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Influence of Testing Environment on Balance Error Scoring System Performance

Carrie Rahn

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by

CARRIE RAHN

(Under the Direction of Thomas A. Buckley)

ABSTRACT

Context: The Balance Error Scoring System (BESS) is a commonly utilized and recommended sideline assessment tool to evaluate post-concussion postural stability. Baseline BESS scores are typically recorded during preseason physical examinations in the athletic training room or nearby laboratory. However, post-concussion assessment typically takes place on the sideline during a sporting event. Objective: The purpose of this study was to evaluate the effect of a sideline environment on BESS performance. Setting: 37 NCAA Division 1 healthy, female student-athletes (SA) and 32 healthy, female non-athlete healthy young adult (HYA) controls were assessed on BESS performance in three different environments: a controlled laboratory or baseline (BL), a basketball arena (BKB) and a football field (FB). The SA group performed the experimental trials during a live competition while the HYA group was tested with minimal distractions. Interventions: The BESS was administered using an Airex Pad and videotaped from the frontal and sagittal planes. Main Outcome Measures: Two 2 x 3 ANOVAs with repeated measures, one 2 x 6 ANOVA with repeated measures, and a frequency distribution were used to analyze the results. Results: A significant main effect was found for the two groups ($p = .001$) with the SA group scoring higher than the HYA group. Significance within the SA group was found between BL and FB ($p = .047$) environments and FB and BKB ($p = .005$) environments. Significance within the HYA group was noted between BL and BKB trials ($p = .025$).

Significance was found between groups for the single leg firm ($p = .032$), single leg foam ($p < .001$), and tandem foam stances ($p < .001$) with the SA group scoring significantly higher. Conclusions: A previous study reported no differences in total BESS score between a controlled environment and a baseball dugout, however our results suggest that a more distracting environment may impair BESS performance in female intercollegiate athletes. While this study is limited by testing athletes outside of their sport environment, the results of this study suggest that clinicians should consider the ambient environment when performing BESS during a post-concussion assessment.

INDEX WORDS: Balance error scoring system, Balance, Performance, Concussion

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by

CARRIE RAHN ATC, LAT

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CARRIE RAHN

Major Professor: Thomas Buckley
Committee: Barry Joyner
Barry Munkasy
Thomas Buckley

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CHAPTER 1

INTRODUCTION

Approximately 1.6 to 3.8 million sports-related traumatic brain injuries occur annually in the United States.[1] McCrory defines a concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces".[2] The typical rate of concussion among high school and collegiate athletes that is generally accepted is approximately 5-8% of all injuries.[3-5] Covassin[6] reported that 5.9% of all reported collegiate injuries from 1997-2000 were concussions while Gessel[4] found that concussion represented 8.9% of all high school injuries. Concussions can be caused by direct or indirect blows to the head, face, or neck and typically results in neurologic impairments that can be temporary or long-lasting and resolve spontaneously.[2]

Along with these primary effects of concussive injury to the brain, a more serious injury can occur if a second concussion occurs while the brain is still recovering from an initial concussive episode. Second impact syndrome is defined as any secondary blow to the head that occurs when an athlete is still suffering post-concussive symptoms from an initial injury.[7] Second impact syndrome, although extremely rare, is a devastating injury that typically leads to repeat injury, rapid deterioration, and ultimately death.[8] Approximately seven athletes die annually due to catastrophic head injury in football, some of which can be attributed to second impact syndrome.[9] Due to the potential devastating result of second impact syndrome, identifying the presence of concussion during competition in the athletic population is crucial.

Identifying concussions can be challenging and is best performed using a multi-faceted approach that considers a variety of factors including self-reported symptoms, cognitive abilities, and postural stability.[2,10] Postural and cognitive deficits may also occur as a result of the concussion therefore many concussion assessment protocols include clinical evaluations and symptom checklists.[2,11-13] The Balance Error Scoring System (BESS) is the recommended and most commonly utilized method to identify postural stability deficits.[2] Surveyed athletic trainers in 2001 and 2005 reported that BESS testing was used in 5 – 16% of participating institutions as part of a comprehensive concussion assessment however more current research in 2009 suggests the percentage has increased to approximately 28%.[11-13] Utilizing a comprehensive approach to concussion assessment, athletic trainers may better recognize the presence of a concussion, reducing the number of athletes that return to play while still suffering from deficits related to the initial concussion. More effective concussion assessment protocols could help limit the potential devastating side effects associated with concussions.

The BESS test was developed as an inexpensive and simple sideline assessment to evaluate postural stability.[14] Obtaining baseline measures on the BESS test prior to beginning a competitive season provides a benchmark to measure post-injury recovery.[10] The NCAA, NATA, and 3rd International Consensus Statement on Concussion all recommended athlete baseline testing on the BESS test so that post-concussion follow-up measures can be compared with the baseline values.[2,10,15] These baseline measures usually occur in a quiet, controlled environment during a pre-participation physical examination. Post concussion testing, however, may take place in a variety of locations that could potentially involve distractions to the concussed athlete.[28] Immediately following concussion there is a 3 – 5 day period in which athletes appear to suffer a postural stability deficit.[17,18] The BESS test has been found to identify postural stability deficits within the first 24 hours following concussion that may take 3 – 5 days to resolve.[19]

Postural control is defined as "controlling the body's position in space for the dual purposes of stability and orientation while postural stability or "balance" describes the ability to control the total body center of mass in relationship to the base of support."[16] The central nervous system helps to maintain balance and includes visual input, vestibular mechanisms, and proprioceptive reflex activities.[3] Balance is maintained by combining information received from the vestibular, visual, and somatosensory systems in healthy individuals. In the event of a concussion, it becomes possible that these systems may become impaired resulting in postural instability of athletes following a concussion.[17,18] This deficit may be a result of a "sensory interaction problem" that occurs when athletes are unable to exchange sensory information correctly from the visual, vestibular, and somatosensory systems.[18]

There are inherent limitations to the BESS test that question the validity of its use as a method to assess postural stability, however at the present time it is the recommended test used during concussion assessment. Interrater reliability coefficients have been reported from 0.44 – 0.83 and intrarater reliability coefficients from 0.50 – 0.88 with a mean minimum detectable change of 7.3 - 9.4 points.[20] These numbers do differ from earlier findings that showed an intertester reliability coefficients range from and 0.78 to 0.96.[14] The presence of a potential practice effect has been noted by several authors in the athletic population.[21-23] Valovich found that BESS scores were significantly improved on days 5 and 7 compared to baseline values in high school athletes however after 30 days the scores were not different from baseline.[21] In addition to this limitation, other factors have also been explored to determine potential factors that may influence BESS test scores. Fox reported that there were changes in postural stability following anaerobic and aerobic exercise protocols, however those differences did not last longer than 13 minutes after the exercise was completed.[24] Schneiders suggests that footwear has an effect on tandem gait tasks and recommends that all testing should be standardized by the type of footwear worn during the initial testing.[27] Overall there seems to be few factors that play a major role in effecting BESS scores, however Onate has identified environmental conditions as a significant factor for the postural stability measure.[28]

Onate tested a population of 21 healthy, collegiate baseball players over two trials of the BESS test, first in the controlled setting of a baseball locker room with minimal distractions and then in the baseball dugout during live batting practice with no control for any external stimuli.[29] The results showed that BESS scores were higher (worse) when tested in the dugout compared to the scores obtained in the locker room, however the finding was not statistically significant.[29] Even though this study did find significance on the single leg foam stance of the BESS test there were limitations such as the need for more testing sites and a control group. These findings suggest that the environment does play a role in BESS scores and calls for further research to explore using multiple different environments and utilizing a control group to determine if uncontrolled, sideline BESS evaluations can be compared to controlled, baseline results following a sports related concussion. The addition of a control group would aid researchers in identifying factors that contribute to a change in overall BESS score by helping to eliminate factors such as the physical environment and the presence of a practice effect.

Therefore, the purpose of the present study was to investigate the influence of sporting environments on the performance of the BESS in uninjured female NCAA Division I athletes. The sidelines of a football field and basketball court during live competitions were utilized as the experimental environments. We hypothesized that BESS scores will be higher (worse) in an uncontrolled environment when compared to scores obtained in a quiet, controlled environment. An additional purpose of this study was to investigate the scores of a non-athlete control group tested at the same locations with minimal distractions present. We hypothesized that BESS scores in this group would decrease (improve) with repeat administrations of the test. Finally, we aimed to also examine which stance of the BESS test caused the most errors and determine which types of errors occur most commonly. Our hypothesis was that the single leg stance on the stable and unstable surfaces would be responsible for the majority of the errors while a step, stumble, or fall would be the most common error committed. (Appendix A)

CHAPTER 2

METHODS

Subjects

Sixty-nine subjects were recruited and placed into one of two groups based upon whether they were student-athletes (SA) or healthy young adults (HYA). The SA (age = 20.0 ± 1.1 years, height = 170.0 ± 7.7 cm, and mass = 66.7 ± 9.5) group consisted of 37 National Collegiate Athletic Association Division I healthy female athletes from the same institution that were members of the intercollegiate soccer (n=17), softball (n=8), or volleyball (n=12) teams. The HYA group consisted of 32 female students (age = 20.8 ± 1.1 years, height = 162.6 ± 6.0 cm, and mass = 63.7 ± 10.6 kg) that were not collegiate athletes enrolled at the same university. The inclusion criteria required the female subjects be a student of the participating university and at least 18 years of age or older. Exclusion criteria consisted of any participant with previous formal instruction on how to administer the BESS test. Additionally, for the SA group, exclusion criteria included no current injury preventing them from participating in full contact team athletic activities. A power analysis based on an effect size of 0.25 estimated that at least 25 subjects per group were needed to achieve a power of 0.8. Informed consent was obtained from each subject prior to enrolling in the study as approved by the University's institutional review board.

Instrumentation

A questionnaire assessing basic demographics and injury history was answered by each subject prior to their first experimental trial (Appendix C). The BESS test was administered using an Airex Pad (45 cm^2 x 13 cm thick, density 60 kg/m^3) (Alcan Airex AG, Sins, Switzerland) for the unstable surface placed on a hardwood floor (BL and BKB) or natural grass (FB) surface depending on the testing condition. Two video cameras (Canon, HV20) were utilized to capture (60 Hz) each subject during the testing and were placed at 90° from each other to obtain a frontal and sagittal plane view (See Figures 1-3 For Setup). The cameras were adjusted to maximize the image size while capturing a full picture of each subject. Stopwatches were used for timing of individual trials during the live BESS test.

The BESS test has intratester reliability coefficients ranging from 0.50 – 0.88 and intertester reliability coefficients ranging from 0.44 – 0.96.[14,20] The testing procedure consisted of three different stances performed twice, first on a firm surface followed by a repeat assessment on the foam surface, for a total of six trials (Appendix D):[2,14,17]

1. Double Leg Stance with feet together on a firm surface
2. Single-Leg (SL) (Non Dominant) Stance with contralateral limb in 20-30 degrees of flexion on a firm surface
3. Tandem Leg Stance (Non Dominant behind Dominant) on a firm surface
4. Double Leg Stance with feet together on the foam surface
5. SL (Non Dominant) Stance with contralateral limb in 20-30 degrees of flexion on the foam surface
6. Tandem Leg Stance (Non Dominant behind Dominant) on the foam surface

Each stance was performed for 20 s and subjects were required to stand with their hands placed on the iliac crests while keeping their eyes closed.[3] They were instructed to stand in the specified position as still as possible and if they had to leave that position for any reason to get back into the start position as quickly as possible. Timing began when the subject achieved the start position with their eyes closed.

An error on the BESS test is defined as any of the following: hands being lifted off of the iliac crests; opening of the eyes; step, stumble, or fall from the stance; movement of the hip into more than 30 degrees of flexion or abduction; lifting of the forefoot or heel; or remaining out of the testing position for more than 5 s.[3] In the event that the subject was unable to maintain a stance for longer than 5 s, the trial was scored a 10.[3] BESS tests were scored based upon the number of errors committed during each of the 20 s trials. A maximum number of ten errors were allowed per trial and in the event that multiple errors occurred simultaneously, only one error was added to the total score to be consistent with the 3rd International Conference on Concussion in Sport.[2]

Procedures

There were three test sessions for each subject. The first, or baseline (BL) trial occurred in a quiet, controlled setting inside of a biomechanics laboratory. The BL data for the SA group was collected as part of the athlete's pre-participation physical examination during the semester they begin participating in athletics at the university, thus the time from the BL screening to the first experimental test varied by subject. The experimental trials occurred just off of the sideline of a basketball arena (BKB) and sideline football field (FB). The SA group experienced these settings during a live competition while the HYA performed the trials in the same locations during a time when no athletes or spectators were present. For the BKB site (mean attendance 1,617 $\pm$ 0), subjects performed the BESS test on the hardwood surface in the arena in close proximity to the band and approximately 5 m from the playing surface. The site provided ample distractions associated with the game, fans, and cheerleaders that were positioned nearby. At the FB location (mean attendance 20,252 $\pm$ 252), subjects were positioned out of bounds and on the grass near the visiting team sideline at the 3 yard line, approximately 5 m from the playing surface. This location was the most level spot available within the view of the cameras in the acceptable range of possible locations. The home team's band and student section were both located behind the testing site and the subjects faced the crowd with their backs to the field during the testing session. Because testing occurred during live events, there were times when the current play was near the testing site and testing was suspended until the play had moved back to a safe distance. No breaks were needed during the BKB collection because the subjects were located such that play did not place them in danger. The order of the experimental trials was determined based on the availability/recruitment of the athletes. The order of the experimental trials for the HYA group was matched to the order in which the SA group completed the trials.

Data Analysis

Initial scoring took place live during all three trials for each participant, however due to distractions to the testers, actual scoring took place during analysis of the videos from the test days. Two collection areas, very near to each other, were utilized to aid in capturing all of the necessary trials for the SA group's experimental trials during times which provided ample distractions. Both collection areas were led by testers who have had extensive experience administering BESS tests. In addition to the total number of errors committed, a chart was utilized to track the number of errors per trial and the types of errors during the test administrations. The dependent variables were the total score, number of errors, and type of errors for each subject on the BESS test and the independent variables were the two groups (SA and HYA) and the environment in which the subjects were tested (BL, BKB, and FB).

Statistical Analysis

Two 2 (group) x 3 (environment) repeated measures analysis of variance **(**ANOVA) compared the total BESS score between the groups in the three environments, one with the trials separated by environment and one with the trials separated by the order in which they were completed. The alpha level was set at .05. Post hoc testing was performed using contrasts, independent t-tests, and paired samples t-tests to determine where the differences existed. Additionally, a 2 (group) x 6 (stance) repeated measures ANOVA was used to compare the number of errors per stance during the BESS test between the two groups. Again, contrasts, independent t-tests, and paired samples t-tests were used as post hoc testing to determine where the differences existed. A frequency distribution was used to determine the types of errors that occurred during the individual stances.

CHAPTER 3

RESULTS

All subjects completed all trials of the tasks at three different locations without incident, difficulty, or falls. There were significant differences between groups on age, as the SA group was younger (20.0 ± 1.1 years and 20.8 ± 1.1 years respectively, $t = -3.277$, $p = .002$) and height, as the SA group was taller (170.0 ± 7.7 cm and 162.6 ± 6.0 cm respectively, $t = 4.363$, $p < .001$) than the HYA group. There was no significant difference between the groups for mass (SA: 66.7 ± 9.5 kg and HYA: 63.7 ± 10.6 kg respectively, $t = 1.237$, $p = .221$). (See Table 1)

For the effect of environment on total BESS score, there was no significant interaction between groups over the three trials ($F = 2.147$, $p = .121$). There was however, a significant trial effect ($F = 5.209$, $p = .007$). Contrasts revealed a significant trial effect for FB compared to BKB ($F = 10.498$, $p = .002$, and cohen's $d = .324$) but no significant difference between BL and FB ($F = 1.557$, $p = .217$) or between BL and BKB ($F = 3.8787$, $p = .053$). The results do suggest a trend of increasing scores as comparison between the BL and BKB trials almost reached a significant difference. There was also a significant main effect for the two groups ($F = 11.600$, $p = .001$, and cohen's $d = .873$) with the SA group (10.42 ± 4.67) scoring higher than the HYA group (7.6 ± 3.3) across the three trials. When each trial was examined individually using an independent t-test, the SA group scored significantly higher than the HYA group at all three environments (BL: $t = 2.099$, $p = .040$, and cohen's $d = .535$; FB: $t = 3.888$, $p < .001$, and cohen's $d = 1.198$; and BKB $t = 2.801$, $p = .007$, and cohen's $d = .962$). (See Figure 4)

Results of a paired samples t-test showed that within the SA group there was a significant difference between the BL and FB (10.1 ± 4.0 and 11.5 ± 4.8 errors respectively, $t = -2.058$, $p = .047$, and cohen's $d = .375$) environments as well as the FB and BKB environments (11.5 ± 4.8

and 9.7 ± 5.1 errors respectively, t = 2.955, p = .005, and cohen's d = .376). There was no significant SA group difference between BL and BKB (10.1 ± 4.0 and 9.7 ± 5.1 errors respectively, t = .594, p = .556). Within the HYA group, the only significant difference was noted between the BL and BKB trials (8.1 ± 3.6 and 6.8 ± 3.0 errors respectively, t = 2.360, p = .025, and cohen's d = -.364). There was no difference noted within the HYA group for the BL and FB trials (8.1 ± 3.6 and 7.8 ± 3.1 errors respectively, t = .660, p = .514) or the FB and BKB environments (7.8 ± 3.1 and 6.8 ± 3.0 errors respectively, t = 1.633, p = .113). (See Figure 4)

For total BESS score by order of the assessment, there was no significant interaction (F = .648, p = .525) or trial effect (F = .614, p = .539). In this assessment, trials were analyzed based on the order in which they were completed rather than by the environment in which they were performed. All subjects performed the BL trial first. There was, however, a significant group effect (F = 9.755, p = .003, and cohen's d = .830) with the SA group (10.3 ± 4.7) scoring significantly higher than the HYA group (7.6 ± 3.3) across the three trials. Specifically, a significant difference between the two groups was found for each trial with the SA group scoring higher than the HYA group at BL (10.3 ± 4.0 and 8.1 ± 3.6 errors respectively, t = 2.099, p = .040, and cohen's d = .604), follow up 1 (10.1 ± 4.5 and 7.4 ± 3.5 errors respectively, t = 2.723, p = .008, and cohen's d = .775), and follow up 2 (10.4 ± 5.5 and 7.2 ± 2.6 errors respectively, t = 3.009, p = .004, and cohen's d = 1.245). (See Figure 5)

There was also a significant interaction (F = 10.379, p < .001 and cohen's d = .271) for number of errors per stance with the SA group (1.7 ± 2.2 errors) consistently scoring more errors than the HYA group (1.3 ± 1.8). For total number of errors per stance there was a significant difference between groups on the SL firm (t = 2.162, p = .032, and cohen's d = .289), SL foam (t = 4.121, p < .001, and cohen's d = .573), and tandem foam stances (t = 5.275, p < .001, and cohen's d = .735) with the SA group scoring significantly higher than the HYA group in those stances (SA = 1.7 ± 2.0, 5.0 ± 1.6, and 3.0 ± 1.9 errors respectively and HYA = 1.2 ± 1.3, 4.1 ± 1.6, and 1.8 ± 1.3 errors respectively). (See Figure 6) A frequency analysis identified a step, stumble or fall as the most common type of error (59.8%) followed by committing multiple errors simultaneously (20.2%). (See Figure 7)

CHAPTER 4

DISCUSSION

The purpose of this investigation was to identify the influence of different environmental conditions and distractions on BESS performances. The primary finding of this study was a clinically and statistically significant increase in BESS scores for the SA group who performed the test during live sporting events as opposed to significant improvements in the HYA group who performed the test at the same locations during quiet times. Specifically, the SA group scored the highest at the FB setting (11.5 ± 4.6 errors) compared to the BL (10.1 ± 4.0 errors) and BKB (9.7 ± 5.1 errors) environments. There was also a significant between groups with the SA group scoring higher than the HYA group at all three environments. Typical administration of the BL BESS test occurs in a controlled environment, such as the athletic training room during pre-participation physical exams, however the initial post-injury assessment is recommended as a sideline evaluation.[2,29] These results are important to athletic trainers, who use the BESS test as part of a comprehensive, evidence based concussion assessment protocol, to consider that BESS performance may be altered due to the environmental conditions and not solely as the result of a potential concussion.

Results of the analysis for between group differences across the environments showed that there were significant differences for all three environments with the SA group scoring significantly higher (BL: 10.1 ± 4.0 and 8.1 ± 3.6 errors, FB: 11.5 ± 4.8 and 7.8 ± 3.1 errors, and BKB: 9.7 ± 5.1 and 6.8 ± 3.0 errors). This indicates that there is some factor present during the SA group trials that contributes to increased BESS scores compared to the HYA group. This finding is similar to Onate's results which showed a non-significant increase in BESS scores when healthy collegiate baseball players were tested in an uncontrolled environment.[28] The BL environment, which was the same for both groups, provided a setting where scores were expected to be somewhat similar, however our results differed from this expectation as the scores were significantly different at the BL trial between the two groups. This could be attributed to SA BL testing occurring as a part of an already lengthy day during the pre-participation physical examinations as recommended by the NATA. [10]

The higher scores during the FB condition for the SA group indicate that there are potential external factors that may contribute to postural stability deficits in a distracting environment. FB scores were significantly higher (11.5 ± 4.8 errors) than either the BL (10.1 ± 4.0 errors) or BKB (9.7 ± 5.1 errors) environments within the SA group yet scores for the BL and BKB environments were similar. Onate reported an increase of four errors in an uncontrolled baseball dugout whereas the current study only reports a one to two error increase.[28] The current study utilized a scoring system that calculated multiple errors occurring simultaneously as one error however the BESS can be scored by recording each error individually, even if they occurred at the same time. Thus, the increased rate of errors could be contributed to a difference in scoring techniques or may be attributed to the differences in the type of analysis between the two studies.[28] Because of Bonferroni adjustments, Onate's alpha level was set at .008 whereas the current alpha was set at .05.

Within the HYA group however, scores decreased (BL: 8.1 ± 3.6 errors, FB: 7.8 ± 3.1 errors, BKB: 6.8 ± 3.0 errors) with the repeat assessments despite being tested in the different environments. The one to two error decrease in scores across three administrations is also consistent with the current literature that showed a two error improvement in high school athletes over a 5 – 7 day period where significant decreases have been observed as early as the first follow up assessment or can occur with the second or third administration.[21,22] This type of practice effect has been demonstrated by other research in which control groups have shown lower BESS scores over repeat assessments within a period of one week but not at 30 days.[21,22] Thus, despite the change in the environment, HYA scores did improve which contributes to the justification of ruling out the physical environment as the cause for the increase in scores within the SA group. It also warrants further analysis to explore the order in which the assessments occurred.

An analysis of the trials by the order they were completed (rather than analyzed by environment) showed significant differences between the two groups, but no significant difference within either group. The number of participants in this analysis differed from the analysis by environment because not all of the SA group completed the BL assessment first so they were not included in this analysis. Within the SA group, scores were not significantly different and were very similar across the three assessments (BL: 10.3 ± 4.0 errors, Follow Up 1: 10.1 ± 4.5 errors, and Follow Up 2: 10.4 ± 5.5 errors) but were significantly higher than the HYA scores (BL: 8.1 ± 3.6 errors, Follow Up 1: 7.4 ± 3.5 errors, and Follow Up 2: 7.2 ± 2.6 errors). The HYA group did show a clear trend as scores improved over the three administrations even though the results were not statistically significant ($p = .080$). Guskiewicz has suggested that clinicians should not only be concerned with a increasing BESS score, but also should consider the absence of a decrease in score just as important.[29] As with the HYA group in this study, scores should steadily decrease with two to three repeat assessments as the subjects become more familiar with the test. Failure of decreased scores in the SA group at the follow up assessments, although not statistically significant, is still an important finding indicating a potentially undetected factor responsible for the decreased performance. A higher score indicates either a decrease in postural stability or could be linked to something in the testing environment. The existence of this practice effect should be strongly considered, especially when administering multiple assessments over a short period of time. This becomes important if BESS tests are used as a daily re-evaluation tool to determine recovery of postural stability following concussion because improved scores may not be a result of improved postural stability, but rather familiarity with the BESS test.

Other analysis aimed to determine which stances were responsible for the largest percentage of errors. A significant interaction was found for the number of errors per stance as the SA group scored significantly more errors than the HYA group. Significant differences were found for the single leg firm, tandem foam stances, and single leg foam between the two groups. Errors on these three stances were the highest and contributed to 16.1, 26.7, and 49.9% of all errors, respectively. The single leg and tandem foam stances have also shown to be significant factors constituting a high percentage of errors in other literature.[17,22,28] Therefore, it can be assumed that these stances are likely considered the most difficult and it is not surprising that the current results showed the largest difference between the groups on these two stances.[17,22,28] Onate found medium to large effect sizes on the single leg and tandem foam stances and only reported a significant difference between groups on the single leg foam stance.[28] The present study also found a medium effect size on the single leg foam stance (cohen's d = .568) and a large effect size on the tandem foam stance (cohen's d = .920). These findings support other research that suggests not all stances of the BESS test are necessary to find a significant difference amongst BESS scores.[17,22] Hunt found significant differences in high school athletes using only the single leg and tandem stances on a firm and foam surface.[22] This evidence could possibly lead to a modification of the BESS test to eliminate the double leg stances due to the low error rates in those stances.[22] Analysis of error type revealed that a step, stumble, or fall

(59.8%) was the most common error committed among all of the participants followed by multiple errors occurring simultaneously (20.2%). Again, this is not an unexpected finding because the highest percentage of errors came from a single leg stance.

One potential limitation of the BESS test is a substantial practice effect shown during repeat administrations within the same week in youth, high school, and collegiate athletes however the effect was not noted after a period of 30 days.[21,30,31] These findings suggest a 30 day window that could potentially be needed in between repeat administrations to reduce the likelihood of a practice effect. The present study incorporated this finding by designing the repeat administrations to be several weeks apart and each participant was tested with at least 23 days between trials (range 23 – 389 days). At least 30 days between repeat assessments would have been preferred however, some participants were tested prior to the end of the 30 day interval. Although the practice effect of a second administration after 23 days has not been examined previously, the literature clearly shows repeat administrations within a seven day span elicit a practice effect that can be minimized if the assessments are spread over a 30 day span.[21,22] This becomes important when interpreting the results because the length of time between trials for the SA group is much longer than the HYA group (mean 177.0 ± 92.2 days and 57.7 ± 36.4 days, respectively). This limitation can be explained as the controls were recruited as a part of this study whereas the athletes were all baseline tested upon entering the current institution. Some of the changes with the scores from the HYA group may be attributed to a practice effect however previous research suggests a much smaller window of one week.[21,28]

In addition to the practice effect, surface has also been explored as a potential factor contributing to changes in postural stability. Baseline testing surface may or may not be consistent with the follow up testing surface. For instance, if baseline assessments are obtained indoors on a hardwood floor for a football athlete, sideline assessments would likely occur on natural grass or artificial turf. Schneiders found that for a group of amateur athletes performing a tandem gait task, surface (hardwood court, natural grass, and artificial turf) was not a significant factor when comparing trials that were performed barefoot.[27] The present study involved all barefoot conditions on two different surfaces and found that the SA group's score increased while the HYA group scores decreased, indicating that surface alone is not the cause for the change in scores thus further research is needed to explore alternate possibilities for changes in BESS score.

Other factors, such as the role of dual-task procedures have also been studied and shown to have a relationship with postural control.[31,32] Previous literature suggests that when two tasks are being performed together there is a noted deterioration of performance on one or both tasks.[32] The present study asked participants to stand as still as possible, maintaining a specific stance either in the presence or absence of a distracting environment. The SA group's attention may have been altered due to the external environment containing distractions associated with a live sporting event which could account for the increase in number of errors in the live event trials.

Scoring of the individual BESS trials is also an important area for discussion. Two scorers were used to ensure that all of the student-athletes were tested within the time constraints of a live sporting event. However, the final scoring of the individual trials in this study was calculated during video analysis by a single researcher (CR). This scoring protocol, while reducing some clinical applicability as BESS is typically not scored using recorded video, is common in the BESS literature and likely provides the most accurate method of scoring.[20,22,30,33] Indeed, as the purpose of this study was to investigate the influence of distractions in the environment, it is plausible that investigators scoring "live" may also be subject to the same distractions; thus influencing the BESS scoring. Therefore, as the aim of the study was to identify changes in BESS performance, as opposed to scoring accuracy, the use of video based scoring likely maximizes the probability of accurate results.

There are several limitations that need to be considered when interpreting the results of this study. Primarily, multiple games were used in order to accommodate all of the participants' availability to collect sufficient data on the SA group. For example, some subjects were only available for testing at one home football game while others had to attend a different game due to their team travel schedule. Comparable issues were present when attempting to schedule the participants for the BKB trials. Therefore, the number of days between testing sessions differed for most subjects (mean 121.7 ± 93.3) as some were tested at BKB first while others were tested at FB first; however there was at least 23 days between the testing dates to minimize the practice effect. The completion of the follow up trials for HYA subjects, after the initial BL assessment, was matched to the order in which the SA subjects completed the experimental trials. Additionally, during the experimental live sessions the noise levels naturally varied throughout the testing paradigm.

Further, the student-athletes in this study were tested at environments (football and men's basketball) with far larger crowds (average regular season attendance: 17,627 and 1,538 respectively) and, likely, noise and distractions than typically occur at their events (average regular season attendance: soccer 185, volleyball 593, and softball 238). Therefore, it is possible that individuals more familiar with these environments may have performed better by being less distracted and this is a potential area for future investigations. Finally, the intentionally liberal inclusion criteria for this study allowed participation by subjects with chronic injuries as long as they were cleared to fully participate in team activities. The rationale for this inclusion criteria was that if the athlete would have competed, they would have had the potential to have sustained a concussion and thus would have needed to be evaluated appropriately. Further, while limiting participation to only individuals without current or chronic injuries would have improved the control of the study, it would have substantially reduced the clinical applicability as relatively few collegiate athletes are free of acute or chronic injuries over the duration of an athletic season. According to the NCAA, women's soccer reported the highest injury rate (16.4 injuries per 1,000 athlete exposures) during games for any women's sport from 1988-1989 – 2003-2004 indicating that the majority of soccer athletes will sustain an injury at some point during the season and would have greatly reduced the number of available subjects for the present study.[33] Volleyball and softball injury reporting rates were 4.6 and 4.3 per 1,000 athlete exposures indicating that even though the numbers are much lower than soccer, there is still a substantial risk for sustaining an injury while participating in those sports.[34] Future research should focus on evaluating which factors in the environment affect BESS scores the most. Perhaps the increase in the number of errors can be specifically linked to the temperature, humidity, wind speed, or noise level at a given environment.

The results of this study further suggest that athletic trainers should standardize the testing environment for all BESS testing. If baseline tests continue to take place in a quiet and controlled environment then it is important that follow-up testing should take place in a similar environment. Conversely, if sideline testing is desired then an uncontrolled baseline environment is recommended. Recently, the National Hockey League updated their concussion assessment policy to mandate that athletes suspected of sustaining a concussion have to be removed from the game and sent to a "quiet place free from distraction so they can be examined by the on-site team physician".[35] In this case, all concussion evaluations would be performed in a controlled environment which is consistent with the results of the present study. Conversely, the National Football League has implemented a new sideline concussion assessment protocol.[36] Rather than taking the athletes to a quiet environment, the National Football League is recommending that athletes be assessed on the sidelines using a symptom checklist, a brief neurological examination, and a balance assessment to be consistent with the 3rd International Consensus Statement.[2,36]

The clinical application this study provides for current athletic trainers is to understand that testing environment for the BESS test may have a significant effect on BESS scores. These findings showed that scores did deteriorate significantly when testing occurred in a distracting environment. Future research should focus on determining which factors in the environment (e.g. wind, temperature, humidity, condition of the surface) have the largest impact on BESS scores. Future study is also encouraged to expand the current results by testing a larger group of athletes in additional environments to see if similar findings are achieved. Based on the results of the present study, baseline and follow up administrations should be performed in similar environments to minimize the possibility that the external environment may contribute to changes in BESS scores. With the implementation of this strategy, athletic trainers and team physicians may be better positioned to assess athletes suspected of sustaining a concussion, thus improving the concussion management protocol.

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APPENDIX A

RESEARCH HYPOTHESES

H_0: BESS scores will not change significantly in the SA or HYA groups for the BL, FB, or BKB testing.

H_{A1}: There will be a significant difference in the scores for the SA group but no significant change in the HYA group.

H_{A2}: The SA group will score highest (worst) during the football environment compared to the baseline or basketball environments.

H_{A3}: The HYA group scores will decrease (improve) when analyzed by the order in which the trials were completed.

H_0: There will be no significant difference in the number errors committed in each stance of the BESS test.

H_{A1}: The single-leg stance on the stable and unstable surfaces will elicit the highest number of errors.

H_0: There will be no significant difference in the type of errors committed during the BESS trials.

H_{A1}: A step, stumble, or fall will represent the highest percentage of all errors during the BESS trials.

LIMITATIONS

The noise level will vary for each subject in the athlete group due to the unpredictable nature of the sporting event. This is a common occurrence and athletes may be tested on the sideline during an event where the noise level varies within the actual test. Additionally, the testing environment will be different from each athlete's typical environment. We will be testing soccer, volleyball, and softball athletes during football and basketball events. The size of the crowd and noise level may not be consistent with the subjects' usual game day atmosphere. Additionally, multiple test days for each experimental setting will be needed to obtain the necessary number of trials. The BESS test also has a practice effect that has been found over a 13 period in female collegiate athletes.[24]

DELIMITATIONS

Only female subjects will be recruited for participation. All of the subjects will be from the same NCAA Division I institution. Participants will not be excluded based on the presence of chronic injuries. Only those with injuries preventing full participation athletic activities will be excluded from participation.

ASSUMPTIONS

The subjects will be asked to give their best effort during the BESS trials so we have to assume that the best effort will be given during testing. Additionally, subjects will be specifically asked to not be under the influence of alcohol during the testing sessions. We also assume that the injury questionnaires will be answered truthfully.

APPENDIX B

Review of Literature

Epidemiology

Approximately 1.6 to 3.8 million sports-related traumatic brain injuries (TBIs) occur annually in the United States.[1] Concussions are a common type of TBI often related with sports. McCrory[2] defines a concussion as "the immediate and transient symptoms of mild traumatic brain injury". Rhazes, a Muslim physician from the 900s, was the first person to correctly use the term "concussion".[2] Over the years the definition of concussion has changed, but some of the basic principles from over 3,000 years ago still remain today.

Literature involving identifying concussion rates varies depending on the age, gender, and sport of the participating athletes. The typical rate of concussion that is generally accepted is approximately 5-8%.[3,4,5] Shankar's research[6] found that in high school football approximately one out of every eighteen to nineteen football players will receive a concussion. Gessel[4] has found that high school and collegiate female athletes are more likely to sustain a concussion with a rate of 15.1% over males at a rate of 9.4%. Covassin's findings[7] agree as her results show that female collegiate athletes' concussion rates are around 9.5% while male rates are much lower at 6.4%. In addition, research supports the notion that high school aged athletes may be at an increased risk for sustaining a concussion. Research conducted by Shankar[6] concluded that high school athletes were 1.55 times more likely to sustain a concussion than their collegiate counterparts. Also, Gessel[4] found the concussion rate among high school athletes to be 8.9%, while the rate in collegiate athletes to be at 5.8%, supporting the theory that younger athletes may be more susceptible to concussive brain injuries.

In addition to factors such as age and gender, concussive episodes can be affected by the number of previous concussions an athlete has sustained. Zemper[8] found that high school and collegiate football athletes who encountered a concussion while participating in athletics in the previous five years was 5.8 times more likely to sustain a concussion when compared to athletes with no history of concussion. Approximately 14.7% of athletes experiencing one concussion encountered a second concussion within the same season.[3] Also, in 2003, Guskiewicz[9] found that athletes with a history of three or more concussions were three times more likely to suffer a subsequent concussion. These findings suggest that athletes with a history of previous concussion should be considered at a higher risk for ensuing concussions than those with no previous history. Therefore, concussion management and return to play (RTP) guidelines may need to be more conservative when an athlete has experienced multiple concussive episodes, especially in the same athletic season.

Two other important factors to consider when evaluating the prevalence of concussions in athletics are rates of loss of consciousness (LOC) and post-traumatic amnesia (PTA). Langlois[1] estimates that over 300,000 TBI occur each year that involve LOC. Additionally, LOC rates that are supported throughout concussion literature range from 6.3%[9] to 8.9%[3]. When examining PTA, the rates are much higher, with common rates around 20%. McCrea[10] reports finding a PTA rate of 19.1% in a study involving collegiate football players while Guskiewicz[9] has reported PTA rates of 24.1% for a similar group of athletes. In addition Guskiewicz[3] found that PTA occurred in 27.7% of high school football athletes.

Pathophysiology

After receiving a concussive blow the brain undergoes many changes on the cellular level that Giza[11] describes as the neruometabolic cascade of concussion. First, neuronal depolarization occurs across the entire brain causing a release of the excitatory amino acid glutamate. This release allows for a massive efflux of potassium and influx of calcium resulting in disequilibrium. At this point it is theorized that the high amount of potassium outside the cell is likely the cause of LOC, amnesia, and cognitive dysfunction. Due to the increased presence of the extracellular potassium, sodium/potassium pumps are activated to restore potassium back into the cell. This process requires more energy than the brain is accustomed to providing, thus resulting in hyperglycolysis and eventually leading to an increased lactate production. Typically, potassium levels are restored to normal by six to eight minutes post-concussion. As the lactate turns to lactic acid, the brain becomes more vulnerable to a secondary injury. As a result, the brain becomes engaged in an energy crisis and an accumulation of calcium occurs that could potentially last several days. During this state, the brain is susceptible to further injury in the event of even a sub-concussive blow. In support of this evidence, Guskiewicz[9] found that an athlete who had sustained a concussion during an athletic season was likely to encounter a second concussion in the same season within ten days of the first. The influx of calcium can occur in several different areas of the brain and the location of this influx will determine the symptoms that are displayed by the concussed individual. The decreased ability of the brain to produce energy can lead to severe axonal pathologies including cell death and other structural damage, in addition to functional damage.

In addition to these primary effects of concussive injury to the brain, a more serious injury can occur if a second concussion is endured while the brain is still recovering from an initial concussive episode. Second Impact Syndrome (SIS) is described by Cantu[12] as a head injury sustained by an athlete who has still not recovered from the signs and symptoms of an initial head injury. The effects of this condition are very severe and often result in death of the athlete. The typical presentation of SIS involves some type of initial head injury that can range from cerebral concussion to cerebral contusion. While the athlete is compromised from the initial injury, a second and often relatively minor blow to the head causes additional injury to the brain. Typically, the athlete does not immediately lose consciousness but does seem dazed and is usually able to leave the field under their own power. Within the next several seconds, the athlete rapidly declines and usually collapses and falls into a semicomatose state. As SIS occurs, the brain loses its ability to regulate the blood supply and causes vascular engorgement within the cranium. This engorgement increases pressure within the brain and can lead to brain herniation and other brainstem injury. This process usually lasts only 2 to 5 minutes and results in coma and respiratory failure, and eventually to death. SIS occurs most commonly in adolescents aged fourteen to sixteen and is not seen very often in adults.[12]

Grading Scales

There are several different concussion grading scales that are used throughout the United States to assess the severity of concussion. Generally speaking, a grade 1 concussion is considered a mild injury, a grade 2 is classified as a moderate injury, and a grade 3 is deemed a severe injury. Three of the most commonly used grading classification systems are the American Academy of Neurology's (AAN) Practice Parameter Grading System for Concussion, the Colorado Medical Society Grading System for Concussion, and the Evidence-Based Cantu Grading System for Concussion.

The AAN's Concussion Grading Scale[13] defines any concussion involving LOC as a grade 3, the highest on the scale. The Colorado Medical Society Grading System[14] utilizes the same philosophy, grading all concussions with LOC as a grade 3. Conversely, Cantu's Evidenced-Based Grading System[15], considers the duration of LOC when determining the grading of concussion. His scale considers LOC lasting less than one minute as a grade 2, while LOC lasting greater than one minute as a grade 3.

While LOC is considered an important clinical sign of concussion, LOC is not required for a concussion to occur. LOC rates have been found as high as 27.7%[3] to as low as 19.1%[10], depending on the age and type of athletes studied. McCrea[10] has found that LOC is a poor indicator of the severity of concussions and their symptoms. In spite of this data, many common concussion grading scales still use LOC as a deciding factor when grading concussion. Although the AAN and Colorado guidelines are commonly used throughout concussion research, there are also other studies that provide evidence that LOC is not necessarily associated with a more severe injury. Research conducted by McCrea[10] determined that athletes who encountered LOC showed a similar time to return to baseline on neuropsychological testing and symptom assessments as those who did not have LOC during a concussive episode, indicating that LOC may not be the best indicator of concussion severity.

Due to the multiple different grading guidelines used to measure and assess concussions, it is important to consider the scale used when interpreting the severity of a concussion. While the AAN and Colorado scales are similar and use LOC as the only factor to classify a concussion as a grade 3, there are also other differences between the guidelines. The AAN system utilizes a fifteen minute timeline to help establish the grading system. Concussions that involve confusion and mental status abnormalities less than fifteen minutes are considered a grade 1, while the presence of any symptom after the initial fifteen minutes is considered a grade 2. The Colorado scale incorporates amnesia into its classification system by stating that confusion without the presence of amnesia indicates a grade 1, while confusion in addition to amnesia indicates a grade 2 concussion. Cantu’s Evidence-Based System once again differs from the AAN and Colorado guidelines and places more emphasis on PTA and less on LOC. In Cantu's scale a grade 1 concussion is defined as no LOC and PTA and post-concussion signs or symptoms lasting less than thirty minutes; a grade 2 is identified as LOC lasting less than one minute and PTA and post-concussion signs or symptoms lasting longer than thirty minutes but less than twenty-four hours; and finally a grade 3 is described as LOC lasting longer than one minute, the presence of PTA longer than twenty-four hours, or post-concussion signs or symptoms lasting longer than seven days. Therefore, when using the Evidence-Based Cantu Grading System, the grading of some concussions may be delayed until a full week after the onset of the injury, contrary to other guidelines that allow for a definite grade at fifteen minutes post-injury.

Cantu's new guidelines are a revision of his first grading system published in 1986.[16] Those guidelines included a similar LOC consideration with grade 1 involving no LOC and grades 2 and 3 being associated with LOC less than or greater than five minutes, respectively. He utilized the same guidelines for PTA, but did not include the presence of post-concussion signs or symptoms in his original scale.

Return To Play Guidelines

Though these are the most researched concussion grading guidelines, there are multiple other grading scales available for use that simply add more confusion to the already complex task of grading concussions. As there are a variety of grading scales, there are also multiple philosophies on determining return to play (RTP) guidelines for concussed athletes. Cantu[15] suggests that athletes are eligible to RTP when they are free of any PTA symptoms and all post-concussion symptoms at rest and with exertion. After an initial concussion, athletes are recommended to RTP after seven full days of being asymptomatic after grade 1 or 2 concussions. In the event of a grade 3 concussion, at least one month must elapse before RTP, including a full seven days of being asymptomatic. Research by Iverson[17] suggests that with each subsequent concussion after the first, there may be a cumulative effect and therefore a need for more conservative RTP guidelines. Cantu[15] considers this when suggesting RTP for an athlete who has sustained a second concussion in the same season as his/her first. An athlete suffering a grade 1 may return to play after two weeks as long as they have been asymptomatic for seven days; a grade 2 may return after a minimum of one month, with at least seven days of being asymptomatic; and a grade 3 should terminate the current season of activity and consider returning the following season if they are asymptomatic. The guidelines are yet more conservative for suffering a third concussive episode within a single season stating that any concussion at this point should result in termination of participation for the current season with the possibility to return the following season if they are asymptomatic.

Although it is highly recommended by many RTP guidelines that a concussed athlete should not return to the same event after the concussive episode, there is evidence that players are allowed to return to competition. Guskiewicz[3] reports that about 30.8% of collegiate and high school football players returned to play during the same day they received a concussion, and of that number 14.4% of those concussions were classified as grade 2 according to Cantu's original 1986 guidelines. Also, Kaut[18] found that 28.2% of collegiate athletes continued to play in a game despite feeling dizzy following a hit to the head.

Even though, in many cases, RTP is not recommended until an athlete has been asymptomatic for seven days there is some research to suggest that some activity may be beneficial for concussed athletes. Majerske[19] conducted a study that investigated whether or not post-concussion activity level has any effects on post-concussion symptom checklists or neurocognitive tests in student athletes. She developed an activity intensity scale that consisted of five categories: (0) no school or exercise activity, (1) school activity only, (2) school activity and light activity at home, (3) school activity and sports practice, and (4) school activity and participation in a sports game. Her findings revealed that athletes who participated in a level two activities after a concussive event experienced better symptom and neurocognitive improvements when compared to those participating in the other activity groups. These findings suggest that controlled exertion may help to improve the outcome of athletes after receiving a concussion.

Recovery

While severity and recovery are essential factors to consider when determining RTP guidelines for concussed athletes, another important issue to take into account is the number of previous concussions sustained by the athlete. Findings reported by Slobounov[20] are suggestive that athletes experiencing a second concussion in the same year as a previous concussion recover at a slower rate than those that only sustain one concussion in the same time frame. Although all of the participants in this study were clinically asymptomatic by ten days post injury, the group with a previous concussion history recovered at significantly slower rates on neurological functioning testing when compared with the single concussion group. At one month post injury, the multiple concussion group was only partially recovered whereas the single concussion group had recovered to baseline scores on coherence values. These results stress the importance of a comprehensive approach when determining RTP guidelines. Symptom resolution may be an important indicator of a resolving concussion; however athletes who are asymptomatic may still have neurological deficits.

Slobounov[22] studied twenty-one NCAA Division I athletes who sustained two same-season concussions to compare the rate of symptom and neuropsychological recovery to baseline with the rate of information quality of electroencephalography (EEG-IQ) to baseline values. His results revealed that although all athletes were completely asymptomatic by day seven and were cleared to RTP based on neuropsychological testing, EEG-IQ scores for all subjects had not yet returned to baseline. For those participants who were suffering for their second concussion, EEG-IQ values were well below the baseline findings suggesting that symptom recovery is not necessarily indicative of brain injury recovery.

In a sample of seventy-eight athletes who had sustained a sports-related concussion, Collins[23] investigated potential on-field injury markers related to concussion severity. He found that athletes who experienced retrograde amnesia, posttraumatic amnesia, five or more minutes of disorientation, or the presence of three to four abnormal markers increased an athletes' likelihood to have a poor presentation. LOC and disorientation for less than five minutes were not found to be related to poor presentation within this same group of concussed athletes. These finding reiterate doubts that have been raised about concussion severity and its relationship with LOC.

Due to the potential consequences of repeated concussion among athletes Cantu[12] has published a set of recommendations on absolute and relative contraindications on when to RTP following concussive episodes. He suggests that athletes never return when any of the following signs and symptoms are present: any abnormal neurological assessment; any postconcussion signs/symptoms at rest or with exertion; if available, a neuropsychological battery that has not returned to baseline values or above; or if available, Computerized Tomography (CT) or Magnetic Resonance Imaging (MRI) scans that show any type of lesion placing the athlete risk of further head injury. He also recommends that in the existence of postconcussion symptoms that lasts several months, rather than days or postconcussion symptoms that reoccur after mild, indirect blows to the head, could be indicative of potential reasons to retire from competitive sport. In further discussion of retirement, he stresses that emphasis should not be placed on the number of concussions but rather the severity and symptoms involved with each ensuing concussion.

Concussion Assessment

There are a variety of tests and scales that can be used to assess for the presence and severity of concussive events. Some of the more common methods involved in current research articles include the Balance Error Scoring System (BESS), Standard Assessment of Concussion (SAC), Sensory Organization Test (SOT), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Computerized Tomography (CT) scans, Functional Magnetic Resonance Imaging (fMRI), and post-concussion symptom scales and checklists. These evaluation methods range from subjective self-reports of symptoms to computerized neuropsychological testing that can assess attention, memory, reaction time, and processing speed. No single test has been shown to provide complete and thorough assessment of a concussive event, therefore the best approach to overall concussion management strategy is to use a combination of several of the evaluation tools to provide an accurate assessment. According to the National Athletic Trainers' Association's (NATA) position statement on the management of sport related concussion[24], baseline testing should be implemented to establish normal values for all athletes. With the use of a combination of objective assessment tools, a more comprehensive approach to concussion management can be implemented.

Earlier methods of assessing concussions were utilized in the 1980's by Maddocks[21]. He developed a list of questions that could be used to assess orientation and recent memory. Items used to determine an athlete's orientation included: name, date of birth, age, year, month, the day of the week, date, and time of day. Recent memory was evaluated by asking: location of event, identification of quarter, time remaining in quarter, team that scored the last goal, team that was played last week, and the result of the match from last week. This list of questions became known as “Maddocks” questions and was commonly used as a concussion assessment tool until more modern techniques were developed.

BESS

The Balance Error Scoring System (BESS) test was developed by researchers at the University of North Carolina at Chapel Hill as an affordable and practical means of assessing postural stability following concussion to aid in making RTP decisions.[25] The test requires a standard stopwatch and a 10 cm thick piece of medium-density foam (45 cm^2 x 13 cm thick, density 60 kg/m^3, load deflection 80-90). The testing procedure consists of three different stances that are repeated twice, first on a firm surface followed by a repeat assessment on the foam surface, for a total of six trials (Appendix D). Each position is recorded for a time of 20 seconds. The first position is a double leg stance in which the athlete stands with his/her feet together and faces forward. The second stance is a single-leg position in which the athlete stands on the non-dominant leg and maintains the contralateral limb in 20 to 30 degrees of hip flexion and 40 to 50 degrees of knee flexion. The third and final stance involves the athlete to stand in a tandem position with the non-dominate foot placed behind the dominant foot for the duration of the trial. All of the stance positions require the athlete to stand with both hands placed on the iliac crests with the eyes closed. Athletes are encouraged to maintain the position as motionless as possible while keeping the initial position. Athletes are also instructed to attempt to regain their balance as quickly as possible in the event that they are unable to maintain the required position.

BESS tests are scored based upon the number of errors committed during the trials. An error on the BESS test is defined as any of the following: hands being lifted off of the iliac crests; opening of the eyes; step, stumble, or fall from the stance; movement of the hip into more than 30 degrees of flexion or abduction; lifting of the forefoot or heel; and remaining out of the testing position for more than 5 seconds. Scores are determined by calculating the number of errors committed during each of the 20 second trails. In the event that the athlete is unable to maintain a stance for longer than 5 seconds, the trial is considered incomplete. A maximum number of ten errors are allowed per trial. The scoring of the BESS test is somewhat subjective and can be affected by the experience level of the tester. In addition, when scoring errors, some researchers are inconsistent about the calculation of multiple errors occurring simultaneously. Traditionally, each error committed during a trial was considered a point when scoring that particular trial. Some researchers, however, will only add one point if multiple errors occur at the same time. Although the BESS test has not been established as the best method to assess postural ability following concussive events, it has been shown to have intertester reliability coefficients ranging from 0.78 to 0.96.[26] In addition when compared to force-platform measures, significant correlations were established for five of the six static balance tests (single-leg stance-firm surface, tandem stance-firm surface, double-leg stance-foam surface, single-leg stance-foam surface, and tandem stance-foam surface).

Patel's research[27] explored the effects of dehydration on neuropsychological performance and postural stability. When using healthy, recreational athletes, acute dehydration does increase the number and severity of symptoms reported, but was not found to compromise balance or neuropsychological abilities on the SAC test, Automated Neuropsychological Assessment Metrics (ANAM), BESS, or NeuroCom SOT.

Fox[28] studied healthy, uninjured collegiate athletes to determine if anaerobic or aerobic exercise has any effect on postural control. He determined that postural stability did decrease after the exercise protocols and that the effects lasted up to 13 minutes post-exercise. His results however showed that regardless of the exercise protocol, all of the athletes in his study recovered at basically the same rates. His findings suggest that when clinically applying the BESS test, it is important to consider the athlete's activity immediately preceding the assessment.

Onate[29] used a sample of healthy collegiate baseball players to examine if the testing environment had an effect on BESS scores. His findings revealed that when athletes were tested in a controlled or locker room setting, BESS scores on the single-leg foam stance were significantly improved when compared to testing in an uncontrolled or sideline setting. Although significance was found on one stance of the BESS evaluation, overall BESS performance was not statistically different when compared between controlled and uncontrolled environments.

Riemann[30] conducted a study to compare the effectiveness of the BESS test when compared to results on the SOT. His research involved sixteen injured and sixteen matched control subjects that were tested three times post-injury. His findings revealed that the BESS test is a useful clinical method in the event that force-platform equipment is unavailable. He suggests that clinicians should consider using the BESS test as a sideline evaluation tool to help assist in making RTP decisions following concussion.

SAC

The SAC is a neuropsychological test that was developed to assess four domains: orientation, immediate memory, concentration, and delayed recall.[31] The assessment is relatively short and can be delivered in approximately 5 minutes. SAC testing can be administered by health care professionals without any experience or expertise in psychometric testing. The maximum score on the assessment is 30 points when the scores from all four domains are totaled. There are three forms of the SAC that make repeat testing possible and help to reduce potential practice effects.

The first section assesses an athlete's orientation by asking for information such as the day of the month, day of the week, date, year, and time (accurate within 1 hour). One point is given for each correct response in this section. The next segment addresses immediate memory by evaluating the athlete's ability to immediately recall a list of five words for a total of three trials. Each correct word is awarded one point, making the total possible score a fifteen for this part of the assessment. The third section focuses on concentration and requires the athlete to repeat a set of digits in reverse order. Initially, the string contains only three numbers and increases up to six as the athlete is able to complete each stage. The athlete is then asked to repeat the months of the year in reverse order. A total of five points is possible for the concentration component. Finally, delayed recall is assessed by having the athlete recall the five words that were originally given in the immediate memory section. Again, each correct word adds one point to the overall score.[31]

The results of a study by McCrea[31] showed that the average total score for a group of concussed athletes immediately following injury was 22.88 while a group of control subjects scored significantly higher at 26.58. In additional work by McCrea[32], he found statistical differences in all four domains of the assessment as well as the total score when injured athletes' scores were compared from baseline values to scores immediately following concussion. Even though there is a sudden decrease in SAC scores immediately post concussion, by 48 hours most subjects have reached their baseline scores. Additionally, at 90 days post injury, SAC scores were improved when compared to preseason baseline values.

When evaluating an athlete suffering from a concussion, it is common to test the athlete at selected intervals after the injury. Sometimes this may mean testing an athlete every day after the concussive event to monitor symptoms and neuropsychological recovery. The potential problem this creates is that if the test elicits a practice effect, then improving scores does not necessarily indicate a resolving injury. For example, Valovich[33] studied a group of uninjured high school athletes to test whether repeated administration of the BESS and SAC evaluations resulted in a practice effect among the athletes. Her results showed that the single-leg stance on the foam during the BESS test did show a slight practice effect across multiple assessments. The SAC test however showed no practice effect under the same parameters. The findings on the SAC test differ from McCrea's results of a similar study when concussed high school and collegiate athletes were evaluated. McCrea[32] found that by 48 hours post-concussion, the majority of athletes had either reached or exceeded baseline SAC scores, suggesting a possible practice effect associated with the assessment.

SOT

The Sensory Organization Test (SOT) utilizes a dual force-plate system to measure the ability to maintain equilibrium.[30] The SOT is administered via the NeuroCom Smart Balance Master that allows the support surface and visual surround tilt to alter sensory conditions. The test consists of eighteen total trials that each last 20 seconds. There are three different visual conditions: eyes open, eyes closed, and sway referenced and two different support surface conditions: stable and sway referenced. The different conditions affect the athlete by having the somatosensory system, visual system, or both perceive that the body's orientation to gravity is constant when it is actually changing. A composite report rating an individual's score can be calculated, with higher scores indicating better balance performances.

ImPACT

ImPACT is a computerized neuropsychological assessment that contains six separate tests to measure cognitive functioning. These tests include verbal memory, visual memory, reaction time, processing speed, impulse control, and a twenty-two item post-concussion symptom scale.[34] The verbal memory score represents the total number of points attained on a word recognition paradigm, a symbol number match task, and a letter memory task. Visual memory scores are obtained by combining scores from two recognition memory tasks. Reaction time is measured in milliseconds for three individual tasks while processing speed is determined by the weighted average of three tasks during the memory paradigms. The total number of errors of omission or commission during the testing protocol is combined to establish the impulse control score. The post-concussion symptom scale is scored by accessing one point for each symptom present.

In a study by Collins[23] athletes who had sustained a mild concussion showed decreased memory functioning at thirty-six hours and days 4 and 7 post injury when compared to non-injured controls and baseline values. Additionally, within the control group, no significant practice effects were noted on the memory composite scores. Broglio[35] has found that in a group of collegiate athletes, neurocognitive deficits can still be present even if the concussed athlete asymptomatic. This further reiterates the concept that symptom resolution does not necessarily indicate injury resolution.

CT Scans

A CT scan is a structural imaging technique that is often ordered in the event that a concussive event was severe enough to require the athlete to be taken to the hospital. This test can be very important when helping identify whether or not the athlete is experiencing a sports related concussion or a more serious head injury involving an intracranial hemorrhage. Although useful in certain circumstances, Davis[36] found that that CT scans are not useful when assessing the severity of a concussion. In addition, these scans can pose a potential radiation threat in children and thus should only be used when clinically necessary.

fMRI

Whereas CT scans can help identify potentially life-threatening intracranial hemorrhages, the fMRI offers a different perspective when evaluating brain injuries. According to Chen[37], fMRI has the ability to associate brain abnormalities with the presence of post-concussion symptoms (PCS). These scans can also offer additional information about pathophysiological and functional sequelae of concussive events.[38] fMRI has also been shown to be useful when analyzing recovery patterns following concussion when repeat scans are available.[39] When obtaining a fMRI, there are several other assessments that occur such as finger sequencing techniques, N-back memory assessment, and other verbal and visual memory tasks.[36] The quality of these instrument and importance of the interpretation of the results are all areas that are currently being explored and evaluated when implementing fMRI.

There are however a few major disadvantages to using fMRI. These scans are very expensive and often not widely available for use as a diagnostic instrument. Ricker reports that there are a variety of factors that can influence results such as medications, fatigue, substance use, and pain. Davis[36] states that currently fMRI is only used as a research tool, but hopes that in the near future the fMRI may prove to be an important diagnostic technique.

Research conducted by Chen[37] regarding fMRI and post-concussion symptoms gives support for continued usage of the PCS scale in evaluating and monitoring recovery after concussive injury. He used a small sample of concussed male athletes to establish these results and found that increases in PCS scores lead to a decrease in activation in the three prefrontal regions of the brain. This suggests that in the event a concussion is sustained, the brain has the ability to activate other regions to compensate for those that are injured.

Symptom Assessment

The most common concussion related symptom reported is headach.[3,21] Other frequently reported symptoms include dizziness, blurred, vision, and nausea.[21] In 2004 Iverson[41] explored the concept of "fogginess" as a potential indicator of increased symptom reporting and poor performance on neuropsychological testing methods. His research found that a "feeling of being one step removed from my surroundings" or "feeling like I'm in a fog" was indicative of adverse effects from concussion at one week post-injury in a group of high school athletes. Multiple different symptom assessment scales are available for use, even though many of them have no proven validity or reliability. Symptom checklists are very subjective and depend on the athletes' interpretation of the symptom and their perceived intensity of those symptoms. With all research based on symptom scales, there is a possibility that some athletes will not answer truthfully in an attempt to RTP as soon as possible. Some of the most commonly used concussion symptom scales are the Post Concussion Scale (PCS), the Graded Symptom Checklist (GSC), and the Sport Concussion Assessment Tool Post-Concussion Symptom Scale (SCAT). The format of most of these tests involves a series of seventeen to twenty-two symptoms that are rated on a Likert scale. The values are compared at desired intervals throughout concussion recovery to assist in determining safe and appropriate RTP guidelines. Research by Alla[42] discussed the differences between each scale but could not establish a "gold standard" scale that is proven to be the most effective tool for measuring signs and symptoms of concussion.

Long Term Effects

Guskiewicz[43] has studied the risk of depression associated with recurrent concussions among a population of retired professional football players. He found that athletes who had incurred three or more concussions were at a significantly greater risk for having depressive episodes in later adulthood when compared with those athletes with no history of concussion. In addition, 11.5% of respondents with a history of one or two concussions reported that those injuries have had a permanent effect on their thinking and memory skills. For those with three or more concussions, this percentage increased to 31.1%.

Guskiewicz[44] also found that within the same sample of retired professional football players, the presence of three or more concussions resulted in a fivefold increase of being diagnosed with mild cognitive impairment (MCI). His results are suggestive that retired professional football players have an increased chance of developing early onset Alzheimer's disease (AD). Although these athletes are more prone to early onset AD, by age seventy-five the prevalence of AD in his sample was equal to the general male population. Additionally, no association was found between previous history of concussion and a diagnosis of AD. These finding are reinforced by research conducted by DeBeaumont[45] who found evidence that retired athletes who had sustained one or two concussions during their athletic careers had an increased potential for cognitive and motor function alterations in late adulthood.

Conclusion

In conclusion, sports-related concussion is a common injury in the United States across a variety of age groups and sports. Concussions have been shown to be serious and even life-threatening injuries when they are managed improperly. When the brain has suffered a concussive injury there is a window of time in which it is susceptible to a condition known as second impact syndrome that has been shown to cause death in several adolescent athletes. There is much debate when determining how to grade the severity of these injuries as well as determining and establishing appropriate RTP guidelines. Additionally, there are many ways to assess an athlete's postural and neuropsychological abilities following a concussive episode. Although there is no single "gold standard" assessment available, many have recommended that a multi-faceted approach to concussion assessment may be the best strategy to determine overall concussion recovery. There is evidence that repeat concussions can increase the risk for subsequent concussions and eventually lead to serious long-term medical issues associated with depression, MCI, and AD. Even though concussions can be associated with multiple serious problems, with proper management and treatment strategies, the long term effects of concussion can be controlled.

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APPENDIX C

Georgia Southern University
Influence of Testing Environment on Performance of the Balance Error Scoring System

Subject Initials: ____________________ Subject ID #__________
(First MI Last)

Date of Testing: ____/_____/_____

A. Demographic Data

(1) Subject Date of Birth: ____ /____/ ______

(2) Age: ________

(3) Gender: _________

(4) Year in School: Freshman Sophomore Junior Senior Grad Student

B. Injury History

(1) Have you completed the "Ankle Instability Instrument"? YES NO

(2) Have you ever suffered an injury to either foot, ankle, leg or knee? YES NO
If YES, please describe: ____
____

(3) Have you ever had surgery on either foot, ankle, leg, or knee? YES NO
If YES, please describe: ____
____

(4) Do you have balance disorders? YES NO
If YES, please describe: ____
____

(5) Have you ever been diagnosed with a metabolic disorder? YES NO
If YES, please describe: ____
____

(6) Have you ever been diagnosed with a neurological disorder? YES NO
If YES, please describe: ____
____

(7) Have you ever been diagnosed with a vestibular disorder? YES NO
If YES, please describe: ____
____

(8) Are you currently taking any medications? YES NO
If YES, please describe: ____
____

APPENDIX D

Balance Error Scoring System

APPENDIX E

Figures

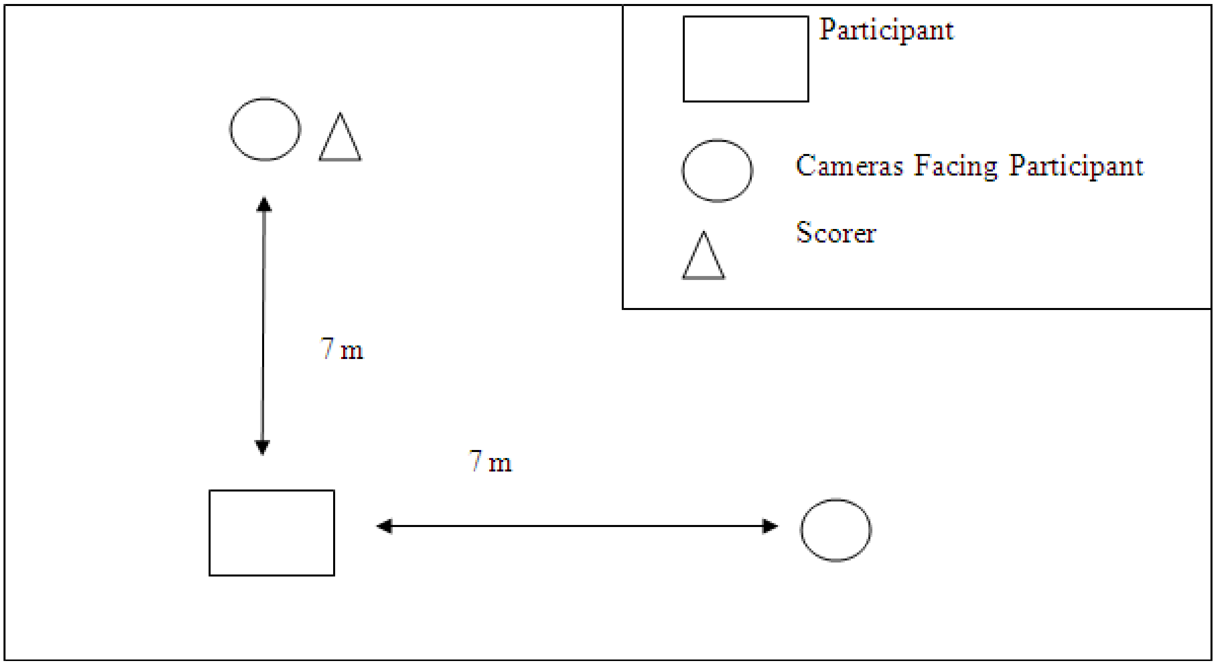

FIGURE 1: BL data collection setup. Cameras were placed 7 m from the participant to obtain a frontal and sagittal plane view. The scorer was positioned near the frontal camera during the data collection.

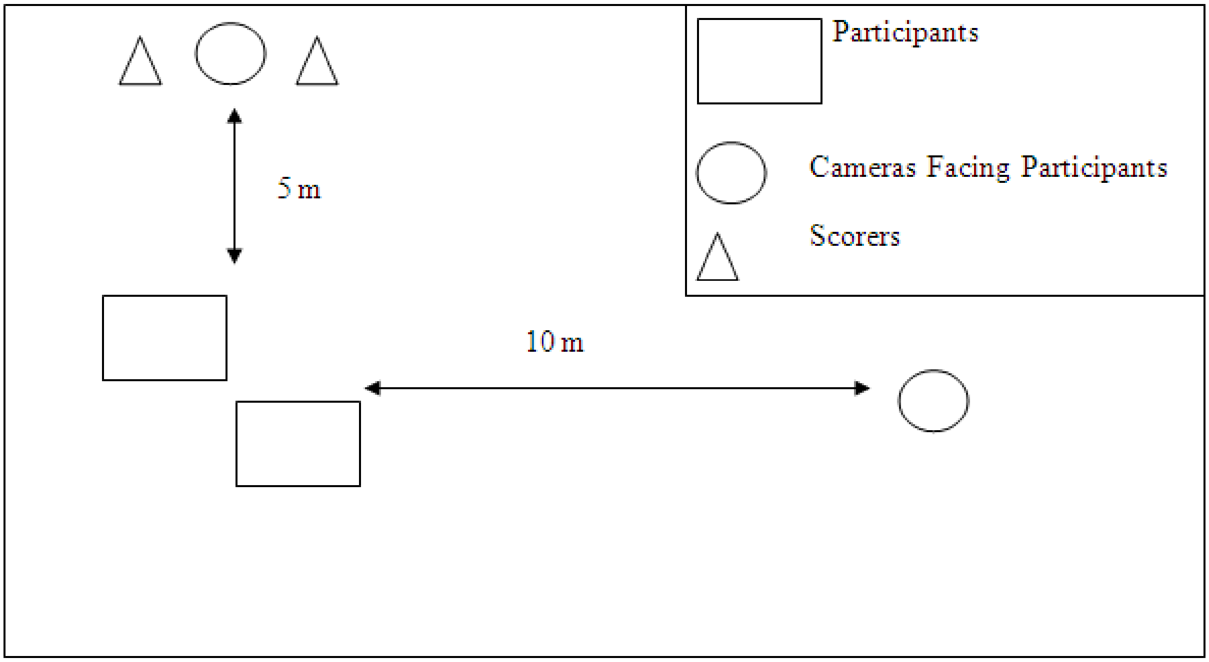

FIGURE 2: FB data collection setup. Cameras were placed 5 m and 10 m from the participants to obtain a frontal and sagittal plane view, respectively. The scorers were positioned at either side the frontal camera during the SA group data collection. During HYA group data collection, only one scorer was utilized however the cameras remained the same distance from the participant.

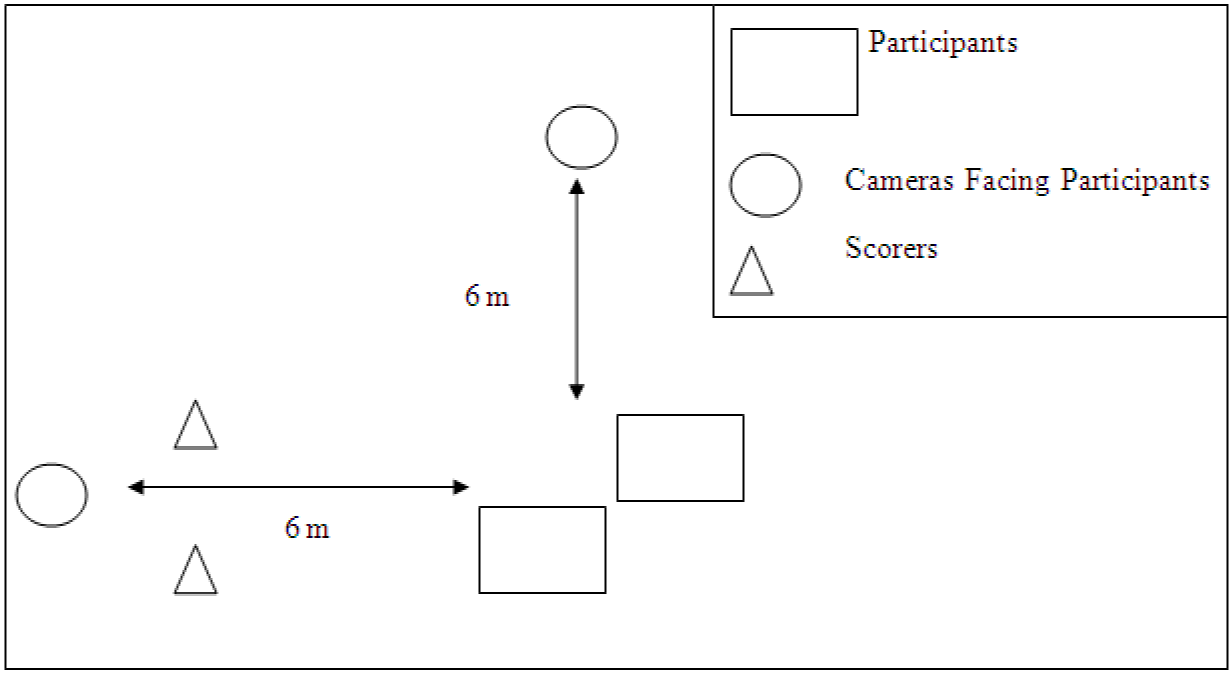

FIGURE 3: BKB data collection setup. Cameras were placed 6 m from the participants to obtain a frontal and sagittal plane view. The scorers were positioned at either side the frontal camera during the SA group data collection. During HYA group data collection, only one scorer was utilized however the cameras remained the same distance from the participant.

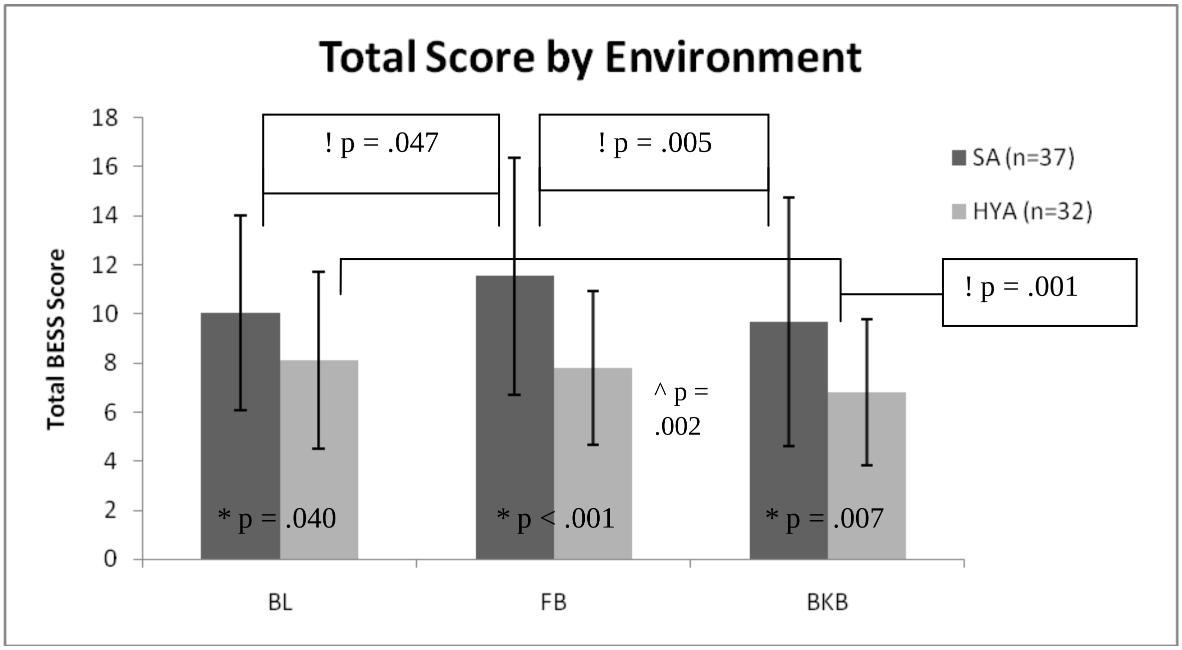

FIGURE 4: Total BESS score by group. A significant trial effect revealed a difference for FB compared to BKB. There was also a significant main effect for the two groups with the SA group scoring higher than the HYA group across three environments. For the SA group there was a significant difference between FB and BL and FB and BKB. Within the HYA group the only difference was between BL and BKB. ^ Denotes a significant difference between environments. *Denotes a significant difference between groups. !Denotes a significant difference within groups.

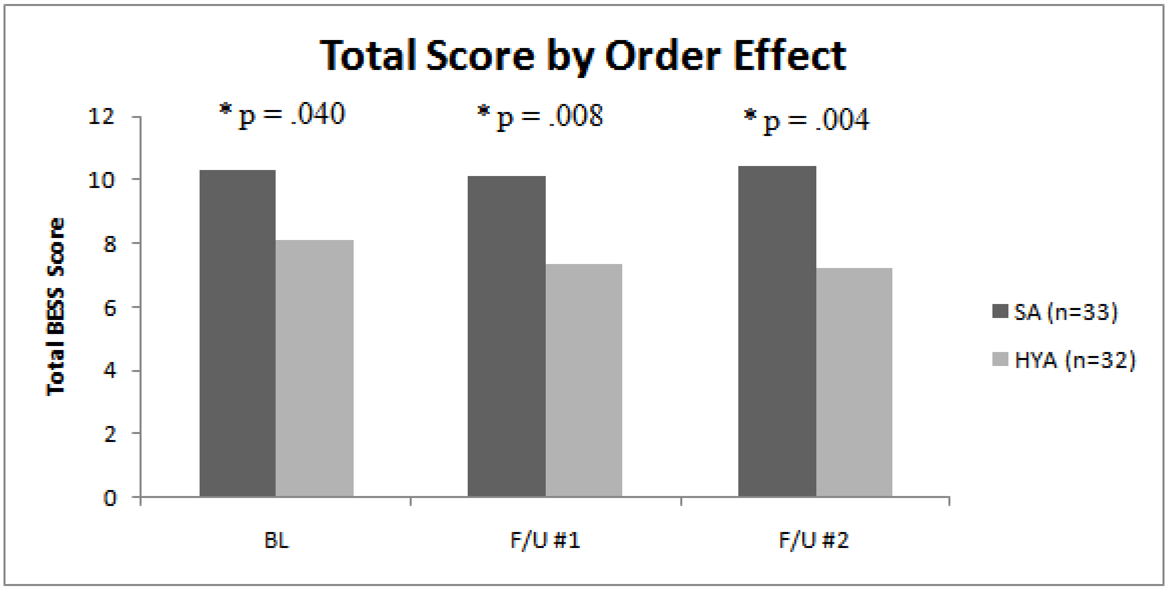

FIGURE 5: Total errors by order. The SA group scored significantly higher than the HYA group across the three trials. *Denotes a significant difference between groups.

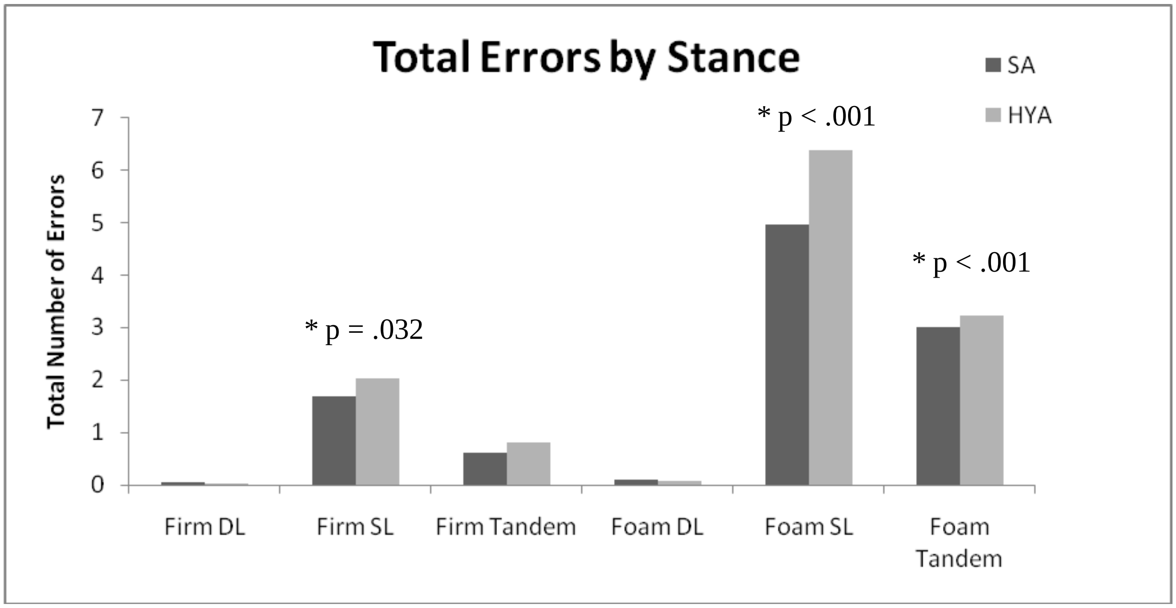

FIGURE 6: Total number of errors per stance. There was a significant difference between groups for the single leg firm, single leg foam, and tandem foam stances. *Denotes a significant difference between groups.

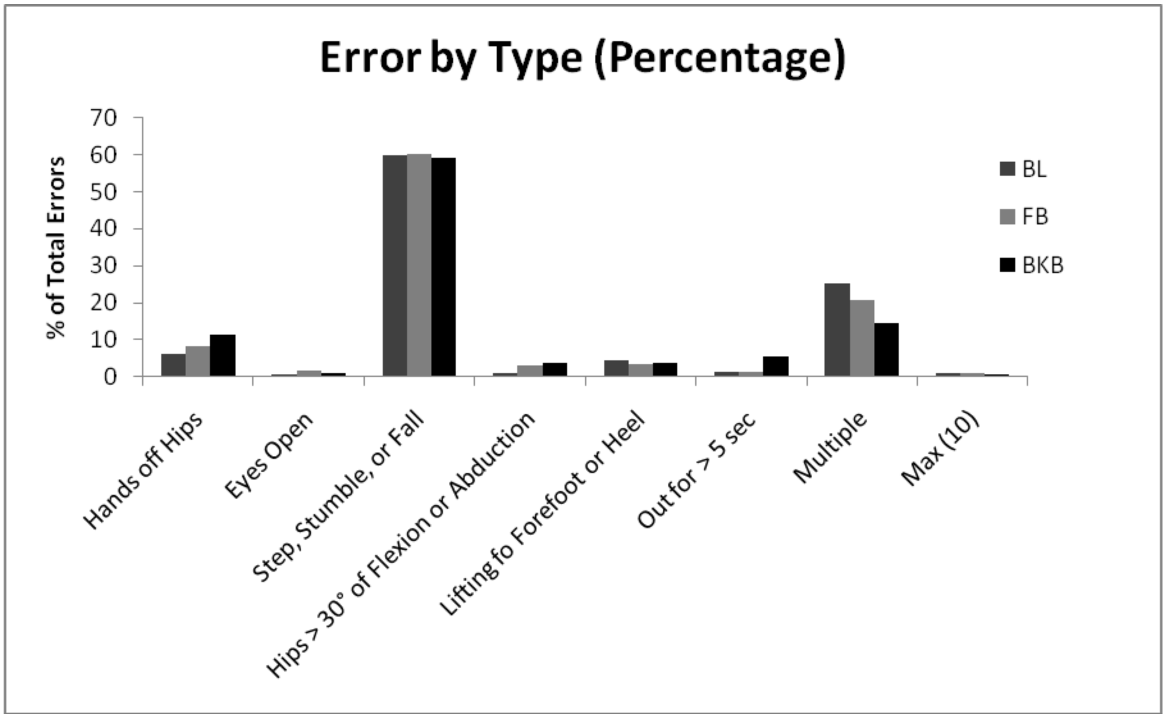

FIGURE 7: Frequency of errors by type. Step, stumble, or fall and multiple errors accounted for 59.8% and 20.2% of all errors, respectively.

APPENDIX F

Tables

	Age (years)*	**Height (cm)***	**Weight (kg)**
SA (n = 37)	19.97 ± 1.09	169.97 ± 7.72	66.68 ± 9.45
HYA (n = 32)	20.84 ± 1.11	162.64 ± 5.97	63.70 ± 10.55

TABLE 1: Demographics. *Denotes a significant difference between groups for age (t = -3.277, p = .002) and height (t = 4.363, p < .001).