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The Effect of a Competitive Athletic Season on the Performance of the Balance Error Scoring System

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THE EFFECT OF A COMPETITIVE ATHLETIC SEASON ON THE PERFORMANCE OF THE BALANCE ERROR SCORING SYSTEM

by

JOHN BURK

(Under the Direction of Thomas Buckley, Barry Munkasy, and Barry Joyner)

ABSTRACT

Context: The Balance Error Scoring System (BESS) is a widely utilized concussion assessment tool used to assess postural stability. Baseline testing is used for comparison if an athlete receives a concussion for diagnosis and return to play guidelines. It is unknown if playing a competitive sports season has any effect on the BESS score. **Objective:** To determine if playing in a competitive sports season has an effect on the BESS score. **Design:** A three group pre-post test study. **Setting:** This study was performed in a controlled laboratory setting. **Subjects:** Fifty-five college females, including twenty-two division one soccer players (age = 19.5 ± 1.6 years, height = 165.3 ± 5.9 cm, weight = 58.8 ± 7.8 kg), fourteen division one volleyball players (age = 19.4 ± 1.2 years, height = 177.4 ± 5.2 cm, weight = 70.1 ± 6.8 kg), and nineteen controls (age = 22.1 ± 1.7 years, height = 163.9 ± 6.5 cm, weight = 62.5 ± 9.0 kg) with no current concussion or injury of the lower extremity that would affect postural stability participated in this study. **Interventions:** The BESS score, including the overall score and the individual stance scores, was measured for women's soccer, women's volleyball and the control at preseason and postseason. **Main Outcome Measures:** Two, two-way ANOVAs with repeated measures, one 3-level, two-way ANOVA with repeated measures, two, 7-level MANOVAs, and one 3-level ANOVA were used to analyze our data. **Results:** Differences were found for all subjects between preseason and postseason with a mean change in total BESS score of 1.04 ± 2.38 ; $P=.005$. Differences were also found for all subjects between preseason and postseason with a mean change in

the absolute value of the total BESS score of 1.96 ± 1.69 ; $P < .001$. Conclusions: There may be a learning effect over a 13 week time period for the BESS. Clinicians should account for this possible learning effect when administering the BESS. This would improve clinicians' diagnoses as well as providing more accurate and confident references for returning an athlete to play post concussion.

Index Words: Concussions, BESS, Postural stability

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CHAPTER 1

INTRODUCTION

There are an estimated 1.6 – 3.8 million concussions reported in the United States each year.¹ A concussion is a complex pathophysiological process affecting the brain which is induced by traumatic biomechanical forces.² A concussion may be caused by a direct blow to the head or body, usually resulting in the onset of short-lived neurological impairment, and it may or may not involve loss of consciousness.^{3,4} Additionally, it has been hypothesized that the brain may be susceptible to mild repetitive sub-concussive effects without a specific brain injury severe enough to elicit symptoms of a concussion.⁵ Individuals suspected of sustaining a concussions should be undergo a full assessment and be given proper guidelines for return-to-play.⁶ Improper management of concussions may lead to catastrophic injuries such as Second Impact Syndrome.³ Further, long-term effects have also been investigated and suggest there may be relationships between multiple concussions and clinically diagnosed depression, early onset of dementia related syndromes and chronic traumatic encephalopathy.⁷⁻⁹ Therefore, appropriate recognition and management of concussions are imperative.

While the initial evaluation and management of concussions are essential, they are one of the most challenging pathologies facing the sports medicine clinician due to their complexity.¹⁰ As a result, research has been geared towards improving proper evaluation and management of sports-related concussions. The International Consensus Statement on Sport-Related concussions recommends utilizing the “Sport Concussion Assessment Tool 2 (SCAT2).” The SCAT2 is comprised of multiple assessments that range from cognitive, neuropsychological, balance, and physical symptom assessments.² Assessment of postural stability, the ability to resist perturbations such that the whole body center of mass is

maintained within the limits of the base of support, is assessed through the Balance Error Scoring System (BESS).¹¹

Both the National Athletic Trainers' Association position statement and the 3rd International Conference on Concussion in Sport recommend conducting baseline BESS testing.^{2,6} The baseline scores are utilized to help interpret post-injury scores as well as helping to gauge recovery and assisting with return to play decisions.² Ultimately, these assessment tools are effective for assessing deficits post injury as well as recovery status. Failure to utilize these assessment tools may cause the clinician to overlook concussion symptoms, which can be key in proper concussion management.

While utilizing the BESS is recommended, there have been previously identified limitations which have raised concerns about accuracy in determining post-injury deficits and recovery.^{2,6} These factors include fatigue up to thirteen minutes post-exercise, dehydration, sleep loss, balance pad foam properties, test surface, chronic functional ankle instability, presence of ankle support, and a learning effect with repeat administration.¹²⁻²¹ Previous investigations have identified mixed results on a learning effect in BESS with some studies suggesting there is not one at 30 days, while others have indicated one may exist for up to 90 days.^{12,14} All of these factors have been shown to alter scores on the BESS which can be detrimental to providing realistic post-injury deficits.

Current research has examined postural control assessments, however the findings are limited when comparing between athletes and non-athletes.⁵ A study was conducted on balance control comparing athletes and non-athletes who either have or have not sustained concussions. This study suggested that, regardless of the presence of a concussion, athletes had less balance control, as evidenced by increased medio-lateral sway, compared with non-athletes during gait.⁵ The authors speculated that there may be a possibility that athletes were subject to more sub-concussive blows than non-athletes and that these sub-concussive blows

were a possible explanation to the altered performance on balance control.⁵ Other studies have supported the idea that sub-concussive blows cause impairment specifically with soccer heading.^{22,23} Matser et al,²² found impairments with soccer players compared to other athletes and also attributed this to numerous sub-concussive blows to the head from contact with the ball.

While sophisticated biomechanical analysis tools can clarify subtle postural deficits, these tools are not regularly available to clinicians because of the cost and expertise required to use them.¹⁵ Thus, the BESS is recommended as a practical and effective common sideline test to assess postural stability.^{2,6} However, if repeated sub-concussive blows impair gait and postural control as suggested by Parker et al,⁵ then the same may be true for performance on the BESS and postural stability. If true, it would suggest that BESS scores get worse with an increased exposure to sub-concussive blows, and therefore may decrease the validity of our baseline scores. To our knowledge, there have been no previous investigations which have evaluated the performance on the BESS over the course of full playing season, nor between athletes in a high contact sport and a low contact sport. Therefore, the primary purpose of this study was to examine the effect of participation in a competitive intercollegiate athletic season on BESS assessment of postural stability. The secondary purpose of this study was to examine if playing in a higher contact sport negatively affects scores on the BESS and postural stability. We hypothesize that athletes will be subjected to more sub-concussive blows and therefore score worse on their postseason BESS compared to non-athletes. We also hypothesized that the postural stability of athletes in high contact sports would be more severely impacted by sub-concussive blows and, therefore, perform worse on their postseason BESS compared with athletes in low contact sports.

CHAPTER 2

METHODS

Subjects

Fifty-five college females, including twenty-two NCAA division one women's soccer players, fourteen NCAA division one women's volleyball players, and nineteen female control subjects participated in this study (Table 1). Of the fifty-five that conducted baseline scores, forty-six completed follow-up testing, including seventeen women's soccer players, thirteen women's volleyball players, and sixteen controls. Control subjects were included in this study if they were healthy, female non-athletes. Experimental subjects were excluded if they were unable to participate or if they did not participate during the season. Controls were excluded if they sustained an injury to the lower extremity between tests. Of the fifty-five subjects that took pretests, four women's soccer players and one women's volleyball player were excluded for not participating during the season. Only one control subject was excluded due to a lower extremity injury three weeks prior to postseason testing. Coaches and athletic trainers of the respective teams were asked to encourage their players to participate, but no other incentive was given. All subjects provided informed consent prior to participation as approved by the university's institutional review board.

Instrumentation

An AIREX (20" L x 16.4" W x 2 1/2" H) balance pad, manufactured under strict ISO 9001 standards, was utilized as the foam surface for the BESS assessment. All testing was recorded using two video cameras (Cannon HV20, Cannon ZR 500) collected at 60 Hz. The BESS has an intertester reliability ranging from .78 to .96 and an intratester reliability ranging from .87 to .98.^{24,25}

Procedures

All subjects completed an informed consent (Appendix C) and an injury history questionnaire (Appendix D) prior to performing the BESS. During the BESS (Appendix E) there are six 20 second balance assessments consisting of three stances (double-leg, single-leg, and tandem) on both a firm and foam surface.¹⁰ The dominant leg was determined as the preferred foot when a soccer ball.²⁰ The double-leg stance is described as feet together, single-leg stance is described as standing on the non-dominant foot, and tandem stance is described as placing the non-dominant foot directly behind the other so that toe is touching the heel. The subjects are instructed to take off their shoes and socks, get into the respective stance with their hands on their iliac crests. Subjects are then instructed when to close their eyes, keep their hands on hips, and stand as still as possible. They are to stay in that position to the best of their abilities, but if they fail to do so, they are instructed to regain the position as quickly as possible. Performance on the BESS is scored by adding one error point for each error committed.² The errors include lifting hands off the iliac crests, opening the eyes, stepping, stumbling, falling, moving the hip into more than 30° of flexion or abduction, lifting the forefoot or heel, and remaining out of the testing position for more than five seconds. If multiple errors occur simultaneously, only one error is recorded, but the subject is instructed to return to the testing position as quickly as possible. This system of counting errors is consistent with the 3rd International Conference on Concussion in Sport.² The BESS was filmed in both the frontal and sagittal plane to the subject's right (Figure 1). The investigator scored the BESS "live" and then later reviewed the videotapes to ensure consistent and accurate scoring.²⁶ The scores totaled from the video data were the scores utilized in this study.

Preseason testing was performed in early August during the athletes' pre-participation physical examination. Follow up testing for the athlete group for their "post-season" score was done within one week of the termination of their respective playing seasons. For both groups this was 13 weeks. The control group was also post-tested 13 weeks after their baseline or "preseason" assessment. During the postseason test, all subjects completed the injury history questionnaire before performing the BESS. Procedures for the postseason BESS were identical to preseason.

Data Analysis

The independent variables in this study were the athlete groups (women's soccer and women's volleyball), and the control group. The dependent variables in this study are the overall BESS score and the six individual stance scores. The BESS is scored by calculating the total errors for each of the six stances (Appendix A) and then adding each of those together to get a total score. The overall change in BESS score and the change in individual stance scores were calculated by taking the absolute value of the differences between the preseason score and the postseason score ($|\text{overall change}| = \text{postseason} - \text{preseason}$).

Errors were classified into seven separate categories: 1) opening the eyes ("eye"), 2) hands coming off the iliac crest ("hand"), 3) moving the hip into greater than 30° of flexion or abduction ("hip"), 4) stepping out of position ("step"), 5) lifting of the heel or forefoot ("foot"), 6) remaining out of the test position for more than five seconds ("out"), and 7) multiple errors (" >1 "). Multiple errors include any errors that occur simultaneously such as stepping out of position and hands coming off the hips.

Statistical Analysis

In order to analyze the change of the total BESS score from preseason and postseason between all subjects, two one-sample t-tests were calculated. The population mean was set at 0 to account for the assumption that BESS score will remain unchanged

between tests. The first one-sample t-test analyzed the overall change from preseason to postseason to examine if the subjects BESS scores varied over the course of a season. The second one-sample t-test analyzed the absolute value of the overall change score to examine the mean change from the preseason score.

In order to analyze both the overall change in BESS score as well as the change in the six individual stance scores, two MANOVAs (multiple analysis of variance) with seven dependent levels were calculated. The first MANOVA examined the overall change of the total BESS score and individual stances among preseason and postseason between athletes and non-athletes. The second MANOVA examined the overall change of the total BESS score and individual stances among preseason and postseason between women's soccer and volleyball.

In order to analyze differences in the overall preseason BESS scores a three level, one-way ANOVA will be used. With multiple comparisons being taken, the P was adjusted from < 0.05 to < 0.01 using a Bonferroni adjustment to correct for any type I errors.

Frequency data was calculated using percentage of stance errors per total errors and percentage of categorized error within each stance.

CHAPTER 3

RESULTS

The means for the total change in BESS score and the absolute value of the total change were calculated for the forty-six subjects who completed both testing dates.

Differences in change scores were found for all subjects between preseason and postseason with a mean decrease in overall change in total BESS score of 1.04 ± 2.38 ($T=2.98$; $r=.41$; $P=.005$). For absolute value change score, differences were also found for all subjects between preseason and postseason with a mean change in the absolute value of the total BESS score of 1.96 ± 1.69 ; $P<.001$.

No differences were found between athletes and non-athletes when comparing total BESS scores between preseason and postseason ($P>.01$). No differences were found between women's soccer and women's volleyball when comparing total BESS scores between preseason and postseason ($P>.01$). There were no differences in means for total change or in individual stance change between athletes and non-athletes ($P>.01$). There was also no difference between women's soccer and women's volleyball ($P>.01$) (Table 2).

There were also no differences found between athletes and non-athletes at preseason and no differences found at postseason ($P>.01$). There were also no differences between women's soccer and women's volleyball at preseason ($P>.01$) and no differences found at postseason ($P>.01$). Mean scores for preseason totals were calculated for all fifty-five subjects who completed a preseason test (Table 3). No differences in preseason totals were found between groups ($P>.01$).

Frequencies were calculated for total errors per stance for all groups combined because there were no differences found between groups. Errors for each stance were calculated at preseason and postseason (Table 4). Of all errors, 79.7% occurred in the

single-leg and tandem stances on foam with 50.1% of all errors coming from foam single leg stance.

Categorized frequency of errors within each stance was calculated at preseason (Table 5). No errors occurred for firm, double leg stance so there was no frequency data. For firm single-leg stance at preseason, 64.6% of errors were classified as “step” followed by 24.1% as “>1.” For firm tandem stance at preseason, 23.8% were classified “foot”, followed by 19.1% as “hand”, and 19.1% as “step”. For foam double-leg stance at preseason, 40.0% were classified as “hand” and 40.0% as “eye.” However, there were only five total errors. For foam single-leg at preseason, 49.2% were classified as “step” followed by 32.5% as “>1.” For foam tandem stance at preseason, 46.8% were classified as “>1”, followed by 19.4% as “step”, and 15.1% as “foot.”

Categorized frequency of errors for the postseason (Table 6) were similar to those of preseason. Again, no errors occurred in the firm double-leg stance. For firm single-leg stance at postseason, 68.0% were classified “step.” For firm tandem stance at postseason, 50.0% were classified as “hand” followed by 33.3% as “>1.” For foam double-leg stance at postseason, 50.0% were classified as “>1”, followed by 25.0% as “eye”, and 25.0% as “out”. However, there were only four total errors for this stance. For foam single-leg stance at postseason, 52.0% were classified as “step” followed by 32.2% as “>1.”. For foam tandem stance at postseason, 60.4% were classified as “>1.”

CHAPTER 4

DISCUSSION

The purpose of this study was to examine the effect of participation in a competitive athletic season on the assessment postural stability. Secondly, we also examined if participating in a higher contact sport, such as women's soccer, had an effect on postural stability. Our main finding was that, overall, subjects, regardless of classification, scored significantly better (e.g., lower BESS scores) on their postseason test than on their preseason test with an average decrease of 1.04 errors. These findings suggest there may be a learning effect with the BESS over a 13 week time period.

A learning effect is a subject's ability to learn and retain a balance task with repeated testing.¹³ Previous investigations on the potential learning effect of BESS performance have had conflicting results. Our findings contradict a study on collegiate athletes by Riemann et al,²⁷ who did not find a practice effect using the BESS over 3 test sessions conducted over a 3 day period. Our findings also differ from those of Valovich et al,¹² who conducted repeat BESS assessments at days 3, 5, 7 and 30 after baseline testing using high school athletes. While there was a learning effect seen at days 5 and 7, no learning effect found was found over a 30 day period. Our findings are more consistent with other studies that examined repeated administering of balance tests in the youth and collegiate populations.^{13,14} In an investigation of serial administration of concussion assessments, the control group had significantly improved BESS scores over 30 days even with only one previous test administration.¹³ These findings are similar to our control group and all subjects who had significantly improved BESS scores with only one previous test administration. Mancuso et al,¹⁴ found similar results using a 1, 2, 3, 5, 7, and 90 day testing time frame. At day 90 for the experimental group, learning was retained in the single-leg/ground, single-leg/foam,

single-leg/box, and tandem/box. This study differed from ours with the addition of a third surface (tremor box) and they also have six test sessions, thus the ability to compare results is limited. While no significant differences were noted in any stance from preseason to postseason in our study, the greatest changes were seen in the single-leg stance in both the firm and foam surfaces with a 28.8% and 54.8% decrease in scores, respectively. This is also consistent with an investigation on repeated static stabilometry testing in a normal population, in which Nordahl et al,²⁸ found that the greatest learning potential occurred with loss of visual references (ie, eyes closed) and change of proprioceptive information to the soles of the feet (ie, foam surface). This occurred in the ECF (eyes closed foam) stance, or eyes closed on a foam rubber mat, during their investigation. Nordahl et al,²⁸ did say, however, that the longer the time between tests, the less likely there was to see a learning effect.

We hypothesize that our results are attributed to the learning effect. While no one stance was significantly changed from preseason to postseason, large gains were seen in the single-leg stances which suggests there may be a possible ability to learn more challenging tasks.²⁸ While we did not measure sub-concussive blows, we would have likely seen some negative effects with women's soccer players and athletes, as a whole, if they had an effect on the BESS. Matser et al,²² found impairments on cognitive testing in soccer players, but no postural stability impairments. It is possible that if there are deficits, the BESS may not be able to identify them. There are also other changes which may occur by participating in sports that could have affected balance and the BESS scores, but we would have likely seen some negative effects with athletes in comparison to non-athletes. Our results indicate no differences between sports and between athlete and non-athlete groups, which suggest there may be a practice effect of 90 days in the collegiate population with only one previous exposure to the BESS.

Clinical Relevance

Clinicians, including athletic trainers and other sports medicine personnel, should be aware of the potential learning effect on the BESS. The results of this study indicating a practice effect of BESS suggest three possibilities; 1) the addition of a dual baseline testing to account for this effect, 2) altering the BESS, 3) removing the BESS as a screening tool for postural stability following a concussion.^{13,26} Adding a second baseline, and conducting it directly after the first one, could possibly account for the learning effect and ultimately give a more accurate score, as reliability increases with multiple trials.^{13,26} Another option would be implementing the Modified Balance Error Scoring System.²⁶ The Modified BESS is a protocol that utilizes only four of the six conditions (single-leg and tandem on firm and foam). Administering of these four conditions is considered a trial and three complete trials are performed as a full test. This revision considers the learning effect and uses trial one as a practice trial. Reliability increased from .60 with the original BESS to .83 and .88 by using the second and third trials. Results from our study as well as others, show a very low number of errors occurring in the double-leg stances, which supports the removal of this stance for the Modified BESS.^{10,12} It should also be discussed that it may be beneficial to remove the single-leg stance in the BESS. As discussed before, the most change from preseason to postseason found in our study was with the single-leg stance. By removing the single-leg stance, the learning effect may be greatly reduced.

Another aspect of our results that raises concern with the BESS is the change in overall score for some individuals from preseason to postseason. While the overall grouped mean change from preseason to postseason was 1.04, it is important to consider the BESS on an individual basis. An increase in BESS score, even by one, is considered to be clinically significant in terms of abnormal post-injury findings. However, our results showed a range of

± 5 in change in overall BESS score with a mean change of almost 2 errors. Keeping in mind that our subjects are healthy individuals, seven of our subjects would be considered to have concussive symptoms if tested. We also found that 71.7% of all of our subjects had some change in their postseason scores when compared to their preseason scores with only 13 of 46 subjects remaining unchanged. We found that all subjects had a mean change from their original score of 1.96 ± 1.69 . This suggests that an increase in total BESS score of 1 or 2 may not characterize a concussion, but rather maybe an expected variance within the test. With an average variance of approximately 2 in healthy individuals for total BESS score, an increase of 2 in total BESS score may be a more realistic characterization of a concussion. There would still be subjects in our study that would qualify as concussed as defined by this new classification, but it is more accurate than the previous classification. These findings support the need for dual baseline testing as well as showing a need for the use of multiple concussion assessment tools, as the BESS, alone, is not sufficient to identify a concussion. This would improve clinicians' diagnostic efficacy as well as providing more accurate and confident references for returning an athlete to play post concussion.

Clinicians may also benefit from looking at the categorized frequency of errors within each stance. Overall the most common errors were "step" and ">1." Multiple errors and remaining out of the test position are more easily seen, however individual errors, specifically putting the toe down or stepping, can be more difficult to see. Stepping and lifting of the forefoot accounted for 48% of errors at preseason and 43% of errors at postseason so the examiner's focus should remain around the subject's lower body. Only 5% of errors at preseason and 7% of errors at postseason occurred at the waist or above. This trend was only different during the tandem stance on the firm surface. While the total number of errors is low, errors occurring with the hands and foot were more common. At preseason, errors of the hands accounted for 19% of all errors and errors of the foot accounted for 24% of all

errors. At preseason, 50% of all errors occurred with the hands and 8% of all errors were with the foot. Considering these findings, it is recommended that the examiner's focus should be towards the subject's lower body except during the tandem stance when errors of hands occur more often. Regardless of which stance is being examined over 99% of all recorded errors occurred at the waist or below so clinicians should keep their focus at or below the subject's waist.

Limitations

One limitation of this study is the inequality of the number of subjects in each group. When the women's soccer and women's volleyball groups were combined for the "athlete" group, they were compared against the non-athlete control which had just over half the number of subjects. Results may have differed with an even amount of subjects for each comparison. Another limitation of this study is that during testing, the type of clothing worn was not controlled. While all subjects were barefoot during testing, they were free to wear anything else (ie, jeans, sweatshirts). While this added a convenience factor for the subjects, it may have made it more difficult to observe certain errors if clothing got in the way. The chance of missing an error was greatly reduced, however, with the use of two separately angled cameras, but we still acknowledge that this could have affected the results.

Conclusions

Our main finding from this study is that there is a small, but clinically and statistically significant, learning effect found across a thirteen week period when using the Balance Error Scoring System consistent throughout all groups. Clinicians should consider accounting for these errors by having a dual baseline or administering the Modified BESS, however, future research should further explore the validity and reliability of the proposed modifications to the BESS. The Modified BESS seems to show evidence of accounting for the learning effect and having high reliability but research should look into similar effects of repeat testing. The

Balance Error Scoring System will continue to be used for concussion assessment as well as return-to-play guidelines, so efforts should continue to enhance its reliability and validity as a clinical tool in the battle against proper concussion management. It should, however, be utilized in congruency with other concussion assessment tools because these findings raise yet another concern about the appropriateness of this assessment tool being used on its own.

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APPENDIX A

Research Hypotheses

H_{A1}: There will be a significant difference in overall BESS score seen at preseason between the three groups.

H_{O1}: There will be no significance in overall BESS score seen at preseason between all three groups.

H_{A2}: There will be a significant change within the six individual stances comparing preseason and postseason among the athletes and non-athletes.

H_{O2}: There will be no significant change within the six individual stances comparing preseason and postseason among the athletes and non-athletes.

H_{A3}: There will be a significant change within the six individual stances comparing preseason and postseason among women's soccer and women's volleyball.

H_{O3}: There will be no significant change within the six individual stances comparing preseason and postseason among women's soccer and women's volleyball.

Limitations

- There was inequality between the number of subjects in each group. Results may have varied with an even distribution of subjects.
- Clothing was not controlled for which may have comprised the examiner's view while counting errors.

Delimitations

- The use of a high contact and a non contact sport.
- Division I collegiate athletes will be used
- There will be a female control group used to provide comparison to women's soccer and women's volleyball.

Assumptions

- The subjects will be truthful on their injury history questionnaire.
- Subjects are giving maximal effort at all times during the testing.

APPENDIX B

Review of Literature

Concussions have always been involved in the sports world, but there has not been much research or understanding about concussions until recently. A table presented by Notebaert shows that between 1980 and 1999 there were only 177 articles published on concussions in sports. Between 2000 and 2004 there were already 172 articles written.¹ With the research being fairly new, there are many different results and findings that do not seem to be clear. These areas include the following: history/definition, epidemiology, symptoms, assessment tools, grading scales, previous history, repeat concussions and most importantly the effects of concussions. The purpose of this review, therefore, is to examine multiple sources of literature to get a better understanding of concussions. After gaining some in depth knowledge of concussions, the secondary purpose is to analyze literature that focuses on the effects that concussions have on postural stability.

Background

To understand concussions, it is a good idea to look back at the history of concussions as McCrory did.² Reports of concussions date back as far as Hippocrates (~460-370BC) when he seems to be referring to a person in a state of unconsciousness.² The term concussion was first used in a modern sense by Rhazes (AD 850-923) when he distinguished concussions as “an abnormal physiologic state rather than severe brain injury.”² The definition has since been changed multiple times until, finally, in 2009, the 3rd International Conference on Concussion in Sport defined a concussion as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces.³ There are still multiple definitions used today by many different experts in the field which adds to people’s misunderstanding on the subject.

Biomechanics

In an attempt to understand the definition of concussion, it is important to understand how a concussion occurs and what goes on physiologically within the brain. Giza defined a concussion as any transient neurologic dysfunction resulting from a biomechanical force.⁴ The biomechanics of a concussion were described as the immediate transfer of kinetic forces such as acceleration followed by a rapid deceleration.⁵ Concussions may be avoided by minimizing the motion of the head, which causes the biomechanical force to be transmitted throughout the rest of the body and not directly to the head.⁵ One concept discussed was the two separate forces involved which are translational or linear acceleration, and rotational or angular acceleration.⁵ The research found that in primate head injury models it was rotational or angular acceleration that was solely responsible for loss of consciousness in concussions.⁵ The findings contradict Pellman's findings, which do not necessarily discuss loss of consciousness, but do state that translational or linear forces are the most important forces resulting in concussions.⁶

Physiology

In Giza's review of the neurometabolic cascade of concussions, the pathophysiologic process involved in brain injuries was presented.⁴ Immediately after an injury to the brain such as a concussion, there is an abrupt release of neurotransmitters and ionic fluxes occur.⁴ Binding of transmitters causes an efflux in potassium and an influx of calcium which in turn leads to changes in cellular physiology. In order to restore the neuronal membrane potential, the sodium-potassium pump has to work extra hard. The pump requires more energy or ATP which causes a spike in glucose metabolism. This excess work on the sodium-potassium pump and glucose metabolism happens at the same time there is a decrease in cerebral blood flow so in essence, there is an "energy crisis."⁴ The energy crisis is the likely mechanism for

postconcussion vulnerability.⁴ Other important aspects of posttraumatic cerebral pathophysiology include generation of lactic acid, decreased intracellular magnesium, free radical production, inflammatory responses, and altered neurotransmissions to name a few.⁴ Excess lactate levels can ultimately leave neurons more vulnerable to a secondary injury. Low magnesium levels have been related to post-injury neurologic deficits. Free radical production and inflammatory responses can lead to permanent damage to the axons and may also trigger cell death. Neurotransmitters may also be permanently altered which can lead to long-term deficits in memory and cognition. These reactions are what could be causing postconcussive symptoms and putting the brain at a more vulnerable state for a more severe head injury.⁴

Epidemiology

The exact prevalence of concussions in sports in America is not known although Langburt stated that 75% of all head injuries are concussions.⁷ Many studies state that there are around 300,000 sport related concussions reported each year.^{3,8-15} More recent evidence suggests there are an estimated 1.6 – 3.8 million concussions reported in the United States each year.¹⁶ Majerske stated in an article published in 2008 that 60,000 of all of the concussions occurred at the high school level with the majority coming from football, although Schulz found cheerleading had the highest rate of concussions during practice.^{10,17} A study done by Gessel stated that 8.9% of all injuries among 9 different high school sports was a concussion.¹¹ The study was done between the years 2005 and 2006. There is numerous data that came from this study including concussion rates among high school and college athletes, rates among sports, rates among genders, rates among practices and games, and even the prevalence of activity during which the concussions occurred. It was found that there was a difference between high school and college concussion rates. As stated earlier, 8.9% of all high school injuries were concussions, while the study found that only 5.8% of

college injuries were concussions.¹¹ While the percentage of concussions was greater in high school sports, the rate of concussions per 1000 athlete exposures was higher in college sports. The majority of concussions occurred in athletes who participated in football (40.5%), followed by girls soccer (21.5%), boys soccer (15.4%), and girls basketball (9.5%).¹¹ The study also showed that boys had a higher rate of concussion per 1000 athlete exposures than girls in both college and high school sports. The rate of concussions received during practice was 0.11 and the rate during competition was 0.53.¹¹ A study performed by Guskiewicz broke down prevalence of concussions between Division I, Division II, Division III, and high school.¹⁰ High school had the highest player injury rate at 5.6%, followed by Division III at 5.5%, Division II at 4.5%, and finally Division I at 4.4%.¹⁸ The epidemiology of concussions will continue to change as the limitations of the current studies are addressed which will give researchers and clinicians a more concise understanding of the issue.

Limitations of Epidemiology Studies

The issue found with this new information is that it is still not known just how accurate this information because of the limitations many of these studies have. Examples of limitations from the studies include small sample size, small region of study, and a small time period for research. It is easy to see, therefore, why concussions are such a debated topic. While Gessel found that 8.9% of injuries were concussions among high school athletes, Guskiewicz found only 5.6% of injuries among high athletes were concussions.^{11, 18} Other studies show concussion rates varying from 3.8%, 3.9%, 5.9% to 10%.¹⁹⁻²² Some even say up to 70% of football players show signs and symptoms of concussions.²³ The reason these studies vary is their methodology. Most studies define a concussion differently. For instance, some studies list an injury as a concussion if the athlete elicits at least one symptom following a blow to the head.^{23, 24} It is hard to compare data when diagnosing a concussion is mostly subjective and would make data vary from study to study. There is no standard test that,

when positive, can indicate that an athlete has a concussion. It is based on what someone sees and an assessment completed by an athletic trainer or a physician.¹³

Reporting Issues

One major problem found with concussions is that if no one sees the injury occur or notices any postconcussive symptoms, then it is up to the athlete to report the concussion. Detection and diagnosis of concussions is even harder still because of athletes' tendencies to underreport or hide symptoms in effort to return to play faster.¹³ These tendencies were thought to be the entire reason behind athletes underreporting until a survey published by McCrea in 2004 showed that a greater percentage of football players did not think it was serious enough to be reported compared to a lower percentage of those who did not want to leave the game. Over 66% of football players who received a concussion and did not report it did not think it was serious enough, compared to only 41% who did not want to leave the game. Another alarming statistic was that over 36% of the players did not even know it was a concussion.¹³ Another study shows that less than 20% of collegiate athletes experiencing a concussion realize that they have been injured.²⁵ In a group of high school rugby players, less than 65% reported they had a concussion to anyone.²⁶ While this is a higher number than seen before it is still not a high enough report rate. These three studies show that there are far too many concussions going underreported. The survey results from McCrea give a new spin on previous ideas. It seems that underreporting may not be due to the fact that athletes do not want to be removed from participation, but rather that, in general, athletes just are not educated enough about concussions.¹³ The research is very new on concussions and more is being learned about them every day, but it is so easy to say that athletes are too tough to want to be removed from competition rather than saying there is not enough being done to educate the athletes.

Assessment

Assuming that a concussion is reported or there is an athletic trainer or physician on staff that sees a blow to the head, there are several different tools that can be used to properly assess the injury. There are multiple symptoms that can result from sustaining a concussion with some being more important and more prevalent than others. There are numerous grading scales that have been developed to attempt to quantify the severity of the concussion based on the presence and duration of symptoms. There are also a multiple number of other assessment tools that can be used.

Symptomology

Concussions never present the exact same in every person. There are multiple symptoms that are associated with concussions but not all have to be involved. There is no distinction, however, whether or not the incidence of having one symptom is considered a concussion or if it is the combination of two, etc. What is known about concussions is that they present with different symptoms and at different intensities in different people. The most common symptoms can be seen in the chart below and in an attempt to quantify the intensity of the symptom, a Likert scale is used. The Likert scale is graded from 0-6 in terms of severity with "0" being none and "6" being severe.¹²

TABLE 1. *Postconcussion Symptom Scale*²⁶

Symptom	Rating						
	None	Moderate			Severe		
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
Sleeping more than usual	0	1	2	3	4	5	6
Sleeping less than usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling more emotional	0	1	2	3	4	5	6
Numbness or tingling	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling mentally "foggy"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Visual problems	0	1	2	3	4	5	6
Total score	0	1	2	3	4	5	6

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This scale can be referred to as either the Postconcussion Symptom Scale (PCS) or the Graded Symptom Checklist (GSC).^{12, 14, 27} In most studies, headaches are reported by more concussed athletes than any other symptom. During a sideline evaluation of concussed athletes in a study carried out by Erlanger, headache was reported in over 90% of the cases.²⁸ Headache was followed by dizziness in 85% of cases, confusion/disorientation in 83%, nausea in 53%, and loss of consciousness (LOC) in 25.5%.²⁸ In one study done to evaluate the prevalence of headache in high school football players, 85% of football players had headaches associated with hitting during the course of the season.²⁹ By using similar means to define a concussion, Delaney found that 70% of football players had a headache associated with playing and therefore had a concussion.²³ A similar symptom-based study showed headache being the most prevalent at 43.5%, followed by feeling dazed and confused at 23%, dizziness at 20%, and difficulty concentrating at 18%.²⁴

Loss of Consciousness

Loss of consciousness was once thought to be the key concussion indicator. Many athletes still believe that today.²⁴ Collins discussed the importance of the occurrence of LOC in concussions. Many similar studies have shown that only between 6% and 39% of cases involve LOC.^{12, 18, 25, 28, 30, 31} Most studies have the LOC rate under 10%.^{18, 25, 28, 31} Collins found that LOC did not significantly affect the number of symptoms or the outcome of the concussion and that “LOC might not be a potent predictor of postinjury neuropsychological deficits.”¹² Erlanger showed similar results in that LOC was not directly to postconcussive symptoms. The presence of nausea and dizziness were better indicators of the severity of the injury. Memory related problems at 24 hours were also better indicators of a severe injury than brief LOC, which shows that LOC may not be as important as people once thought.²⁸

Grading Scales

With new research showing that LOC may not be that important in the severity of concussions, new grading scales have been adjusted. There are currently at least 19 different grading scales available.³² A survey of 339 athletic trainers revealed that 28% use the Colorado rading system, followed by the Cantu and American Academy of Neurology (AAN) grading systems at 19% and 13% respectively.³³ The difference among the three scales are not great but could ultimately change the grading of a concussion based on the symptoms present. The Colorado and AAN grading systems list a grade 3 concussion as being one with any LOC. The AAN identifies their grades 1 and 2 concussions by confusion and symptoms that resolve within 15 minutes or last longer than 15 minutes and with no LOC. The Colorado system incorporates amnesia but does not involve symptom duration. A grade 1 is confusion without amnesia and no LOC while a grade 2 is confusion with amnesia and no LOC. The Cantu scale involves both posttraumatic amnesia and LOC. A grade 1 is no loss of

consciousness with posttraumatic amnesia lasting less than 30 minutes. A grade 2 is LOC less than 5 minutes or posttraumatic amnesia lasting longer than 30 minutes but less than 24 hours. A grade 3 is loss of consciousness for more than 5 minutes or posttraumatic amnesia for more than 24 hours.³⁴ Once again, it is easily seen that concussion assessment is not clear. There is not one single indicator of a concussion, there are multiple different symptoms, and there is not one set grading scale in which to use. That is why assessment of concussions is so difficult.

Assessment Tools

In order to assist in the evaluation and management of concussions there have been multiple tools which have come forth in recent years. The tools include neuropsychological testing, cognitive testing, and postural stability testing. There are tools which can be used on the sidelines of a game or practice or ones that require a computer. Specific tools include ImPACT, Sideline Assessment of Concussion (SAC), fMRI or functional MRI, and the Balance Error Scoring System (BESS). It is important that baseline measurement should be taken before the season in order to maximize the results and understanding of these tools. By having a baseline, which should be taken when healthy and concussion free, athletic trainers and physicians have a reference to compare test results in the case of a concussion.

Immediate Post-Concussion Assessment and Cognitive Testing or ImPACT is a computerized neuropsychological test that measures the domains of memory, learning, reaction time, and speed at which information is processed.³ This test takes about 20 minutes to complete and has little practice effect so it can be repeated to assess for improvement of neurocognitive functioning. It is also sensitive to differences of 1/100th of a second. Other computerized tests include CogSport and Headminder.³

The Sideline Assessment of Concussion, or SAC test, is a neurocognitive test.²¹ This test requires approximately 5 minutes and tests four cognitive domains including: orientation,

immediate memory, concentration, and delayed recall. The maximum score on the SAC test is 30 points. There are three different versions of the form to minimize the practice effect.²¹ Results from McCrea showed that scores immediately after concussion dropped an average of 4.3 points below the baseline score. At 15 minutes postinjury the score was only an average of 2.3 points below and at 48 hours postinjury the average was actually higher than the baseline.²¹ A second study done on the SAC test immediately following injury showed that scores of concussed athletes dropped 4.2 points below the baseline score.³⁵ This stresses the importance of this test to be completed as quickly as possible following the injury.

A third method of assessment can be done using fMRI or functional MRI. Functional MRI looks at changes in brain activity by looking at blood oxygen level dependent (BOLD) regions of the brain.³⁶ Results showed concussed athletes had different BOLD responses compared to control subjects. This study showed that it is plausible to identify an underlying pathology in symptomatic concussed athletes with normal results.³⁶ This new assessment tool shows just how far concussion awareness and research has come.

Another common test is the Balance Error Scoring System or the BESS test. The BESS test is used to assess postural stability and balance. The BESS was compared with results from force plate data and it was determined that the BESS correlated with this data.³⁷ It was later shown by Riemann that there were significant differences seen in concussed individuals up to 3 days post-injury on the BESS. This suggests the BESS is a valid test in showing postural deficits post-concussion.³⁸ The BESS also has intertester reliability coefficients that range from 0.78 to 0.96 so the test is highly reliable.^{39,40} A baseline test should also be done in order to have something to compare the results to after a concussion. During the BESS test, there are a total of 6 different trials at 20 seconds a piece.³⁷⁻⁴¹ There are 3 different stances (double, single, and tandem) which are done on a firm surface and repeated again on a piece of medium-density foam measuring 45 cm² x 13 cm, with a density

of 60 kg/m^3 , and having a load deflection of 80-90 kg.⁴¹ During the double stance, feet are placed together. During the single stance, the subject is asked to stand on the non-dominant foot and during the tandem stance the non-dominant foot goes in the back with the dominant foot directly in front of it.³⁷⁻⁴¹ Subjects are asked to close their eyes, place their hands on their iliac crests and stand as still and as motionless as possible in the stance position. They are to stay in that position to the best of their abilities. If they fail to do so, they are asked to regain the position as quickly as possible.⁴¹ There are six errors that the subjects are told to avoid during the 20 seconds. A picture of the six test positions and a table of the errors are shown below.



Errors

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

BESS score calculated by adding 1 error point for each error committed.³⁷

For each error the subject commits, it is calculated as 1 point. Each trial as a standard maximum error score of 10.

There are multiple limitations that affect scoring on the BESS. These factors include repeated administration practice effects, fatigue up to thirteen minutes post-exercise, dehydration, sleep loss, balance pad foam properties, test surface, chronic functional ankle instability, and presence of ankle support.^{40,43-49} Valovich et al, conducted a study to

determine if the BESS test showed a learning effect.⁴⁰ This was done by having a control group do a baseline and then follow-up test 30 days later. The practice group took both tests for a baseline, again at day 3, 5, and 7, and was then asked to take a final test on day 30 with the control. There was a significant difference in the two groups on the BESS test at day 30 with the control group scoring worse (higher amount of errors) than the practice group.⁴⁰ However, there was not a significant difference within the practice group from day one to day 30.⁴⁰ Fox et al, conducted a study to determine if BESS was affected by anaerobic and aerobic exercise.⁴³ Anaerobic and aerobic exercise negatively affected the BESS up to 13 minutes post exercise.⁴³ McKinney et al, found that dehydration negatively affected BESS performance with as much as a 57% increase in errors on unstable surfaces.⁴⁴ Goloski et al, found that performance on the BESS was negatively affected in subjects who got less than two hours of sleep.⁴⁵ Patel et al, found that different foam properties may alter balance with greater variances recorded on firmer foam.⁴⁶ Onate et al, found that while testing the differences in a clinical setting and sideline setting, single-leg foam scores for the sideline setting were worse compared to the clinical setting.⁴⁷ Docherty et al, found that subjects with chronic functional ankle instability have deficits during the BESS, however, it is stated that chronic functional ankle instability should not affect the use of BESS in assessing concussions since the deficits would be present during preseason testing.⁴⁸ Broglio et al, found that different ankle support can affect performance on BESS suggesting that ankle support should be consistent throughout testing.⁴⁹

Postural Stability

When attempting to understand concussions' effects on postural stability, it is important to understand what controls posture. The nervous system is responsible for providing the necessary data in order to maintain balance. This data includes visual input, vestibular mechanisms, and proprioceptive reflex activities.³⁹ During a concussion it is believed that

communication of the three previous mentioned data is lost causing symptoms such as dizziness, vertigo, tinnitus, lightheadedness, blurred vision or photophobia.³⁹ In order to test the visual, vestibular, and proprioceptive input, the Clinical Test of Sensory Interaction and Balance (CTSIB) and the Sensory Organization Test (SOT) were developed.

The CTSIB was developed as a way to isolate and clarify which of the three sensory inputs are most involved. The SOT was developed to disrupt the sensory selection process by changing the somatosensory and/or the visual inputs while having the subject still maintain proper balance. These tests have shown to be effective for up to three days because that is how long the deficits tend to last.³⁹ In attempt to make postural testing more accessible and affordable the BESS test was created. McCrea showed that BESS scores tested at the time of concussion, post game, and everyday after the concussion did not return to baseline until between days 3 and 5.³¹ Guskiewicz stated later that some research found that concentration and attention impairments could be a contributing factor to the decreased balance.³⁹

Studies that agreed with Guskiewicz research, which addressed concentration and attention, were conducted using gait stability following concussions as the guide for testing postural stability.⁴³ The study showed that concussed athletes were able to maintain dynamic stability during gait during single task conditions. The concussed athletes were then assessed while completing dual-task conditions in which they performed simple mental tasks. There was a significant increase in medio-lateral center of mass sway which can be interpreted as a decrease in postural stability.⁴³ While studying single and dual task conditions, Parker also compared athletes to non-athletes.^{50,51} In one of Parker's studies, 28 concussed individuals (14 athletes and 14 non-athletes) and 28 non-concussed individuals (14 athletes and 14 non-athletes) were tested. The results of that specific portion of the study show that whether or not an athlete is concussed or not concussed, they had greater gait imbalance.⁵⁰ Athletes walked slower and swayed more and faster compared to non-athletes.⁵⁰

Parker attributed this finding to the number of sub-concussive blows that are involved in high-impact sports and that these may have detrimental effects on balance control. The results of the Parker studies bring up some interesting thoughts on concussion assessment using tools such as the BESS.

Questions

It has been shown that BESS measures static postural instability.³⁷ It has also been shown that athletes have poorer gait/postural stability than non-athletes due to the theory of subconcussive blows.⁵⁰ Concussed individuals also have poorer postural stability when their attention is divided into two tasks.⁵¹ Based on these three facts, more research could be done focusing on athletes versus non-athletes and single task versus dual task assessment of postural stability using the BESS rather than assessing gait control. If athletes in a higher impact sport such as football are tested using the BESS, would their results be different compared to athletes that are in a lower impact sport such as tennis? If Parker's results are supported, then football players would score higher (worse) on the BESS. Is there a change in BESS scores over the course of a season? Assuming, now, that the second part of Parker's study is true when it discussed dual-task conditions during gait, it would be correct to assume that a dual-task BESS test would score worse. This could be a more efficient way to assess concussions. More research needs to be followed up using the information gathered from the Parker studies because it may show results that could improve the assessment of concussions using the BESS.

Management

After understanding concussions in general and the assessment of concussions, it is important to know how to manage concussions properly. This is probably the most important aspect in athletic training when it comes to concussions. Management of concussions includes everything from informing the athletes of the risks of returning to play too quickly,

understanding the recurrence rate, understanding return to play guidelines, and informing the athletes of the risks of having too many concussions.

Risks

There are many risks associated with concussions. The one that sticks out the most is death. However, many athletes do not know that having a concussion predisposes them to having another. Other risks involved with concussions are the long term effects that may not even be seen until later in life.

The reason concussions have been such a hot topic lately is due to the occurrence of multiple deaths in athletes caused by a condition called second impact syndrome (SIS). Second impact syndrome occurs when athletes with one concussion return to play while still symptomatic and receive another head injury. It is usually more prevalent in adolescents between the ages of 14 and 16.⁵² Athletes being returned to play too quickly is the most dangerous risk for athletes having second impact syndrome. On average, over 30% returned to play on the same day.¹⁸ With grade 1 concussions, the average time before returning to play was 4 days, and with a grade 2, the average time before returning to play was 8 days.¹⁸ Another study has similar data with an average time to return to play after a concussion of 3 days.²⁰ Cantu's guidelines for return to play state that athletes who have a grade 1 concussion must sit out a minimum of 7 days and a grade 2 must sit out a minimum of 14 days.³⁴ It is obvious that athletes are returning to play quicker than recommended.

Repeat Concussions

Even if the athlete returns to play at the right time or not, he or she is already more susceptible to receiving another concussion. Multiple studies show that with a history of concussion, there is an increased risk of receiving another.^{14,15,17} Players that receive one concussion during a season are 3 times more likely to sustain a second concussion during the same season.¹⁴ Athletes with a history of concussion are at a 5.8 times greater relative

risk to receive a concussion than those with no prior history of concussion.²² The risk of receiving a concussion are increased twofold in athletes with a history of concussion compared to those with no history.¹⁷

Return to Play Guidelines

Return to play guidelines have always been challenged by athletes who wish to return to play faster. There are many different ways to assess when an athlete is ready to return to play. There is a set guidelines set forth by Cantu which addresses how long an athlete should be removed from participation based on the severity and how many concussions the athlete has had. These guidelines can be seen in the table below.

Table 10. Guidelines for Return to Play After Concussion*

	First Concussion	Second Concussion	Third Concussion
Grade 1 (mild)	May return to play if asymptomatic for 1 week	Return to play in 2 weeks if asymptomatic for 1 week	Terminate season; may return to play next season if asymptomatic
Grade 2 (moderate)	Return to play after asymptomatic for 1 week	Minimum of 1 month; may return to play then if asymptomatic for 1 week; consider terminating season	Terminate season; may return to play next season if asymptomatic
Grade 3 (severe)	Minimum of 1 month; may then return to play if asymptomatic for 1 week	Terminate season; may return to play next season if asymptomatic	

*Asymptomatic in all cases means no postconcussion symptoms, including retrograde or anterograde amnesia, at rest or with exertion.

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A more systematic approach is discussed by Lovell which is a step by step process to return to play.⁵² The step by step involves remaining symptom free starting with no activity and progressing to light aerobic exercise, to sport-specific training, to noncontact drills, to full-contact drills, and finally to game play.⁵² Return to play guidelines are just as subjective as diagnosing a concussion. There is no clear way to determine when the best time to return to play is other than when the athlete's symptoms cease but those are mostly based off of what the athlete is reporting. There is no sure way to prove if an athlete is symptomatic or not. That is why today there are multidimensional approaches of assessment, management, and return to play guidelines being used.¹ Athletic trainers and physicians are no longer one-dimensional. They are using multiple assessment tools and return to play tools. There is a trend towards using the assessment tools such as ImPACT and the BESS when looking at

return to play. That is why it is so important to have baseline scores so that the best approach can be taken to see if an athlete is really ready to return to play.

Long Term Effects

Some literature has recently been published discussing the long term effects of concussions and playing in high-risk sports such as football. One study showed that there was an association with recurrent concussions and the diagnosis of lifetime depression.⁵³ Retired NFL players that reported three or more previous concussions were three times more likely to be diagnosed with depression and those that had one or two previous concussions were 1.5 times more likely to be diagnosed with depression.⁵³ There is a clear trend between the number of concussions and the diagnosis of depression. Another study that looked at the risk of MCI or mild cognitive impairment and Alzheimer's disease with concussions showed that retired NFL players with three or more concussions had a fivefold prevalence of being diagnosed with MCI.⁵⁴ It also showed a threefold prevalence of memory problems. The most alarming results showed that there was an earlier onset of Alzheimer's disease in the NFL retirees as a group than in the general American male population.⁵⁴ It is easy to see why ore athletes are retiring due to this new knowledge that concussions may have long term effects and increase the chances for conditions such as depression and Alzheimer's.

Conclusion

Concussion research has increased tremendously in the last few years accounting for an increased understanding of concussions. There is still a long way to go in order to truly understand concussions. More research needs to be done in so many different aspects. There still needs to be a better understanding of what concussions are, what causes them, and how they are caused. Hopefully, with more research there will be a clear way to somehow assess concussions in the future which will in turn help to manage concussions

properly to prevent or at least minimize the second impact syndrome cases, the depression, and the memory problems associated with long term effects.

While research continues to get better and people start to understand concussions more clearly, the most pertinent task is to educate the young and the old. Contrary to what was believed before, athletes are not trying to be tough and continue to play. Rather, they just do not seem to be educated enough about concussions to know how dangerous and detrimental they can be to their health. Until there is a time that concussions are completely understood, the easiest way to minimize deaths and the long term effects is to educate the American population.

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APPENDIX C
INFORMED CONSENT

COLLEGE OF HEALTH AND HUMAN SCIENCES
DEPARTMENT OF HEALTH AND KINESIOLOGY

CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

1. Title of Project: The Effect of Sports on the Balance Error Scoring System

Investigator's Name: John Burk, ATC Phone: 770-312-3828

Participant's Name: _____ Date: (___ / ___ / ___)

Data Collection Location: Biomechanics Laboratory, Georgia Southern University Campus

2. The purpose of this study is to determine if the course of a playing season has an effect on the Balance Error Scoring System (BESS). There will be sixty subjects who will participate in this study. The results of this study will help athletic trainers in determining the efficacy of the BESS which will help with the evaluation and treatment of post-concussive symptoms.
3. You are being asked to participate in this study because you are a female soccer or volleyball player at Georgia Southern University or because you are not actively participating in athletics and wish to be involved in this study as a control subject.

If you agree to participate in this study, you will be asked to attend two testing sessions approximately three to four months apart from each other. Each session will last approximately 10 minutes. During each session you will be asked to perform six different stances with your eyes closed for 20 seconds each.

There are three stances each performed, once on a stable surface, and once on a foam pad, for a total of six stances. The three stances are feet together, single-leg, and tandem. These will be performed without shoes.

During each stance, you will be standing on a force plate or a foam pad, which will be directly over a force plate. You will stand with your eyes closed and your hands on your hips. You will be asked to stand as still as possible without opening your eyes, lifting your foot, bending at the waist, or staying out of the test position for more than 5 seconds. Each of the six stances will be performed for 20 seconds each.

During the session, you will be video-taped from two angles to calculate the errors that you have during each stance. The force plate will measure your center of balance. You will not be in any discomfort or pain at any part during these sessions.

4. The risks during the sessions will be no greater than the risks experienced during normal daily activities. You understand that medical care is available in the event of injury resulting from research, but neither financial compensation nor free medical treatment is provided. You also understand that you are not waiving any rights that you may have against the University for injuries resulting from negligence of the University or investigators. Should medical care be required, you may contact Health Services at (912) 478 – 5641.
5. You will not receive direct benefit from participating in this study. However, at your request, you will be provided your results, once calculated. The results of this study may help with the evaluation and treatment of concussions.
6. You will be required to participate in two sessions approximately three to four months apart from each other. Each session will be approximately 10 minutes in duration.
7. You understand that all data concerning myself will remain completely confidential and available only upon written request to John Burk, or Dr. Buckley. You understand that any information about my records will be handled in a confidential manner consistent with medical records. Your identity on all records will be indicated by a case number. You will not be specifically mentioned in any publication of research results. All information and research records will be kept for a period of five years after the end of the study.
8. If you have questions about this study, please contact John Burk, ATC at (770) 312 – 3828 or the researcher's faculty advisor, Thomas Buckley at (912) 478 – 5268. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843 or by email at; oversight@georgiasouthern.edu.
9. You will not receive compensation for your participation in this study. You will not be responsible for any additional costs for your participation in this study.
10. You understand that you do not have to participate in this study and your participation is completely voluntary. At any time, you can choose to terminate your participation in this study by telling the primary investigator.
11. You understand that you may terminate participation in this study at any time without prejudice to future are or any possible reimbursement of expenses, compensation, employment status, or course grade except provided herein, and that owing to the scientific nature of the study, the investigator may in his/her absolute discretion terminate the procedures and/or investigators at any time.
12. You understand there is no deception involved in this study.

13. You certify that you are 18 years of age or older and that you have read the preceding information, or it has been read to you, and understand its contents. Any questions you have pertaining to the research have been, and will continue to be answered by the investigators listed at the beginning of this consent form at the phone numbers given (770) 312 – 3828.

14. You have been given a copy of this consent form to keep for your records.

Title of Project: The Effect of Sports on the Balance Error Scoring System

Principal Investigator: John Burk, ATC
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Other Investigator(s): Thomas Buckley, Ed.D., ATC
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Participant Signature Date _____

I, the undersigned, verify that the above informed consent procedure has been followed.

Investigator Signature Date _____

APPENDIX D

Medical History Questionnaire

Please answer the following questions as honestly as possible. Your answers will remain confidential and will NOT be shared with your coaches or athletic training staff

Subject ID _____ Date: ____ / ____ / ____

Gender: M / F Year in School: FR SO JR SR 5th Grad

Age: _____ Height: _____ Weight: _____

Please answer the following questions about your injury history;

- | | | | |
|----|---|------------|----------|
| 1. | Have you ever suffered a concussion?
If Yes; How many? _____
If Yes: When was your last concussion? _____ | YES | NO |
| 2. | Have you sprained your ankle within the last six months? | YES | NO |
| 3. | Have you ever broken a bone in your foot or leg within the last six months?
If Yes; which bone(s): _____
Does this injury still bother you? | YES | NO |
| 4. | Have you injured your knee within the last six months?
If Yes, did you ever tear meniscus?
If Yes, did you have surgery? When? _____
If Yes; did you ever tear a ligament?
If Yes; which ligament, when, surgery? _____

_____ | YES
YES | NO
NO |
| 5. | Have you injured your hip within the last six months?
If Yes, please explain: _____ | YES | NO |
| 6. | Have you strained or torn a leg muscle within the last six months?
If Yes, please explain: _____ | YES | NO |
| 7. | Have you injured your low back or had a nerve problem?
If Yes, please explain: _____ | YES | NO |
| 8. | Do you have any known balance/metabolic/neurological disorders?
If Yes, please explain: _____ | YES | NO |
| 9. | Have you ever been knocked out playing sports?
If Yes, how many and when: _____ | YES | NO |

10. Have you ever been “knocked silly/seen stars” (confused/disorientated) while playing sports? YES NO

If Yes, how many times? _____

If Yes, has this happened in the last year? _____

11. Have you ever been hit so hard you lost your memory while playing sports? YES NO

If Yes, please explain: _____

12. Have you had any other muscle/bone/joint injuries to your head, back, legs, or feet within the last six months? YES NO

If Yes, please explain: _____

APPENDIX E

Balance Error Scoring System (BESS)

The BESS consists of three different stances (double, single, and tandem) which are done on a firm surface and repeated again on a piece of medium-density foam (10cm thick) to measure the participant's postural control. Subjects are provided with the test requirements and instructed to stand in the proper position and close their eyes to indicate when they are ready to begin a test trial. They are to stay in that position to the best of their abilities for twenty seconds. If they fail to do so, they are asked to regain the position as quickly as possible. The subject's performance is scored by adding 1 point for each error committed during each trial.



(Guskeiwicz 2001)

Errors:

- Hands coming off the iliac crest
- Opening the eyes
- Stepping, stumbling, or falling
- Moving the hip into more than 30° of flexion or abduction
- Lifting the forefoot or heel
- Remaining out of the test position for more than five seconds

(BESS score calculated by adding 1 error point for each error committed)

APPENDIX F

Tables

Table 1. Descriptive Statistics for All Subjects (Participants with Preseason and Postseason Scores).

Significance was found with age between all three groups, $F(2)=17.85$; $p<.001$. Tukey post hoc reveals differences between controls and women's soccer ($p<.001$) and controls and women's volleyball ($p<.001$). Significance was found with height between all three groups, $F(2)=26.96$; $p<.001$. Tukey post hoc reveals differences between women's volleyball and controls ($p<.001$) and women's volleyball and controls ($p<.001$). Significance was found with weight between all three groups, $F(2)=10.40$; $p<.001$. Tukey post hoc reveals differences between women's volleyball and women's soccer ($p<.001$) and women's volleyball and controls ($p=.004$).

Group	n	Age, y	Height, cm	Weight, kg
Women's Soccer	22 (17)	19.5 ± 1.6 (19.4 ± 1.6)	165.3 ± 5.9 (165.7 ± 6.3)	58.8 ± 7.8 (58.9 ± 7.9)
Women's Volleyball	14 (13)	19.4 ± 1.2 (19.3 ± 1.3)	177.4 ± 5.2 (177.4 ± 5.4)	70.1 ± 6.8 (70.3 ± 7.1)
Non-Athlete Control	19 (16)	22.1 ± 1.7 (21.9 ± 1.8)	163.9 ± 6.5 163.0 ± 6.6	62.5 ± 9.0 (61.2 ± 7.9)

Table 2. Mean Changes Per Stance From Preseason to Postseason

No differences were found for mean changes per stance or total change.

Mean Changes Per Stance From Preseason to Postseason					
Stance	Group	n	Mean	F	Sig
Change Firm Double	Women's Soccer	17	0.00 ± .00	N/A	N/A
	Women's Volleyball	13	0.00 ± .00		
	Non-Athlete Control	16	0.00 ± .00	N/A	N/A
	Athlete	30	0.00 ± .00		
	Total	46	0.00 ± .00		
Change Firm Single	Women's Soccer	17	1.41 ± 1.06	0.01	0.945
	Women's Volleyball	13	1.38 ± 1.04		
	Non-Athlete Control	16	0.62 ± 0.72	7.08	0.011
	Athlete	30	1.40 ± 1.04		
	Total	46	1.13 ± 1.00		
Change Firm Tandem	Women's Soccer	17	0.18 ± 0.39	3.44	0.074
	Women's Volleyball	13	0.62 ± 0.87		
	Non-Athlete Control	16	0.50 ± 0.63	0.43	0.515
	Athlete	30	0.37 ± 0.67		
	Total	46	0.41 ± 0.65		
Change Foam Double	Women's Soccer	17	0.12 ± 0.33	0.08	0.782
	Women's Volleyball	13	0.15 ± 0.38		
	Non-Athlete Control	16	0.25 ± 0.58	0.74	0.395
	Athlete	30	0.13 ± 0.35		
	Total	46	0.17 ± 0.44		
Change Foam Single	Women's Soccer	17	1.00 ± 0.87	1.79	0.192
	Women's Volleyball	13	0.62 ± 0.65		
	Non-Athlete Control	16	1.06 ± 1.06	0.69	0.412
	Athlete	30	0.83 ± 0.79		

Mean Changes Per Stance From Preseason to Postseason					
Stance	Group	n	Mean	F	Sig
	Total	46	0.91 ± 0.89		
Change Foam Tandem	Women's Soccer	17	0.65 ± 0.61	0.01	0.907
	Women's Volleyball	13	0.62 ± 0.87		
	Non-Athlete Control	16	1.25 ± 1.13	5.14	0.028
	Athlete	30	0.63 ± 0.72		
	Total	46	0.85 ± 0.92		
Change Total	Women's Soccer	17	2.18 ± 1.88	0.26	0.617
	Women's Volleyball	13	1.85 ± 1.63		
	Non-Athlete Control	16	1.81 ± 1.60	0.176	0.677
	Athlete	30	2.03 ± 1.75		
	Total	46	1.96 ± 1.69		

Table 3. Total Preseason Scores.

No significance was found between groups at preseason.

Mean Preseason Totals By Group		
Group	n	Preseason Totals
Women's Soccer	22	8.23 ± 1.95
Women's Volleyball	14	9.86 ± 2.48
Non-Athlete Control	19	8.37 ± 3.08
Total	55	8.69 ± 2.57

Table 4. Frequency of Errors by Stance

(Subjects with both preseason and postseason data)

Frequency of Errors Per Stance				
	Stance	Preseason	Postseason	Overall
Firm	Double Leg	0 (0.0%)	0 (0.0%)	0 (0.0%)
	Single Leg	79 (16.1%)	50 (14.1%)	129 (15.3%)
	Tandem	21 (4.3%)	12 (3.4%)	33 (3.9%)
Foam	Double Leg	5 (1.0%)	4 (1.1%)	9 (1.1%)
	Single Leg	246 (50.2%)	177 (50.0%)	423 (50.1%)
	Tandem	139 (28.4%)	111 (31.4%)	250 (29.6%)
Total	Total	490 (100%)	354 (100%)	844 (100%)

Table 5. Categorized Frequency of Errors Within Stances at Preseason

(Subjects with both preseason and postseason data)

Categorized Frequency of Errors Within Stances (Preseason)									
	Stance	Eyes	Hands	Hips	Step	Foot	Out	>1	Total
Firm	Single Leg	0 (0%)	0 (0%)	3 (3.8%)	51 (64.6%)	5 (6.3%)	1 (1.3%)	19 (24.1%)	79 (100%)
	Tandem	0 (0%)	4 (19.1%)	0 (0%)	4 (19.1%)	5 (23.8%)	1 (4.8%)	7 (33.3%)	21 (100%)
Foam	Double Leg	1 (20.0%)	2 (40.0%)	0 (0%)	1 (20.0%)	0 (0%)	0 (0%)	1 (20.0%)	5 (100%)
	Single Leg	1 (0.4%)	1 (0.4%)	4 (1.6%)	121 (49.2%)	0 (0%)	39 (15.9%)	80 (32.5%)	246 (100%)
	Tandem	0 (0%)	8 (5.8%)	2 (1.4%)	27 (19.4%)	21 (15.1%)	16 (11.5%)	65 (46.8%)	139 (100%)
Total	Total	2 (0.4%)	15 (3.1%)	9 (1.8%)	204 (41.6%)	31 (6.3%)	57 (11.6%)	172 (35.1%)	490

Table 6. Categorized Frequency of Errors Within Stance (Postseason)

Categorized Frequency of Errors Within Stances (Postseason)									
	Stance	Eyes	Hands	Hips	Step	Foot	Out	>1	Total
Firm	Single Leg	0 (0.0%)	1 (2.0%)	2 (4.0%)	34 (68.0%)	3 (6.0%)	0 (0%)	10 (20.0%)	50 (100%)
	Tandem	0 (0.0%)	6 (50.0%)	0 (0.0%)	1 (8.3%)	1 (8.3%)	0 (0.0%)	4 (33.3%)	12 (100%)
Foam	Double Leg	1 (25.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (25.0%)	2 (50.0%)	4 (100%)
	Single Leg	0 (0.0%)	0 (0.0%)	5 (2.8%)	92 (52.0%)	3 (1.7%)	20 (11.3%)	57 (32.2%)	177 (100%)
	Tandem	1 (0.9%)	6 (5.4%)	4 (3.6%)	15 (13.5%)	4 (3.6%)	14 (12.6%)	67 (60.4%)	111 (100%)
Total	Total	2 (0.6%)	13 (3.7%)	11 (3.1%)	142 (40.1%)	11 (3.1%)	35 (9.9%)	140 (39.5%)	354

APPENDIX G

Figure

Figure 1. Lab Set-up

