnose brain injuries were not published until 2008 (Iverson et al., 2008). Iverson et al., (2008) tested a sample group of 589 adults from a healthcare clinic in Canada without any neurological, balance or lower extremity pathology using the traditional BESS protocol. In this study, total overall BESS scores for each age group revealed no significant difference until the mid-50's. More specifically, BESS means and standard deviations for overall scores were similar in all age groups, but scores significantly increased in people ages <55 years old. The normative data uses the "natural distribution" of BESS scores in each age group performed in this study. A few years later Iverson et al. (2013) further expanded his research on normative data for adults (N= 1,236) using the same protocol.

They continued to find a trend indicating that balance decreases with age. Their work now stands as a reference point for healthcare providers needing to distinguish how poorly or well a person can balance. Table 2.1 categorizes age groups to identify a person's total score in ranges from very poor to superior rankings (Iverson & Koehle, 2013). Having normative statistics with which to interpret data collected from BESS testing is vital when using BESS testing to evaluate head injuries like concussions.

Table 2.2. Normative reference values for the BESS stratified by age

Age	N	Mean	Median	SD	Superior	Above Average	Broadly Normal	Below Average	Poor	Very Poor
20-29	65	11.3	11.0	4.8	0-5	6-7	8-14	15-17	18-23	24+
30-39	173	11.5	11.0	5.5	0-4	5-7	8-15	16-18	19-26	27+
40-49	352	12.5	11.5	6.2	0-5	6-8	9-16	17-20	21-28	29+
50-54	224	14.2	12.0	7.5	0-6	7-8	9-18	19-24	25-33	34+
55-59	197	16.5	15.0	7.6	0-7	8-10	11-20	21-28	29-35	36+
60-64	148	18.0	16.5	7.8	0-8	9-12	13-20	23-28	29-40	41+
65-69	77	19.9	18.0	7.1	0-12	13-15	16-24	25-32	33-38	39+
MEN										
20-29	26	10.4	10.0	4.4	0-4	5-6	7-14	15	16-21	22+
30-39	97	11.5	11.0	5.5	0-4	5-6	7-15	16-18	19-26	27+
40-49	212	12.5	12.0	5.7	0-5	6-7	8-16	17-20	21-27	28+
50-54	142	13.6	12.0	6.9	0-6	7	8-17	18-23	24-28	29+
55-59	117	16.4	15.0	7.2	0-7	8-10	11-20	21-28	29-34	35+
60-64	89	17.2	16.0	7.1	0-8	9-11	12-21	22-27	28-35	36+
65-69	56	20.0	18.0	7.3	0-12	13-14	15-23	24-33	34-39	40+
WOMEN										
20-29	39	11.9	11.0	5.1	0-5	6-7	8-14	15-19	20-25	26+
30-39	76	11.4	10.5	5.6	0-4	5-6	7-15	16-19	20-27	28+
40-49	140	12.7	11.0	6.9	0-5	6-7	8-15	16-20	21-29	30+
50-54	82	15.1	13.0	8.2	0-7	8-9	10-20	21-24	25-35	36+
55-59	80	16.7	15.0	8.2	0-8	9-10	11-21	22-28	29-39	40+
60-64	59	19.3	17.0	8.8	0-9	10-12	13-22	23-31	32-43	44+
65-69	21	19.9	18.0	6.6	0-13	14	15-24	25-27	28-38	39+

Overall, to produce an accurate and reliable BESS test protocol, a mean must be identified over a series of three assessments administered at one occasion to a person for baseline recording. If BESS is used to identify injury or pathology over the course of two or more days, each trial of the test only needs to be administered twice instead of three times at each session and averaged to find the mean. Once all data are averaged it should be compared to the normative data to identify if the person is able to return to full daily activity (Broglio, Zhu, Sopiartz, & Park, 2009).

2.6 Other Healthcare Fields Balance is Assessed

Various healthcare fields assess balance to identify disorders with symptoms of postural control. Postural control is dependent upon the interaction of sensory, motor and the biomechanics of the central nervous and musculoskeletal systems (Shumway-Cook & Horak, 1986). It is important to consult a physician if a person is unable to stand or walk without falling (Thapa, Gideon, Fought, Kormicki, & Ray, 1994), feeling uneasy on their feet or has spells of dizziness and blurred vision (Forssberg & Nashner, 1982). Depending upon the symptoms the opinion of a neurologist, otolaryngologist, or orthopedist may need to be consulted to further evaluate the source of the problem.

2.6.1 Neurological Disorders

Physicians who specialize in the diseases and disorders of the brain and central nervous system are referred to as neurologists. Neurologists have many areas of expertise; however the two most important in this study are sensory and motor control (Padgett, Jacobs, & Kasser,

2012). Parkinson's disease and multiple sclerosis (MS) are only two diseases where balance assessment is a fundamental tool in diagnosing impairment.

2.6.2 Orthopedic Injuries

Certified athletic trainers, physical therapists and orthopedists implement the assessment of proprioception, coordination and balance into physical examinations of musculoskeletal and head injuries. After injury damage to various aspects of the central nervous system can dramatically influence the postural control of an athlete. Neuromuscular control and movement technique are factors that can influence the risk of injury (Distefano, Distefano, Frank, Clark, & Padua, 2013). It is important that when assessing balance to compare outcomes to baseline measures or compare to the opposite limb. However, when orthopedic injury involves the head the assessment needs to be compared to baseline measures before return to activity is permitted (Notebaert & Guskiewicz, 2005; Oliaro, Anderson, & Hooker, 2001)

2.6.3 Vestibular Diseases

Vestibular diseases and disorders can be identified with the help of an otolaryngologist. Suffering from nausea, dizziness, insomnia, headache, and ataxia are symptoms (Cymerman, Muza, Beidleman, Ditzler, & Fulco, 2001) that further assessment of the ears, throat, head, and nose need to be performed. Acute mountain sickness is known to impair balance as a person descends in elevation and cause vestibular symptoms (Macinnis, Rupert, & Koehle, 2012). Aforementioned balance assessment is used to diagnose head injuries. Commonly head injuries are identified with vestibular deficits such as severe headache disorders (Kuritzky, Ziegler, &

Hassanein, 1981) that can impact musculoskeletal control (J. Register-Mihalik, Guskiewicz, Mann, & Shields, 2007; J. K. Register-Mihalik et al., 2008).

2.6.4 Older Adults

The relationship between age and balance decreases with age. A group of researchers in 1984 studied approximately 200 volunteers between the ages of 20 and 79 years, with 30 or more subjects representing each decade. Prior to this study no other research existed showing quantitative data for the hypothesis that balance gets worse with age. All subjects were able to maintain balance for a longer duration when their eyes were open versus with eyes closed. More specifically, the study was able to find that every subject younger than 45 years of age was able to balance for 30-seconds with eyes opened on one-leg and only 75 percent of them were able to hold the same position with eyes closed. Subjects above the age of 70 years old could not balance for more than 13 seconds in the same stance. In addition to the information mentioned above, the researchers found that if subjects are unable to maintain balance while standing on both feet with either eyes opened or closed they have a postural deficit (Bohannon, Larkin, Cook, Gear, & Singer, 1984).

2.7 Summary

Assessment of balance has developed over the past century as technology has advanced to increase the outcome reliability for diagnosing multiple injuries, diseases and disorders. Balance assessments are commonly used in the orthopedic sports medicine setting to diagnose musculoskeletal injuries and concussions; however, various healthcare fields such as, neurology, otolaryngology, and exercise science observe balance to analyze the central nervous system's

function. A wide spectrum of diagnostic methods exists for the analysis of the somatosensory, vestibular, and visual stimuli of the central nervous system.

One of the most commonly used methods is BESS. This balance test is a relatively recent innovation developed to assist in concussion management and diagnosis for athletic trainers. This method is cost- and time-efficient that can be easily transported due to the small equipment. Studies documented the intra-and inter-rater reliability with the assistance of a video camera to validate the scoring. Most of the studies were able to identify that double-leg stance on both firm and foam surfaces as insignificant, therefore, a modified BESS may provide greater reliability if four conditions are used instead of the original six (Finnoff et al., 2009; Hunt et al., 2009). However, other literature produced evidence that when a mean is calculated over three trials of each stance more reliability can be found in the original BESS protocol (Broglia et al., 2009).

Literature has shown that BESS is fairly reliable and used by many professions to diagnose diseases and disorders of the central nervous system (Bell et al., 2011). A number of research groups have documented the use of video recordings (Table 2.2) while BESS testing subjects in different atmospheres to quantify their reliability measures, but there has yet to be a study that evaluates the scoring of BESS in two different analysis speeds. The literature review presented here could lead to a conclusion that BESS scoring should be further evaluated for errors documented in video playback documentation.

CHAPTER 3

METHODOLOGY

3.1 Research Questions

This study's premise seeks to address these questions:

1. Is there a difference in errors identified when scoring BESS stances through video playback between two different analysis speeds (real-time vs slow-motion) in twenty seconds?
2. Is the current process of balance assessment in sports identifying all errors?

3.2 Site and Participant Selection

This study was conducted at Wichita State University in Wichita, KS. All balance assessments were conducted in the Human Performance Laboratory located in the Heskett Center. Due to testing Division I NCAA athletes, a location outside of their normal athletic arena had to be utilized to ensure that there is no assumption that these assessments would account for athletically related activity as in reference to NCAA bylaw 17.02.1.

3.2.1 Participants

66 participants (34 female, 31 male), age ranging from 17 to 22 (19.68 ± 1.27) years were recruited from the Wichita State University NCAA Division I Track and Field Teams.

The study design and consent form were approved prior to any recruitment of participants and data collection from the Wichita State University Institutional Review Board (IRB) for research involving human subjects. Wichita State University-ICAA approved the use of the NCAA Division I Men's and Women's Track and Field team with the full understanding of

NCAA bylaw 17.02.1. All participants were given a written consent form that was also explained verbally. Each form was signed by both the participant and a witness to verify full understanding of the study. Participants were assured all results are kept confidential by combining data with other participants not making it possible for individual identification at any point. Electronic data were kept in a password coded laptop and all hard copies of data were stored in a locked filing cabinet. HIPPA regulations apply for all data results and information obtained in this study.

3.3 Instruments and Measures

All participants' height and weight were recorded prior to balance assessments. Three BESS stances were recorded using the Apple Inc. iPad application, *Coach's Eye*. *Coach's Eye* is a phone and tablet application that allows for on-the-spot video analysis in both real-time and slow-motion. Another iPad was set up next to the subject being tested with a visual timer set for 20 seconds. The test-rater is a Certified Athletic Trainer with experience in BESS evaluations over a vast population.

Errors were determined using the original BESS standards set by University of North Carolina, Chapel Hill: opening the eyes, stepping, stumbling or falling, abduction or flexion of the hip/s beyond 30 degrees, lifting the forefoot (toes of the foot) or heel/s off of the testing surface, and remaining out of the proper testing position for greater than five seconds. Except for moving hands off the iliac crests (hips) criteria. If the hands moved off of the sternum they were granted an error. Accumulated total errors scored (TES) consisted of all errors committed in the entire twenty-second stance. BESS errors criteria (BEC) only accumulated a maximum amount of 10 errors per twenty-second stance only allowing for a maximum score of 30 points for all three stances.

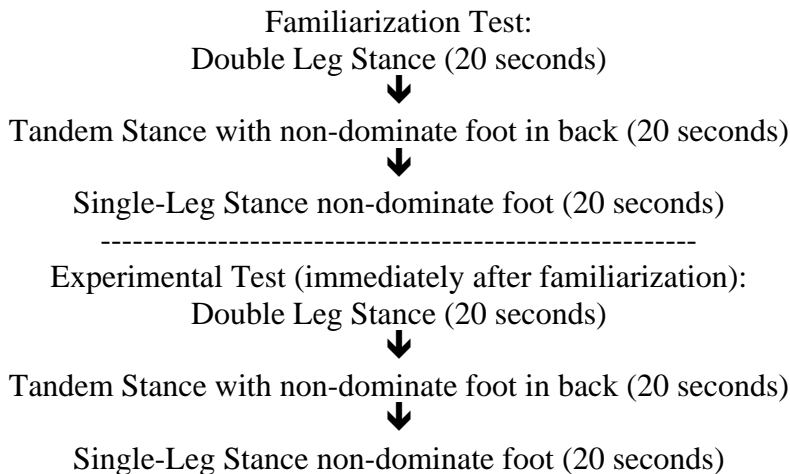
Table 3.1. BESS Error Scoring Criteria

- | |
|---|
| <ul style="list-style-type: none">- Moving the hands off of the sternum- Opening the eyes- Step, stumble, or fall- Hip flexion or abduction greater than 30°- Lifting the forefoot or heel off of the testing surface- Remaining out of testing position for more than 5 seconds |
|---|

3.4 Procedures

The participants were asked if they were taking any medication that would inhibit vestibular control or were currently suffering from any neurological or visual problems. A script was then read to each participant listing all expectations and procedures to familiarize them with the protocol. A modified version of BESS was used to assess the balance of each individual that consisted of hands on the mid-sternum instead of on the iliac crests. The first stance was bipedal followed by tandem (non-dominant foot in back), then non-dominant single leg stance. All stances were performed in a square two-foot box that was taped to a firm ground surface to ensure all participants were tested in the same arena. Foam padding was not used in this protocol. A familiarization trial of each 20-second stance was assessed with each participant. Immediately following the familiarization trial, each participant repeated the modified protocol completing it back-to-back without a given rest period. Each assessment was recorded using an iPad approximately 15 feet from the participant to be analyzed by the test administrator two weeks later.

Figure 3.1. Summarization of procedures for modified BESS. ↓ represents the transition between stances.



3.5 Statistical Analysis

Data analyses were conducted using the statistical software program Statistical Packages for the Social Sciences for Windows version 21 (IBM, Seattle, WA). All data are presented as mean \pm standard deviation (SD). Descriptive statistics were computed on all the data collected to find mean and SD. Mean differences in BESS scores were analyzed using a paired samples t-test. Cohen's D effect size (ES) was computed as a measure of meaningful change using the following formula: $ES = (\text{Mean}_{SM} - \text{Mean}_{RT}) / \text{pooledSD}$. ES was evaluated using the following scale: small = 0.2, moderate = 0.5, large = 0.8. Statistical significance was accepted at $p \leq 0.05$.

CHAPTER 4

RESULTS

4.1 Subjects

Seventy-one participants (female=36, male=35) were originally recruited to participate in the study. Five participants were excluded (female=4, male=1) due to current injury, illness or medication. Twenty of the participants who participated in the study have a previous history of concussion (n=10) and/or musculoskeletal injury (n=10), but are currently asymptomatic and fully participating in sport without limitation. Each participant completed a full day of practice approximately two hours before any assessments were done.

Physical characteristics of the participants are presented in Table 4.1.

Demographics	N	Minimum	Maximum	Mean	Std. Deviation
Age (years)	66	18.0	23.0	19.7	1.3
Height (cm)	66	116.9	192.8	174.9	11.4
Weight (kg)	66	51.7	114.0	73.5	14.0
BMI	66	18.0	45.41	24.1	4.4

4.2 Real-Time vs. Slow-Motion

Paired samples t-test was used to determine differences in recorded errors in modified BESS tests using video playback at two different speeds. The paired samples t-test looked at the two speeds: real-time playback and slow-motion playback for the overall total accumulated errors ($6.0 \pm 4.3_{RT}$, $6.8 \pm 5.2_{SM}$) during the test and the amount of errors that could be counted according to the BESS protocol ($6.0 \pm 4.3_{RT}$, $6.7 \pm 4.9_{SM}$).

Table 4. 2 shows a significant difference was found between both the measures ($p=0.3_{\text{BEC}}$; $p=0.1_{\text{TES}}$). Cohen’s d effect size was calculated in Table 4.2 revealing that the difference found between real-time video playback and slow-motion playback is not clinically meaningful.

BESS scores for real-time and slow-motion playback are presented in Table 4.2.

	Real-Time <small>(N=66)</small>	Slow-Motion <small>(N=66)</small>	P-value	Effect Size
BEC _{exp} errors	6.0±4.3	6.7±4.9	.031	.2
TES _{exp} errors	6.0±4.3	6.8±5.2	.012	.1

CHAPTER 5

DISCUSSION

5.1 Overview

BESS is a relatively new method to assess postural control in various healthcare settings. Approximately eleven studies were conducted between 2004 and 2013 using video recordings to assist the analysis of scoring BESS in different settings. This is the first prospective BESS study on participants using video recordings to comparatively identify differences in scoring in real-time playback and slow-motion playback of both BEC and TES. Previous studies found in Table 2.2 used significantly smaller numbers of participants (n=39 (Burk et al., 2013), n=12 (Distefano, Casa, et al., 2013), n=30 (Finnoff et al., 2009), n=24 (A. V. Patel et al., 2007), n= 46 (Sheehan et al., 2011), n=50 (Valovich McLeod et al., 2004), n= 32 (Weber et al., 2013)) than the 66 healthy participants used in this study. Three other groups were able to recruit a larger population (n=78 (Hunt et al., 2009), n=1,236 (Iverson & Koehle, 2013), n=80 (Susco et al., 2004)) for balance assessments using BESS.

Finnoff et al. (2009), Burk et al. (2013), and Susco et al. (2004) tested collegiate athletic populations conversely, Furman et al. (2013), Valovich McLeod et al. (2004), and Hunt et al. (2009) tested high school and adolescent athletes for overall reliability and inter- and intra-rater reliability. These studies were conducted in a clinic or laboratory for sports medicine research. Several studies conducted (Weber et al. 2013, Patel et al. 2007, and Distefano et al. 2013) testing participants in a dehydrated state to assess the impact that exercise and temperature have on BESS. Each of the aforementioned studies either scored BESS with multiple test-raters (Iverson & Koehle, 2013) or a single rater (Furman et al., 2013; Hunt et al., 2009; Weber et al., 2013), but

none of them specified if outcomes differ using the recordings. This study serves to give insight to how well a test-rater is able to score errors using two different speeds of analysis.

The test-rater for this present study is a Certified Athletic Trainer with experience in BESS evaluations over a vast population. Sheehan et al. (2011) tested the reliability of BESS in children (nine and ten years old) using an experienced rater and three other raters from diverse career settings without mentioning their experience level of BESS procedures. In a similar fashion to the study conducted, Sheehan et al. (2011) scored errors using two methods of BESS; UNC protocol BESS and complete total errors in twenty seconds. However, instead of all participants scored by the same test-rater, multiple raters were used to conduct the assessment.

Observational testing, such as BESS can be argued as a subjective assessment because all errors are recorded by a test-rater in person without any visual record of the evaluation. In order to quantify BESS, video recordings should be used to eliminate the possibility of justifying the error criteria dictated by University of North Carolina, Chapel Hill. Vannatta (2011) gives valuable insight on the practicality of instant replay and how it can provide accountability and quantification for errors in sports. This insight in comparison with the results of BEC and TES slow-motion playback and real-time playback analysis identifies the need to use video recordings in clinical balance assessment.

5.2 Practical Implications

Using slow-motion playback for analyzing BESS scores revealed statistical difference of the means. Generally it can be said that slow-motion BESS analysis mimics instant replay in the fact that more errors were statistically counted when video playback was reviewed. Athletic Trainer's

and other healthcare providers currently are not using video recordings to clinically assess balance for either baseline or post-injury evaluations.

Today, camera's can be found in almost every mobile device due to the advances in technology. Adding video recordings to BESS assessments for more accurate outcomes will increase the reliability of the test. Previous studies solely used video recordings to score BESS for reliability (Hunt et al., 2009; Iverson & Koehle, 2013) identified efficient BESS scores when double-leg stance is refracted from the outcome scores. This may suggest that healthcare professionals should record BESS assessments for greater overall patient care.

5.3 Future Research

Balance assessments have never been used to compare differences in postural control between sports. A future study should be conducted to analyze if one sport is known to have stronger balance than another. This can be used to assist healthcare providers when looking at normative results to help an athlete return to play after injury. The data collected in the present study was done simultaneously with the use of SWAY mobile application for concussion and balance assessment causing the participants to have their hands placed on the sternum instead of their iliac crests. There has not been a study conducted to identify that the same number of errors scored can be found if the hands are placed on the sternum instead of on the iliac crests. Another analysis should be done with the conduction of multiple assessments per participant using the same protocol to see if mean measures of BESS errors differ. This may help to validate the current study and make BESS a more objective method of balance assessment. It is necessary to continually test BESS in different atmospheres, physical conditions, populations, and sporting

events to allow comparison to other methods of balance until another affordable and time-efficient method can be developed.

5.4 Conclusion

At the conclusion of this study, results suggest that experienced BESS raters statistically capture more balance errors when viewed in slow-motion. However, a small effect size (TES: 0.2 and BEC: 0.1) acknowledges that clinically this is not meaningful. Healthcare providers compare evaluation scores to the baseline measure of every assessment. If baseline measures are not recorded than BESS would be conducted over a series of days until symptoms subsided. Therefore, healthcare providers can decide to score BESS in either speed to get an accurate score. Clinically healthcare providers have to compare the scores to baseline measures before clearing someone for activity. BESS continues to be one of the gold standards in concussion and balance management within sports medicine when access to higher technology balance equipment is intangible (McCroory et al., 2009).

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