Fall 2015

History of Concussion and Current Functional Movement Screen Scores in a Collegiate Recreational Population

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HISTORY OF CONCUSSION AND CURRENT FUNCTIONAL MOVEMENT SCREEN SCORES IN A COLLEGIATE RECREATIONAL POPULATION

by

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(Under the Direction of John Dobson)

ABSTRACT

Introduction: 1.6-3.8 million sports-related concussions occur annually (Langlois, Rutland-Brown, & Wald, 2006). Alterations in cognition, gait characteristics, and static center of pressure (COP) have all been identified as potential long-term consequence of concussion (De Beaumont L., 2011; Giza & Hovda, 2001; Guskiewicz et al., 2005; Martini et al., 2011). However, little information is known about the long-term effects of concussion on motor functions other than gait and static COP. The Functional Movement Screen (FMS) has been identified to assesses gross mobility and stability in the body (Cook, 2010). The purpose of this study was to investigate a relationship between concussion history and FMS performance. **Methods**: Fifty-five healthy collegiate club sport athletes (38 male, 17 female) participated in this study. An 11-item questionnaire assessed current and past health history and the seven movements of the functional movement screen were utilized to obtain functional movement ability. Correlations between prior history of concussion and FMS score were run using SPSS both normally and controlling for body mass index (BMI) and age. **Results**: Neither FMS composite score (r=.13, p=.341), nor any of the individual tests were significantly correlated with concussion history. However, after controlling for BMI and age, the Hurdle Step did have a small significant correlation to history of concussion (r=.294, p=.033), but composite score still did not reach significance. **Conclusion**: Previous research suggests that neurological function appears to be altered in those with a history of concussion. The findings of this study show there are no differences in composite FMS score in those with and without a history concussions.

INDEX WORDS: Concussion, Concussion History, History of Concussion, Functional Movement, Functional Movement Screen, FMS.

HISTORY OF CONCUSSION AND CURRENT FUNCTIONAL MOVEMENT
SCREEN SCORES IN A COLLEGIATE RECREATIONAL POPULATION

by

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B.S, East Stroudsburg University, 2013

M.S, Georgia Southern University, 2015

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of Requirements for the Degree

MASTERS OF SCIENCE IN KINESIOLOGY

STATESBORO, GEORGIA

HISTORY OF CONCUSSION AND CURRENT FUNCTIONAL MOVEMENT SCREEN
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ACKNOWLEDGMENTS

I would like to acknowledge the help of everyone on my committee for their outstanding guidance, patience, and mentorship through the conceptualization and refinement of this research. Without their help, this project and all I have gained from it could not have been possible. A special acknowledgment to Dr. Thomas Buckley for providing oversight and mentorship from the very beginning to the end despite transitioning jobs to another state. Secondly, the upmost gratitude and recognition to Dr. John Dobson for providing excellent guidance, oversight, and assistance during all the changes and additions to my thesis. Through all of the bumps and turns in the project, it was a blessing to have your continued support and dedication to my success. Thank you to all the members of my committee.

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CHAPTER 1

INTRODUCTION

In the United States alone, an estimated 1.6-3.8 million sport-related concussions occur annually (Langlois et al., 2006). While most of the attention surrounding concussions focus on football, the incidence rate is actually higher in rugby (8-17.5/1,000 Athlete Exposures)(Gardner et al., 2014). Men's lacrosse also has a relatively high rate (4.0/1,000 AE's), but along with rugby, has received limited attention in the literature (Marar, McIlvain, Fields, & Comstock, 2012). Although football and rugby are predominantly male sports, females sustain 0.7 more concussions per every 10,000 Athlete Exposures (AE's) in gender comparable sports (Marar et al., 2012). After an individual sustains a concussion, the relative risk for sustaining a second increases up to 5.8 times (Zemper, 2003). Prior concussion history is also a prognostic risk factor for more severe concussion symptoms, greater neurocognitive decline, and longer recovery times upon sustaining a subsequent concussion (Collins et al., 2002; Colvin et al., 2009; Covassin, Moran, & Wilhelm, 2013; Covassin, Stearne, & Elbin, 2008). The traditional timeline for acute concussion resolution is 7 to 10 days (Giza & Hovda, 2001; Guskiewicz et al., 2003). However, concussions may have physiological implications on immediate and long term health far beyond the traditional framework of resolution (P. R. McCrory & Berkovic, 2001).

A history of concussions can negatively affect overall Health Related Quality Of Life (HRQOL), and can increase the frequency of headaches in high school and collegiate athletes (Kuehl, Snyder, Erickson, & McLeod, 2010; McLeod, 2010; Register-Mihalik, 2009). Long term studies in retired players from the National Football League (NFL) have found that those who sustain three or more concussions are 3 times more likely for developing clinically diagnosed

depression, and an earlier onset of Alzheimer's Dementia (AD) later in life (Guskiewicz et al., 2005; Guskiewicz, Marshall, et al., 2007; Kerr, Marshall, Harding, & Guskiewicz, 2012). Retired NFL players are also susceptible to a five-fold increase in the risk for being diagnosed with mild cognitive impairments, and a 3 fold increase in risk for developing significant memory problems (Guskiewicz et al., 2005). A known risk factor for AD is the byproduct of the ApoE gene, Apolipoprotein allele E4 (ApoE E4), (Lambert et al., 2002; Saunders et al., 1993; Wenham, Price, & Blandell, 1991). ApoE E4 has been identified to increase risk for AD when present in individuals who are exposed to head trauma (Mayeux R, 1996; Verghese, Castellano, & Holtzman, 2011). The occurrence of ApoE E4 in retired NFL players has been found to be higher (38%) than normal rates for males (23-26%), and was found to be present along with neurobehavioral alterations in boxers (Casson, Viano, Haacke, Kou, & LeStrange, 2014; Jordan et al., 1997). Although there was no increase of rates of ApoE E4 compared to the general population, professional boxers with a higher exposure to head impact (12 or more professional bouts), and whom were positive for the ApoE E4, had the lowest neurobehavioral functioning out of the subgroup of boxers (Jordan et al., 1997). Another potential condition resulting from multiple head injuries is CTE, or Chronic Traumatic Encephalopathy. CTE involves the micro accumulation of tau proteins which aid in the formation of neurofibrillary tangles in the brain (Gavett, Stern, & McKee, 2011). In less than half of people found to have CTE a hallmark sign of AD (Beta-amyloid) is also present (McKee et al., 2009). Symptoms including changes in memory, behavior, personality, gait, speech, and parkinsonism are common in people subsequently diagnosed with CTE (McKee et al., 2009). A review in 2009 by McKee et al identified 46 autopsy-verified cases of CTE consisting of 35 boxers, 5 NFL players, 1 wrestler, and 1 soccer player (McKee et al., 2009).

Following concussion, decreases in motor processing speed, verbal memory, and reaction time on the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) have been seen to last anywhere from 7-21 days following injury (Covassin, Elbin, & Nakayama, 2010; Tsushima, Shirakawa, & Geling, 2013). Further, Iverson et al found a moderate effect of past concussion history on lower verbal memory composite scores on the ImPACT test (Cohen's d=.639) (Iverson, Echemendia, Lamarre, Brooks, & Gaetz, 2012). However, most literature using neurocognitive tests such as ImPACT, and Headminder Concussion Resolution Index (CRI), have found no differences between patients with and without a past history of concussion (Broglio, Ferrara, Piland, Anderson, & Collie, 2006; Collie, McCrory, & Makdissi, 2006; Guskiewicz, Marshall, Broglio, Cantu, & Kirkendall, 2002; Iverson, Brooks, Lovell, & Collins, 2006; Solomon & Kuhn, 2014). Therefore, if cognition is altered long term, either changes are occurring later in life than when was assessed in the studies previously mentioned (high school and college), or measures of computer neurocognitive testing are not sensitive enough to detect them as mentioned by Iverson et al (Iverson et al., 2006).

Aside from cognitive change, long-term neurophysiological changes have been seen in the primary motor cortex (M1) of individuals with a previous history of concussion (De Beaumont, Lassonde, Leclerc, & Theoret, 2007; De Beaumont L., 2011). The change represents an increased Cortical Silent Period (CSP), which is the duration of separation between excitation and response of neurons at different intensities (De Beaumont et al., 2007; De Beaumont L., 2011). The increased CSP is hypothesized to originate from alterations in the intra-cortical inhibitory interneurons which play a role in neural cell maturation, function, and plasticity; as well as GABA receptors which have been linked to decreased motor learning in rats (De Beaumont et al., 2007; Lehmann, Steinecke, & Bolz, 2012; McNamara & Skelton, 1996;

Nakagawa & Takashima, 1997). Lastly, concussion history also appears to have an effect on sensory processing. Patients with a history of concussion an average of six years prior had a decreased P1 amplitude on electroencephalography (EEG) measures, which may negatively affect visual processing long term (Moore, Broglio, & Hillman, 2014).

Although alterations in cognition, sensory, motor appear to be separate, they are vital functions of the central nervous system (CNS) in the accomplishment of movement and balance (Catena, van Donkelaar, & Chou, 2007b; Guskiewicz, 2011). Therefore, lingering and long-term deficits in movement and balance have been the focus of emerging research. Although common assessments of balance detect alterations on average of 3-5 days post concussion, sensitive assessments such as gait analysis and static center of pressure (COP) detect alterations in motor function and postural control at least 1 month after injury (Bell, Guskiewicz, Clark, & Padua, 2011; Buckley, Munkasy, Tapia-Lovler, & Wikstrom, 2013; Catena, van Donkelaar, & Chou, 2009; Catena, van Donkelaar, Halterman, & Chou, 2009; Guskiewicz, 2011; Powers, Kalmar, & Cinelli, 2013; Slobounov, Slobounov, Sebastianelli, Cao, & Newell, 2007). Decrements are likely associated with impairments in all components of balance and are explained to represent the body's increased effort to maintain center of mass within the base of support (Sosnoff, Broglio, & Ferrara, 2008). Changes can be exacerbated by increasing the cognitive challenge by introducing dual task (DT) testing (Catena, van Donkelaar, & Chou, 2007a; Parker, Osternig, P, & Chou, 2006). Although the majority of research using gait and static COP assess immediate to intermediate changes post-concussion, COP changes during quiet standing have been found 19 months following injury (De Beaumont L., 2011). Further, Martini et al reported conservative gait strategies including decreased walking velocity, increased time in double-leg stance support, and less time in single-leg stance support in patients whose most recent concussion was an

average of six years prior (Martini et al., 2011). The number of previous concussions also negatively correlated to the time spent in double-leg stance support during gait which suggests a dosing response between number of concussions and altered gait (Martini et al., 2011). Although much research has been done on gait and static COP in previously concussed patients, little information is known on the long-term effect of concussion other motor functions.

Individuals with a previous history of concussion were analyzed on tasks such as walking, running, walking backwards, single-leg bounding, and ascending and descending stairs using the High Mobility Assessment Tool (HIMAT) (Kleffelgaard, Roe, Sandvik, Hellstrom, & Soberg, 2013). Higher-level mobility was negatively correlated to perceived balance problems at 3 months (rho=-.46), and 6 months (rho=-.63) post-concussion (Kleffelgaard et al., 2013). However, this study only assessed individuals who previously sustained a concussion, and did not compare movement differences of those with a history of concussion to those without. Therefore, other than gait, research on the effect of concussion history on human movement is lacking.

The Functional Movement Screen (FMS) was developed to assess bi-lateral symmetry, mobility, and stability in the body (Cook, 2010). The FMS consists of seven movements that generate a composite score ranging from 0-21. Scores less than or equal to 14 points represent an 11-fold increased chance for injury, and a 51-72% probability of sustaining a serious injury (K. Kiesel, Plisky, & Voight, 2007; Schneiders, Davidsson, Horman, & Sullivan, 2011). Correlation between FMS total score and injury demonstrated a strong relationship of .781 (Schneiders et al., 2011). However, contrary findings using a Receiver Operator Characteristic (ROC) established that even a 17 point cut-off score did not result in an increase in risk of injury (B. M. Wiese, ATC, LAT; Boone, J. MS, ATC, FMSC; Mattacola, C. PhD, ATC; & McKeon, 2014). One

explanation for this was the different populations studied. Weise et al. used collegiate football players as opposed to Keisel et al who used professional (K. Kiesel et al., 2007; B. M. Wiese, ATC, LAT; Boone, J. MS, ATC, FMSC; Mattacola, C. PhD, ATC; & McKeon, 2014). Also, Weise et al. recorded injuries that resulted in one or more days of loss of participation compared to Kiesel et al who recorded those only resulting from 3 or more weeks of lost time (K. Kiesel et al., 2007; B. M. Wiese, ATC, LAT; Boone, J. MS, ATC, FMSC; Mattacola, C. PhD, ATC; & McKeon, 2014). Normative values for the FMS in a collegiate setting, including club sports, is 15.7 out of 21 in which 31% fell at or below the 14 point cut off (Schneiders et al., 2011). Although some studies have assessed previous injury history and FMS performance,(Peate, Bates, Lunda, Francis, & Bellamy, 2007; Schneiders et al., 2011) no studies have been done assessing previous history of concussion and its relation to scores on the Functional Movement Screen.

Growing evidence suggests the possibility long-term impairments in postural control and movement in individuals with a history of one or more concussions. Currently, no research has been done assessing various functional movements in individuals with and without a prior history of concussion. Therefore, the purpose of this study was to investigate a relationship between concussion history and FMS performance. Our hypothesis was that composite FMS score will correlate with participants past history of concussion.

CHAPTER 2

METHODS

Participants:

Fifty eight individuals from a single university competing in collegiate club sports were

recruited for this study. Inclusion criteria was healthy active participation in men's rugby,

women's rugby, men's lacrosse, ultimate Frisbee, or cheerleading from a single university.

Because pain during movement effects FMS grading, any participant with an existing injury

serious enough to restrict participation in sport was excluded. Furthermore, by selecting actively

participating subjects, the possibility of score being affected due to current injury was reduced.

Of the 58, two participants were excluded due to the exclusion criteria. Of the two, one was re-

enrolled the following semester. In addition, two participants requested to discontinue their

participation in the study. Of the 58, 55 healthy collegiate club sport participants (38 male, 17

female, average height = 1.7m ($\pm$ .17), mass = 78.49Kg ($\pm$19.94), age= 20.03 years ($\pm$1.49) were

used for data collection and analysis. All experimental procedures were approved by the

Institutional Review Board (IRB) of the participating university, and all participants were

provided with a written IRB approved informed consent. IRB approved informed consent forms

were obtained from participants prior to testing (App. C, Fig. 1.).

Instrumentation:

An 11 item participation health questionnaire was used to assess participant's current and

past health history (App. C, Fig. 2). Six items assessed concussion history with specific questions

to identify how many concussions an individual sustained, time since the last concussion,

occurrence of post traumatic amnesia (PTA), loss of consciousness (LOC), being "dinged" or

having their "bell rung". Two questions identified past or current history of musculoskeletal

injuries and their implications on current strength, balance, and flexibility. Two questions were related to general medical disorders or medications that could affect balance or overall completion of the test. The concussion section of the questionnaire was a derivative of a pre-participation questionnaire established in literature to identify concussions sustained from sport and recreational activity (Valovich McLeod T. C., 2008). Reliability of that portion of the questionnaire was found to be 0.89, via Cronbach's alpha (Valovich McLeod T. C., 2008). Unlike that questionnaire, the one used for the current study did not separate between concussions sustained during sport or recreational activities, had a separate question to identify the incidence of PTA, and accounted for total numbers of concussions sustained. Face validity was determined by the partial implementation of the questionnaire in previous research, and current changes were validated by expert opinion. Face validity was utilized to ensure that the questionnaire was valid.

To assess functional movement, the FMS was used. It consists of 7 component tests, which have been thoroughly described in the literature (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Cook, 2010; K. Kiesel et al., 2007; Schneiders et al., 2011). The 7 tests include: Deep Squat, Hurdle Step, Inline Lunge, Shoulder Mobility Test, Active Straight Leg Raise, Trunk Stability Test, Rotary Stability Test (App. C, Fig. 4). Interrater reliability of the FMS ranges from .38 using Kalpha to 0.97 using Intraclass Correlation Coefficient (ICC) (Chorba et al., 2010; Shultz R., 2013). Test-retest reliability of FMS has an ICC of 0.63 (CI= .6, .77), and scoring between live testing and video analysis had an ICC of 0.92 (Shultz R., 2013). The sensitivity and specificity of the FMS in predicting injury using scores falling at or below a 14 point cut-off score is 0.579 and 0.737 respectively, and a sensitivity of 0.87 was achieved when including at least 1 side-side asymmetry (K. B. Kiesel, Butler, & Plisky, 2014; Schneiders et al.,

2011). Each of the seven movements are scored on a 0-3 scale based on the objective evaluation of the quality of participant's movement. A score of "3" was awarded if a participant perfectly meets all movement criteria. A score of "2" was awarded if the movement is completed below criteria of a 3, but movement criteria for "2" was met. A score of "1" was given if individual cannot complete the movement, or did not meet criteria of a 2. Zero was awarded if a participant reports any pain outside of soreness regardless of movement ability. See Appendix C, Table 1 for individual scoring of tests. To perform the required tests, the participants utilized one .6x1.8 meter board, one 1.5 meter dowel, a hurdle chord, and two .6 meter hurdle poles (Chatham Virginia, United States). Each participant's performance was video recorded (Sony Handycam HDR-PJ580V (New York NY, USA). The instructional video was played through a Lonovo Thinkcentre computer (Morrisville NC, USA) and projected using a Mitsubishi XD460U Portable DLP projector (New York NY, USA). Video recording of all tests was done by placing the video camera on a tripod 3.9 meters away from participant. On the Deep Squat, Hurdle Step, and Inline Lunge, the participant was facing forward at a 45 degree angle of the camera. During the Trunk Stability Push-Up test and Active Straight Leg Raise Test the participant was at a 90 degree perpendicular to the camera. During the Shoulder Mobility Test the participant's back was facing the camera in order to facilitate accurate scoring on the posterior side of the individual. (Appendix C, Fig. 3). All data analysis was done using SPSS statistics software (Armonk NY, USA).

Procedures:

Recruitment was done at a single university, where the men's and women's club sports including rugby, lacrosse, and Frisbee, as well as the university cheerleading team were targeted.

Specifically, the team captains and coaches were informed about the research details and objectives to gain approval to approach and recruit from their teams. After consent to approach the team was given, oral communication of the details of the research study and an informed consent were presented. The FMS testing was performed during the winter, spring, and fall of 2014. Prior to testing, participants completed the health history questionnaire to ensure inclusion and exclusion criteria were met. Concussion history was identified through medical history questions on the health history questionnaire. For any individual reporting recognized concussion and PTA, LOC, or having their "bell-rung", further follow-up was done to identify if these incidents occurred during the concussion or occurred separately. Any individual reporting having their "bell-rung" that did not identify as having a recognized concussion was classified as having a concussion. For FMS testing, participants were instructed to wear non-baggy gym shorts and shirt, and to refrain from participation in physical exercise up to an hour and a half prior to testing. Any individual wearing sweatpants was asked to roll them up during the Active Straight Leg Raise. Prior to attempting each individual test, participants watched an instructional video with verbal and visual instructions consistent with the FMS instructional manual for each movement. For instruction recall purposes, the video was paused after the instruction for each movement, and any verbal instructions were repeated upon participant request. Participants were instructed to attempt to re-create movements as closely as possible, and they were provided a maximum of three attempts per test. On tests with independent scoring from left from right side (Hurdle Step, In-Line Lunge, Shoulder Mobility Test, Active Straight Leg Raise, and Rotary Stability Test), up to three attempts were allowed on each side. Participants were corrected on starting position, but they were not coached once attempts began. Participants were instructed to

stop if any of the tests caused pain; however, all participants completed all trials without any reported pain. All participants completed FMS testing battery in approximately 20 minutes.

Data Analysis:

This was a cross sectional prospective study. The variables in this study were concussion history, age, height, weight, Body Mass Index (BMI), FMS composite score, as well as individual FMS scores.

Statistical Analysis:

Video analysis for reliability yielded an Intraclass Correlation Coefficient of 0.63 for intra-rater reliability and 0.60 for inter-rater reliability. Descriptive statistics were run to determine normality of the data and provide measures of central tendency and variability. Only mass appeared to have a high kurtosis, however no adjustments were made. To determine the relationship between previous number of concussions and composite FMS score, a bivariate Pearson correlation was performed. A similar analysis was run between number of previous concussions and individual FMS scores. Pearson correlations were performed on participant's composite score and 7 individual movement scores. BMI (-0.34 to -0.8) and age (-0.27) have been shown to be correlated with lower FMS scores (Duncan & Stanley, 2012; Duncan, Stanley, & Leddington Wright, 2013; Perry & Koehle, 2013). Therefore, a partial correlation was run between composite FMS score and individual movements controlling for these variables. An alpha level of 0.05 was adopted for all analyses.

CHAPTER 3

RESULTS

Participant's had an average composite FMS score of 15.76 $\pm$2.36, past history of 1.03 $\pm$1.10 concussions, and a BMI of 27.27 $\pm$6.44 (App. C, Table 2). For individuals with self reported history of concussion, the average time since last concussion was 2.56 years. Neither composite score (r=.13, p=.341) , nor any of the individual tests were significantly correlated with concussion history (App. C, Table 3). Trunk Stability Push-Up (p=.063), and Hurdle Step (p=.096) neared significance but did not meet the alpha level of .05. However, after controlling for BMI and Age, the Hurdle Step did have a small significant correlation to past history of concussion (r=.294, p=.033), and overall composite score came closer to nearing significance (.08). BMI was negatively correlated with composite score by r =-.546 (p=.000).

CHAPTER 4

DISCUSSION

The absence of literature assessing the impact of concussion history on movements other than gait leaves a present void in concussion research. The purpose of this study was to identify the relationship between concussion history and FMS performance. Overall, no correlation was found between past history of concussion and FMS composite score. After controlling for BMI and age a positive correlation was seen between concussion history and score on the Hurdle Step. However, correlational changes in the Hurdle Step were not large enough to effect the composite FMS score's relationship to previous concussion. Therefore other than the hurdle step, concussion history does not seem to relate to an increase or decrease in overall functional movement scores.

The results of this study disagree with prior findings that show motor changes in individuals with a past history of concussion (De Beaumont L., 2011; Martini et al., 2011). Although this study and previous studies are all assessments of CNS functioning, they consist of different methods and outcome measures. DeBeaumont et al (2011) used a force plate to assess approximate entropy, or the randomness of COP movement in the medial/lateral and anterior/posterior direction as a measure of postural control. Martini et al (2011) used a GAITRite instrumented walkway to assess common gait stepping characteristics. Our study used the FMS to screen various functional movements via visual analysis. Measures of static stance COP and scores on the FMS have been identified as independent from each other both at rest and post-exercise (Hartigan, Lawrence, Bisson, Torgerson, & Knight, 2014; Perry & Koehle, 2013). Although De Beaumont et al. (2011) and Martini et al. (2011) uncovered alterations in motor cortex excitation, gait, and postural control in individuals with a history of concussions, the

independcence of these measures and the FMS remain. Similar to the lack of findings in neurocognitive testing, although there may be neurophysiological alterations that lead to changes in gait and static COP, individuals with a history of concussion represents no gross deficit on the FMS (Broglio et al., 2006; Collie et al., 2006; Guskiewicz et al., 2002; Iverson et al., 2006; Solomon & Kuhn, 2014). Growing evidence suggests alterations in both cognitive and motor pathways persist long term following concussion, however standard field measures such as ImPACT, Headminder CRI, and now FMS appear to be unaffected.

Another possible explanation was the FMS may lack sensitivity to more subtle changes. The FMS tool is a field-ready screen used to grossly assess functional movements (Cook, 2010). Scoring of the FMS is on a 0-3 scale with a score of 0 only being awarded for painful movements. However, there are many grading components for each numerical score. For example, there are 4 criteria which must be met to achieve a score of 3 on the deep squat. If an individual fails to meet 3 of the 4 criteria for a score of 3, but meets all the criteria for a score of 2, they can achieve the same score as an individual who only fails to meet 1 of the 4 criteria for a score of 3, and meets all criteria for a score of 2. Therefore, if an individual performing the Deep Squat with their knees collapsing inward, trunk not remaining parrallel with their tibia, and femur not breaking parrallel to the floor they can achieve a score of 2 if the problems are corrected with their heels elevated as per guidelines for scoring of a 2. However, if another individual who only fails to meet the score of 3 by not keeping the bar over the feet during the movement yet corrects it upon elevating the heels will score the same as the first individual. The FMS inherently overlooks these differences and focuses on more of a categorical movement ability. Without a grading system that accounts for the number of individual movement criteria subtle changes may be masked while using the FMS. A more sensitive assessment may also

prove to be achieved through using the raw score which is a summation of each movement including scores for tests which differentiate left and right side. This would account for each individual side's ability to complete a movement instead of taking the numerical score of the lowest side. Therefore, if an individual performing the hurdle step scored a 2 on the left side, and a 3 on the right, their raw score for the movement would be a 5 which indicates assymetrical differences. However, the same results using the total (composite) score would yeild a numerical score of 2 which could either come from a 3 and a 2, or a 2 and a 2. Instead of a scale ranging from 0-21, a raw score would provide utilization of a scale from 0-36. Althouth raw score was not utilized for the purposes of this study, future studies should consider reporting raw score in efforts to improve accuracy of the FMS.

Consistant with previous research on FMS score in active healthy individuals, the results of this study have also found the average score of participants to be 15.7 ± 2.36 (Schneiders et al., 2011). Also similar to previous findings, BMI was negatively correlated to FMS composite score (r=-.546, p=.000) (Duncan & Stanley, 2012; Duncan et al., 2013; Perry & Koehle, 2013). Unlike prior findings, this study did not find a significant association between age and FMS score (p=.69) (Perry & Koehle, 2013). This is likely due to our small sample size (n=55), relatively young population (18-23 years of age), and narrow standard deviation of age ($\pm$ 1.49) compared to Perry et al who used 622 middle aged adults (Perry & Koehle, 2013). As a sub-group of injury, our study looking at concussions would agree with past FMS literature supporting no effect of previous history of musculoskeletal injury on current FMS ability (Agresta C., 2014; Peate et al., 2007; Schneiders et al., 2011). One explanation for this could be that concussions, like musculoskeletal injuries, have initial and lingering deficits, but heal on a macro-level in a way that allows the system to functionally perform overall tasks.

Given the nature of this study, a clear limitation to our results is recall bias of previous

concussion history, height, and weight. However, reliability of self-reported concussion has been

assessed as moderate (weighted Cohen's Kappa=.48) with 61% of individuals reporting the same

number of concussions after a 9 year follow-up (Kerr, Marshall, & Guskiewicz, 2012). When

reliability of concussion history reporting has been checked after the duration of a playing season

results reached a much higher agreement (92%) (McCrea, Hammeke, Olsen, Leo, & Guskiewicz,

2004). Therefore, since our study is occuring closer to the time of injury, we presume the

reliability of self-reported concussions in this study is greater. Second, is the assumption that

individuals are familiar with the signs and symptoms of a concussion, and were able to recognize

those symptoms at the time of concussion. If individuals are unaware of signs and symptoms of a

concussion, then the lack of knowledge of concussion could affect the number of concussions

reported. Last, a possible limitation of the study is that participants were not provided

information on the specific FMS testing criteria prior to the FMS being administered. Awareness

of the FMS scoring criteria has been shown to immediately improve scores on average of 2.6

points (Frost, Beach, Callaghan, & McGill, 2013). Although the proper FMS testing protocol is

to test individuals without knowledge of scoring, these findings raise the question if current

testing protocols are truly capturing movement dysfunction or lack of FMS scoring knowledge

(Frost et al., 2013). Lastly, 5 of the 7 FMS tests take place in the frontal and sagital plane

simultaneously. To create consistency of live rater viewing, we chose an angle of 45 degrees to

adequately grade both planes of movement simultaneously. Switching from a two plane to one

plane view for grading may have affected the accuracy of our scoring by being unable to fully

view both planes. Further, test protocol demanded participants to be able to visually and

auditorily comprehend and rememeber movement instructions prior to the attempt of each

movement. Once the movement began, no coaching was provided to participants. Therefore, if instructions were not fully understood or recalled, score may have been limited due to protocol, and not because of movement restrictions. In attempts to account for this, participants were assessed for questions after viewing every instructional section of the video in which any instructions were repeated prior to attempts.

The study is among the first to assess FMS in those with a previous history of concussion. As research uncovers more information on later life cognitive and motor changes following concussion, studies must also be done to assess the extent of these changes on various motor movements. Our study suggests that although subtle changes may exist, those with a past history of concussion are not impaired from a gross motor function standpoint, in comparison to those with no prior history of concussion when they are 18-23 years old; however, the effect in later life remains unknown. Furthermore, risk for musculoskeletal injury, as predicted by the FMS, is not elevated in those with past history of concussion.

CHAPTER 5

CONCLUSION

With up to 3.6 million concussions estimated to occur annually in sport, the long term outcome of repeated concussions must continue to be a top health priority (Langlois et al., 2006). Our study sought to assess the relationship between prior history of concussion and current Functional Movement Screen scores. Although previous research suggests that neurological function appears to be altered in those with a history of concussion, the findings of this study show that no differences in FMS scores appear to be present (De Beaumont L., 2011; Martini et al., 2011). Future research using more sensitive assessment of CNS must be undertaken to better understand the extent of motor changes in those with a history of concussion.

CHAPTER 6

REFERENCES

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APPENDIX A

Delimitations:

All participants must undergo and adhere to the Georgia Southern University Campus Recreation and Intramurals concussion management protocol.

Assumptions:

We assume that the FMS will be a valid and reliable test for bilateral asymmetries, mobility, and stability. We assume that participants will perform the FMS test to the best of their ability. Lastly, we assume that participants will report all injuries to the CRI Athletic Training staff.

Hypothesis:

H1o- We hypothesize that there will be no correlation to Functional Movement Screen scores and past history of concussion.

H1a- We hypothesize there will be a correlation between Functional Movement Screen scores and past history of a concussion.

APPENDIX B

REVIEW OF THE LITERATURE

Traumatic Brain Injuries' (TBI's) are a worldwide health concern causing at least 10 million injuries serious enough to result in death or hospitalization each year (Langlois et al., 2006). Although sports such as football have been in the limelight of concussions, the leading cause of TBI in the United States are falls, and motor vehicle crashes (Langlois et al., 2006). Despite the fact, 1.6-3.8 million concussions occur annually in America related to sport (Langlois et al., 2006). Furthermore, injuries to the head and face which mostly consist of concussions account for 11.5% of overall injuries in sports such as football (Shankar, Fields, Collins, Dick, & Comstock, 2007). Following a concussion, multiple alterations in the brain can produce symptoms including alterations in mood, loss of consciousness, changes in cognition and gross balance deficits. These alterations may not only increase an individual's risk for repeat injury, but their risk for late life cognition problems (Guskiewicz, 2011; Guskiewicz, Marshall, et al., 2007; Guskiewicz, Weaver, Padua, & Garrett, 2000; McCrea, Kelly, Randolph, Cisler, & Berger, 2002). Furthermore, changes in motor skills can persist long after individuals are injured (Buckley et al., 2013; Catena, van Donkelaar, Halterman, et al., 2009; Kleffelgaard et al., 2013; Slobounov et al., 2007). In light of this research, the once thought of transient nature of concussions is being replaced with a more cautious awareness of late life alterations.

Concussions occurring in sport have more recently been the focus of research and literature. Research has shown that females are more prone to concussions than males. Whether related to playing style differences, biomechanical structure, or concussion reporting differences, females sustain .7 more concussions per every 10,000 Athlete Exposures (AE's) in gender

comparable sports (Covassin, Elbin, Larson, & Kontos, 2012; Garces, Medina, Milutinovic, Garavote, & Guerado, 2002; Marar et al., 2012; Tierney et al., 2005). Most of this difference is seen during competition at which females are at a 1.9 greater rate of concussion than males per every 10,000 AE's (Marar et al., 2012). Although stated previously that women overall have a higher incidence rate than males in gender comparable sports, some high risk sports are not gender comparable such as football. In the year of 2012, 6.5 million individuals participated in contact football (Delgado F, September 2013). A study in 2007 that looked solely at football, quantified that the concussion rate for high school is 4.36 per every 1,000 Athlete Exposures (AE's), and 8.61 per every 1,000 AE's in college(Shankar et al., 2007). A second study conducted in 2007 similarly found the same increase, but largely lower rates (.23 per 1,000 AE's in high school, and .43 per 1,000 AE's in college) (Gessel, Fields, Collins, Dick, & Comstock, 2007). Overall, these studies reveal an upward trend in rate of concussions with higher level of scholastic play. This supported the notion that larger individuals generate larger forces to the head, and went against earlier findings in 2000 that found more than a 2 time increase in rate of concussion in high school (1.03 / 1,000 AE's) compared to Division I college (.49 / 1,000 AE's) (Guskiewicz et al., 2000). This will be discussed later. Outside of football, the prevalence of concussions in high school sports per every 1,000 AE's are boy's ice hockey (5.4), boy's lacrosse (4.0), and women's soccer (3.4) (Marar et al., 2012). Furthermore non-traditional sports such as rugby have had concussion rates much higher than any other analyzed sport. It has been reported that 13-17% of players sustain a concussion over the course of 3 rugby seasons (Gardner et al., 2014). However, current literature assessing this risk has various definitions of injury (Gardner et al., 2014). Taking that into account, the most reliable studies estimate

concussion rates in rugby are between 8.0 and 17.5/ 1,000 playing hours (Gardner et al., 2014). This would make rugby the highest risk sport for concussion per playing time.

As a percent of total injuries, concussions were higher in high school compared to college (Shankar et al., 2007) (Gessel et al., 2007). This often brings the question of fitness and skill level as a component in concussions. It has been shown in professional hockey players that there is statistical significance in playing time above 15.22 minutes/game and rate of concussion, but no significance in overall playing time in the season (Stevens, Lassonde, de Beaumont, & Keenan, 2008). This indicates that fatigue associated with in game duration of play, is independent of, and more significant than an athlete's exposure time over the course of a season (Stevens et al., 2008). Although these epidemiological factors are of importance, the only widely recognized risk factor for concussions is past history of concussions. Furthermore, as concussion history increases, so does risk. An individual who has sustained a previous concussion is 1.4 times more likely to have a repeat concussion, and those who have had 3 concussions are 3 times more likely (Guskiewicz et al., 2003). Other studies have shown that the relative risk for an individual to sustain a second concussion with the past history of one is up to 5.8 times greater than those without history of a concussion (Zemper, 2003). Lastly, cervical neck strength and stability has also been thought of to play a role in concussive risk. A study comparing male and female differences in response to external force to the head found that females activated a higher percent of their neck stabilizers, have higher peak activation, and stabilize more quickly than males (Tierney et al., 2005). However, females still had 39% greater angular head acceleration as a result from external force than males (Tierney et al., 2005). This was hypothesized to be greater in females due to lower neck isometric strength, and overall cervical muscle stiffness (Pellman, Viano, Tucker, & Casson, 2003; Tierney et al., 2005). However, this test only assessed

stability of the cervical segment, and did not account for the role that other segments play such as shoulder, trunk, and legs in stabilizing any segment during motion.

In order to analyze epidemiology, biomechanics, assessment, and postural deficits following concussion, a clear understanding of what the injury is must be established. The first accurately defined state of concussion was found by an Arabic Muslim physician named Rhazes in the year 900. Rhazes was the first to define concussion as an abnormal physiological state rather than a severe brain injury (P. R. McCrory & Berkovic, 2001). As the term came to grow in medicine, many tried to further define the condition (P. R. McCrory & Berkovic, 2001). It wasn't until the end of the Renassance that the "learned Doctor Read" had established the clinical symptoms and stages of concussions that are very accurate to what we know today (P. R. McCrory & Berkovic, 2001). His findings included: "singing of the ears", "falling after the blow", "swooning for a time", "slumbering after the wound is received", "dazzling of the eyes", and "a giddiness which passes rapidly" (P. R. McCrory & Berkovic, 2001). Today there are various definitions existing on what exactly a concussion is, but most recent statements orient around a common principle. According to the The 4th International Conference on Concussion (ICC):

> "Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces (P. McCrory, Meeuwisse, W. H., Aubry, M., Cantu, B., Dvořák, J., Echemendia, R. J., & ... McCrea, M., 2012).

These biomechanical forces result in many alterations in the brain. Several testing measures such as in vivo experiments of concussed animals, Transcranial Magnetic Stimulation,

Functional Magnetic Resonance Imaging, and Diffusion Tensor Imaging provide insight to these alterations.

In vivo experimentation in rats has helped contribute to what we now know as the "Neurometabolic Cascade" (Giza & Hovda, 2001). Surrounding the structure in the brain is the extracellular space. The extracellular space is an environment that is important for the delivery of oxygen and glucose to brain cells (Nicholson, 2001). After an impact, the brain is marked by significant metabolic alterations. First, impact and axonal stretching causes neuronal depolarization. This is followed by uncontrolled neurotransmitters release in the synaptic cleft of the nerves (Giza & Hovda, 2001). This causes a push of calcium into the nerve cells and an ejection of potassium out of the cells (Giza & Hovda, 2001). This switch leads to a reverse in polarity and widespread neuronal depolarization (Giza & Hovda, 2001). As a result, the sodium-potassium pump of the cell goes into overdrive as a counter measure to restore membrane potential (Giza & Hovda, 2001). As the pumps are working, they are continually requiring adenosine tri-phosphate (ATP) as a fuel source resulting in hypermetabolism (Giza & Hovda, 2001). Furthermore, aerobic energy pathways in the mitochondria are inhibited by the increase in intracellular calcium, so energy production relies on glycolysis (Giza & Hovda, 2001). This increases lactate as a by-product which can cause multiple negative affects such as: acidosis, neuronal dysfunction, damaging cell membranes, altering the blood brain barrier permeability, and increasing cerebral edema (Giza & Hovda, 2001). This is all happening at a time of decreased cerebral blood flow which can diminish by 50% (Giza & Hovda, 2001). This imbalance of energy supply, and demand can last for 7-10 days (Giza & Hovda, 2001).

Aside from the metabolic crisis following injury, there is a massive release of excitatory neurotransmitters such as glutamate. This massive excitation is followed by large scale spreading

neuronal depression that affects multiple areas of the brain simultaneously. This may be what is associated with loss of consciousness, post traumatic amnesia, or other cognitive alterations (Giza & Hovda, 2001). Aside from acute depression, a decrease in neuronal excitability has been reported in post-concussed individuals months after initial injury. Research using TMS, or Transcranial Magnetic Stimulation, to look at the excitability of the nerves in the primary motor cortex (M1) following concussion, found that when testing subjects muscle contraction that there was an increased amount of intracortical inhibition (De Beaumont L., 2011). An increase in intracortical inhibition means that there are alterations in the excitability of the nerves within the brain. This is represented by a Cortical Silent Period (CSP), or the duration between excitation and response of a nerve at different intensities. An increased CSP was found on average of 19 months following a concussion (De Beaumont L., 2011). Furthermore, the mechanism for this increase in CSP has been shown to prevent long-term motor learning in animals (McDonnell, Orekhov, & Ziemann, 2007; McNamara & Skelton, 1996). Therefore, not only are nerves in the brain less capable of firing, but may be less capable of storing and learning movements as well. Overall, In animal models the neurometabolic impairment lasts 7-10 days and is hypothesized to be what represents increased susceptibility to repeat head injury (Giza & Hovda, 2001). In 2003 this was backed by a study that showed 75% of repeat concussion occurred 7 days post initial impact, and 91.7% of repeat concussions occurred in 10 days (Guskiewicz et al., 2003).

Recent research using Diffusion Tensor Imaging can evaluate the micro-structural integrity of the white matter in the brain to provide a fractional anisotrophy value and amount of movement of water (Borich, Makan, Boyd, & Virji-Babul; Virji-Babul et al., 2013). In healthy individuals, water molecules moves through-out the extracellular and intracellular space in a random matter based off of diffusion. Diffusion in the extracellular space is not only important

for the movement of oxygen and glucose, but for synaptic transmission, neural excitability, and for re-uptake of neurotransmitters (Vorisek & Sykova, 2009). What Virji-babul et al found, was that there are alterations of diffusion in the brain following concussion (Virji-Babul et al., 2013). They found an increase in whole brain fractional anisotrophy, and decrease in average diffusivity values(Virji-Babul et al., 2013). This means that there was a significant change in the integrity of the white matter, and a decrease in overall water movement in the region. They stated that the forces resulting from an MTBI may lead to stretching of axons and alterations in the ion channels that could lead to an increased amount of intracellular water from the extracellular space (Virji-Babul et al., 2013).

As a result of neurometabolic alterations, concussions can present acutely in an individual with various signs and symptoms. This has made assessment measures for initial diagnosis, and for return to play decisions a largely researched area. Assessments can be grouped into 3 general categories: Symptom reporting, neuropsychological or neurocognitive assessment, and balance/coordination assessment. A commonly used concussion symptom assessment is the Graded Symptom Checklist (GSC). The GSC consists of a large number of symptoms in which each can be graded on a Likert scale from 0-6 (McCrea et al., 2005). Some of which include: loss of consciousness, confusion/ disorientation, headache, dizziness, amnesia, blurred vision, nausea, poor balance/coordination, drowsiness, dizziness, feeling "in a fog", ect. The most common symptoms presenting post-concussion are headache, dizziness, and confusion which present in 86, 67, and 59% of total concussions (Guskiewicz et al., 2000). The GSC is an accurate measure and has been assessed to have 89% sensitivity, and 100% specificity (McCrea et al., 2005). The GSC is the most sensitive stand-alone assessment, but has depends solely on truthfulness of the athlete or patient. As a whole, athletes are very knowledgeable when it comes to concussion

symptoms, however many would not want to stop playing if they were to experience concussion symptoms (Chrisman, Quitiquit, & Rivara, 2013). When asked why, the study found that external factors such athletes dealing with demanding coaches, or not wanting to let down the team were barriers to truthful concussion symptom reporting (Chrisman et al., 2013). This reliance on honestly may diminish the GSC's effectiveness in some settings where external barriers are present. Fitness level may also influence the severity of concussion symptom reporting. A study done in 2013, compared concussion symptom scores between college athletes at a high fitness level to students at a lower fitness level. They found that on average, higher fitness level individuals have 4.3 fewer concussion symptoms at baseline, 6.6 fewer symptoms post exertion, and 3.4 fewer symptoms 24 hours post exertion (Mrazik, Naidu, Lebrun, Game, & Matthews-White, 2013). This may mean that lower fitness individuals may inherently present with more post-concussive symptoms following exertion regardless of presence of concussion. When it comes to resolution of symptoms, 91% percent of individuals are asymptomatic by 7 days (McCrea et al., 2003). Some individuals have very short lived symptoms with 34% of concussed athletes being asymptomatic 1 day post injury and still experiencing neurocognitive impairment on the ImPact test (Broglio, Macciocchi, & Ferrara, 2007). This may cause a natural decline in the sensitivity of concussion symptoms as time progresses, and a heavier reliance on objective assessments of concussion. In some instances prolonged symptoms are present. Research has been done to identify groups of symptoms that may lead to increased length of recovery. Individuals suffering from symptoms in the "migraine cluster" are related to prolonged symptom recovery (Mihalik et al., 2013). This migraine cluster consists of a headache and at least one of the following symptoms: nausea, photophobia, or phonophobia (Mihalik et al., 2013).

The decline in postural stability following concussion is a hallmark sign. To acutely assess these changes, the Balance Error Scoring System (BESS) is done in 3 different positions: Single-leg stance, feet together, and tandem stance on a firm and foam surface for 20 seconds each. Errors are summed for a combined maximum of 60 errors. An increase in errors represents poorer postural stability. The sensitivity of the BESS test is 34%, but the specificity is 91-97%. However, there are a few things to consider when using the BESS. The Inter-rater reliability of each stance ranges from moderate to high (.44-.96) in adults, and testing should be done 3 times and averaged to improve reliability (Bell et al., 2011). The BESS test has been shown to detect postural deficits up to 3-5 days following concussion (Bell et al., 2011). Testing of the BESS can be effected by many things such as braces, tape jobs, hydration, age, and fatigue (Bell et al., 2011). Furthermore, post-season results may differ from pre-season by a average decrease in 2 errors (Burk, Munkasy, Joyner, & Buckley, 2013). Because of the inherent reliability issues with the BESS test, In order to detect postural changes the test statistically requires a 7.3 mean difference in errors when the same tester is measuring, and 9.4 mean point difference when using multiple testers (Finnoff, Peterson, Hollman, & Smith, 2009). This is extremely problematic being that the average change in BESS scores following concussions is 6 errors (Bell et al., 2011). This means that a poorer score representing a concussed athlete is on average a result of poor reliability in testing as opposed to actual change in postural stability.

The NeuroCom Smart Balance Master Sensory Organization Test, or the SOT, is also an assessment used for testing postural stability. A balance score change of 6.83 has been suggested to represents significant postural change, and has been identified as 61.9% sensitive in detecting deficiency with concussions (Broglio et al., 2007). A common limitation to the SOT is that it is a

very expensive non-portable unit. This often leaves the BESS test as the common postural stability assessment.

The IMPACT test has the highest stand-alone sensitivity of neurocognitive tests with 79.2%, and test-retest reliability has been shown to vary depending on the study ranging from .23-.75 (Broglio et al., 2007; J. Resch et al., 2013). ImPact is a computer based system which is easily affordable for most clinicians. Currently, 94.7% of Athletic Trainers administer baseline ImPact testing (Covassin T, 2009). However, it is worth noting that these responses came from only 32.7% of the total target population of Athletic Trainers (Covassin T, 2009). However, research has shown a 22.2% false positive rate of impact testing between baseline and second testing measure (J. Resch et al., 2013). When calculating a third ImPact test on individuals, the overall false positive rate was between 22-46% (J. Resch et al., 2013). This means that upon the second test, and increasing during the third, 46% of individuals may be falsely be identified as a concussed (J. Resch et al., 2013).

Lastly, all research agrees that a combined concussion assessment battery using testing measures from all categories is the most accurate measure for assessing concussions. Sensitivity of combined assessment (neurocognitive, postural control, and symptom inventory) ranges from 89-96% depending on neurocognitive measure used (Broglio et al., 2007).

Biomechanics of concussive blows have been a topic used to analyze the direction, magnitude, and effect of blows causing concussions. Typically, these variables are commonly expressed using linear acceleration, rotational acceleration, location of impact, force, velocity, impulse, and impact duration (Broglio et al., 2009). When looking at these impact variables amongst different groups in football, the NFL had an average linear head acceleration of 98g's, average impact velocity of 9.3m/s, 7.2m/s average change in head velocity, an average peak

rotational acceleration of 6,432 rad/s2, and average impact duration of 15milliseconds (Pellman, Viano, Tucker, & Casson, 2003). However, for comparison purposes these results were found from laboratory reconstructed impacts compared to later studies which mainly use the Head Impact Telemetry (HIT) system. The HIT system is a group of accelerometers that fit inside a Ridell helmet and analyze and record impacts in real time during play. Using the HIT system, NCAA football players the average concussion had a higher linear acceleration the NFL with 102.8g's (Guskiewicz, Mihalik, et al., 2007). Although you may expect this number to decrease in high school and younger athletes, non-concussive impacts are comparative to those seen in college and the NFL. High school impacts have been shown to average 24.7g's in games which is greater than the average seen in Division 1 college which is 21-23g's (Broglio et al., 2009; Mihalik, Bell, Marshall, & Guskiewicz, 2007). Furthermore, impacts in youth football aging 7-8 years old had linear accelerations ranging from 10-100g's with an average impact of 18g's (Daniel, Rowson, & Duma, 2012). This potentially goes against the argument that the bigger, faster, and stronger individuals hit harder and cause more concussions. When taking the impact data and looking for their relationship to concussion we see that linear acceleration, not rotational acceleration has a higher correlation of .62 compared to .56 (Pellman, Viano, Tucker, & Casson, 2003). Lastly, calculations can be made using linear acceleration, among other components, to create a severity index (SI), or a Head Injury Criteria (HIC). Both measures have been shown to be highly connected to concussions with a correlation of .68 for SI, and .70 for HIC (Pellman, Viano, Tucker, & Casson, 2003).

Where a player is hit, or strikes his head also influences the severity of force. Players who use the top portion of their head are 6.5 times more likely to register an impact above 80g's (Guskiewicz, Mihalik, et al., 2007). This is an issue as Pellman et al reports that 78% (Q3 +Q4)

of striking players hit with the top of their head. However none of the impacts of striking players reviewed in Pellman's research resulted in a concussion (Pellman, Viano, Tucker, Casson, & Waeckerle, 2003). In Pellman's findings, one can extrapolate that although striking player's impact velocity was slightly greater than the struck players, their average change in head velocity, and linear acceleration was roughly half of that suffered by that of the struck players (Pellman, Viano, Tucker, Casson, et al., 2003). This is due to two factors. One is because the striking player just before impact aligns his head, neck, and torso in order to "drive through" the opposing player (Pellman, Viano, Tucker, Casson, et al., 2003). Secondly, players are able to detect impact better when the "closing angle" is within 0-30 degrees (Pellman, Viano, Tucker, Casson, et al., 2003). This closing angle falls within "Category A" of Pellman et al.'s study. Category A impacts are from 0-45 degrees of the facemask and helmet. These impacts represented 67% of all impacts to the facemask, but only represented 36% of the overall concussion sample (Pellman, Viano, Tucker, Casson, et al., 2003). This shows that most concussive impacts are outside the detectable closing angle. Category B alone, which is just outside the closing angle (45-90 degrees) represented 40% of total concussions (Pellman, Viano, Tucker, Casson, et al., 2003). Further evidence is Category A, out of the 4 categories, had the highest impact velocity, but lowest resultant change in head velocity, and linear acceleration (Pellman, Viano, Tucker, Casson, et al., 2003). This likely results from a stuck player's ability to detect impact and brace in anticipation. It is also worth noting that Category D, falls to the back of the head, resulted in the most severe head response with an average change in head velocity of 8.4m/s, and linear acceleration of 117g's (Pellman, Viano, Tucker, Casson, et al., 2003). This is likely due to the rebound of the head as hits the ground (Pellman, Viano, Tucker, Casson, et al., 2003). Last but not least, height of impact has a great deal to do with concussive blows. 76% of

concussive impacts to the facemask were below the heads center of gravity, and 79% of impacts by helmets and 89% of impacts by other parts or ground hit the shell above the center of gravity (Pellman, Viano, Tucker, Casson, et al., 2003). This shows an upward shift of concussive impacts from facemask to rear of the head.(Pellman, Viano, Tucker, Casson, et al., 2003)

Postural control following concussion is an area of continual research. It is reported that 30% of concussions result in balance deficits (Guskiewicz, 2011). However, this research has been largely played down due to the use of the Balance Error Scoring System (BESS) which as stated prior has substantial issues with reliability that raise question to the test's overall sensitivity (Bell et al., 2011; Finnoff et al., 2009). Postural stability defines the body's ability to maintain a desired position either statically or dynamically in response to internal or external perturbations (Cavanaugh, Guskiewicz, & Stergiou, 2005). Postural stability is a complex task using a combination of the visual, somatosensory, vestibular, and motor system (Guskiewicz, 2011; Shaw, 2002). Changes in these systems post-concussion are believed to be due to functional neurophysiological changes in the cortex and brainstem reticular formation (Shaw, 2002). After integration of sensory information, the brain is responsible for producing an appropriate motor response to achieve balance. Aside from motor response, cognition is also important in balance. Normally, the addition of a cognitive task such as a question and answer combined with a motor task produces enhanced effects. Improvements in both balance and cognitive response were seen above that of each assessment individually when combining the dual task of cognitive plus balancing on the SOT (Broglio, Tomporowski, & Ferrara, 2005). Furthermore, by combining an auditory cognitive function component balance scores improved in two categories of the SOT, and by an overall mean composite improvement of 1.8 (J. E. Resch, May, Tomporowski, & Ferrara, 2011). However, during dual task there were longer

response times as well as an increase in the rate of response errors during which goes against

prior stated research (J. E. Resch et al., 2011). This study showed that cognitive function

bolstered postural control, but when one system had to "give" balance was maintained at the

expense of the cognitive function (J. E. Resch et al., 2011). Although there are various theories

on the relationship between cognition and balance, the relationship is still somewhat unknown.

One such theory is that when an individual switches tasks from balance to cognition, balance

transitions from a focused cognitive task to more of a sensorimotor task (Broglio et al., 2005).

This is believed to create more natural balance. The relationship between cognition and motor

tasks following concussion has been assessed to have a correlation of .63, and unlike before this

relationship decreases performance (Sosnoff et al., 2008). Assessing cognitive task and gait

analysis found concussed individuals have longer gait durations, a decreased COM motion peak

velocity in the anterior/posterior direction, and an increase in medial/ lateral sway (Sosnoff et al.,

2008). All of these differences were magnified between single task and dual task in concussed

group. This effect shows that concussed individuals may be adopting a more cautious gait in an

attempt to control center of mass displacement during motion (Sosnoff et al., 2008).

One measurement used to assess deficits in static postural control is the use of linear

dynamics which focus on the magnitude or intensity of perturbation (Cavanaugh et al., 2005). An

alteration in linear dynamics is believed to represent disruption in this feedback loop. Nonlinear

dynamics are less concerned with magnitude of perturbations, and more concerned with patterns

of variability in center of pressure movement (Cavanaugh et al., 2005). Approximate entropy

(ApEn) is the amount of randomness in an individual's center of pressure captured on a force

plate (Gao, Hu, Buckley, White, & Hass, 2011). Research of ApEn following concussions has

shown that in the acute phase of injury, approximate entropy in the anterior/posterior direction is

worse in concussed groups as opposed to controls (Cavanaugh et al., 2005). In one study using

Shannon & Renyi entropies that analyze the total area of COP were used over a time span of 2

minutes (Gao et al., 2011). Results showed an increase of entropy covered by movement in COP

has been noticed in concussed athletes at least 10 days post injury (Gao et al., 2011). These

studies conclude that amount of area traveled and randomness of COP movement occurs as a

result of concussions. There is also evidence of an increase in COP movement velocity during

static stance in a concussed group versus control (Powers et al., 2013). This increase was even

higher when concussed group did static stance with eyes closed (Powers et al., 2013). This

increase in COP velocity during static stance may be an indicator of poor balance. It is

hypothesized that an increase in COP velocity indicates a greater muscle response in attempts to

control displacement of the center of mass (COM) (Powers et al., 2013).

Most literature agrees that an increase in COP changes correlates to a decrease in postural

control, however there is some conflicting research. Cavanaugh et al explains how COP location

while standing is not the result of "random error." That irregular and erratic oscillations are

hidden signals of orderliness that result from interactions among postural control systems

(Cavanaugh et al., 2005). Evidence supports that as age progresses and in disease situations,

there is an increase in regularity not irregularity of COP oscillations (Bodfish, Parker, Lewis,

Sprague, & Newell, 2001; K., 1998). This would postulate that lower ApEn values result in

worse postural control.

When using these methods to assess gait and dynamic postural stability following

concussion there is a separation between results of lower cost assessments and those in a

laboratory. Using terminal gait analysis on force plates, concussed participants showed

alterations in gait patterns at least 10 days post injury despite being cleared by traditional

assessments. These altered gait patterns displayed lowered gait velocity, propulsive %, and breaking % (Buckley et al., 2013). This change in gait was further exacerbated up to 28 days when combined with a cognitive task (Buckley et al., 2013; Catena et al., 2007a; Parker et al., 2006). This decrease in walking speed represents a more cautious gait which may be an effort to allow COP enough time to control the COM during movement.(Powers et al., 2013) Even more disturbing, altered gait has been seen years later in individuals with a past history of concussions (Martini et al., 2011). Those with a history of concussions still represented more cautious gait strategies with a .1 meter per second decrease in gait velocity, a greater time spent in double leg support, and a decrease time in single leg support (Martini et al., 2011). Furthermore, lingering deficits in dynamic postural control have been seen 30 days post injury using virtual reality to assess visualkinesthetic integration (Slobounov et al., 2007). These studies not only show the difference between dynamic and static assessments, but the need for a more sensitive postural stability field test that detects the changes well past the 3-5 day window of the BESS test. Currently, the equipment used for these more sensitive assessments are seen almost exclusively in laboratory settings.

The overall injury rate in competitive collegiate athletics is 63.1 per every 10,000 Athlete Exposures (Yang et al., 2012). Furthermore, distinction between acute and chronic injuries has found that almost 3/4ths of injuries that occur are chronic (Yang et al., 2012). Injury in athletics can result in loss time in participation, alterations in activities of daily living, emotional disturbances, increase in healthcare costs, and an increased risk of repeat injury. For this reason, continual research has been done to identify further risk factors associated with acute and chronic injuries in sports. The Functional Movement Screen (FMS) was developed by Gray Cook and Lee Burton to identify those at risk for injury by assessing compensatory movement patterns

(Cook, 2010). It does this by assessing bi-lateral symmetry, mobility, and stability across the body (Cook, 2010). There are seven tests in the FMS: 1) Deep squat, 2) hurdle step, 3) inline lunge, 4) shoulder mobility test, 5) active straight-leg raise, 6) trunk stability, and 7) rotary stability (Cook, 2010). Five of the seven tests are scored unilaterally testing one side at a time (Cook, 2010). The remaining two measures, deep squat and trunk stability push-up, are scored as a whole (Cook, 2010). An individual has three attempts to perform each test, and raw scores on each individual task range from 0-3. If any pain is present the individual is instructed to stop the movement and a score of 0 is given. Scoring a one is when an individual is unable to perform the movement with the standards to achieve a 2. A score of 2 is given when there is an inability to perform the movement standards of a 3, or ability to perform standards of three is met with a modification to the movement. A score of 3 indicates the unquestioned ability to perform the movement as intended with no modifications. Raw scores carry the number of the lowest scoring side of an individual movement (Cook, 2010). Therefore, if an individual scores a 2 on their left hurdle step, but a 3 on their right, a total raw score of 2 is awarded. A final composite score is given once all scores are graded and added together (Cook, 2010).

The FMS has been mostly validated in literature to predict an increased risk for injury. In 2005, 46 NFL players were baseline tested with FMS and tracked during the course of the season (K. Kiesel et al., 2007). Those players under 14 points were associated with an 11 fold increase in the chance of injury, and a 51% probability of sustaining a serious injury over the course of the competitive season (K. Kiesel et al., 2007).This study advocated the use of a 14 points cut-off score, in which 22% of their population fell at or below (K. Kiesel et al., 2007). Although the population and population size of this study creates a serious limitation, there is further supporting research to these findings. A study conducted on 38 female Division II athletes in

three different sports found that 48% of athletes who sustained injuries scored at or below

15points, 72% of individuals who were injured scored at or below 14 points, and 81% scored at

or below 13 points (Chorba et al., 2010). Chorba et al using the 14point scale had a sensitivity of

.579, specificity .737, positive likely hood ratio of 2.0, and odds ratio 3.85 (Chorba et al., 2010).

Correlation of test score and injury was .781, and when predicting lower extremity injury the

sensitivity rose to .952 when subtracting the shoulder mobility test (Chorba et al., 2010). One

major limitation to this study was the loose injury criteria which implied that injury did not have

to follow an injury diagnosis, but any individual seeking "advice" from an athletic trainer, or

athletic training student was deemed injured. Lastly, individuals representing movement

asymmetry or side to side differences on the FMS likewise represent risk of injury. A movement

score below the 14 point cut-off combined with at least one movement asymmetry represented a

relative risk of 1.80 and increased specificity of .87 (K. B. Kiesel et al., 2014). However, not all

literature has shown significance between FMS score and injury (B. M. Wiese, ATC, LAT;

Boone, J. MS, ATC, FMSC; Mattacola, C. PhD, ATC; McKeon, P. PhD, ATC, CSCS; Uhl, T.

PhD, ATC, PT, 2014). One study showed only a modest increase in odds ratio of 1.45 and

likelihood ratio of 1.15 (B. M. Wiese, ATC, LAT; Boone, J. MS, ATC, FMSC; Mattacola, C.

PhD, ATC; McKeon, P. PhD, ATC, CSCS; Uhl, T. PhD, ATC, PT, 2014).

Inter-rater reliability of the Functional Movement Screen is between 0.38-0.97, and

intrarater reliability is .92 (Chorba et al., 2010; Schneiders et al., 2011; Shultz R., 2013). One

study extrapolated reliability by having 6 different testers score the videos which received an

Inter Class Correlation, or ICC, of .38 (Shultz R., 2013). However, this low value of reliability

may be due to fact that there were a total of six different scorers. More practical studies have

used only two separate scorers to evaluate inter-rater reliability, and found an ICC of .976 and

.971 (Chorba et al., 2010; Schneiders et al., 2011). Taking this into account, the reliability of the FMS is very good when using one to two testers to score results. Scorer experience with FMS also plays a role in reliability. Individuals who have under 1 year of experience are surprisingly more reliable than those with experience greater than 1 year (Shultz R., 2013). Furthermore, greater reliability comes from testers with equal level of experience (Schneiders et al., 2011). Lastly, different individual movements are more or less reliable. Of the most reliable are the Active Straight Leg Raise and the Shoulder Mobility Test (Chorba et al., 2010). The least reliable test is the Inline Lunge, and studies are split when determining if the Hurdle Step test is the most or least reliable (Chorba et al., 2010; Shultz R., 2013).

Now that we know the use and accuracy of the test, research has been conducted to analyze the normative values in a likely population. Current literature shows that there is an upward trend in composite FMS score and level of play.(K. Kiesel et al., 2007; Schneiders et al., 2011) Scheiders et al took 200 individuals from club sport teams, and the general student population and tested them on the FMS (Schneiders et al., 2011). Their results showed that the average combined test score was 15.7 out of 21 (Schneiders et al., 2011). They also found that 31% of their population fell at or below the 14 point cut off (Schneiders et al., 2011). This normative composite score similar but slightly lower to that seen in NFL players (16.9) (K. Kiesel et al., 2007). Between gender the FMS varies very little in combined scores, but has sub-categorical differences (Schneiders et al., 2011). Tests that rely heavily on mobility such as, active straight leg raise and shoulder mobility test are performed much better in females than in males (Schneiders et al., 2011). Conversely, males perform better in strength based tests such as the trunk stability push up in which 76.2% of males record a 3 compared to 58% of females who record a 1 (Schneiders et al., 2011). However, only the rotary test showed statistical significance

between males & females. Although 88% of all participants scored a 2 on this test, on average

males scored higher. This leads us to believe that males have better strength and core stability

than females (Schneiders et al., 2011). Although statistical significance for gender was noted at 4

out of the 7 scores, the average composite score varies very little (M=15.8, F=15.6) (Schneiders

et al., 2011). Age, physical activity, Body Mass Index (BMI), and past history of injury seem to

be a factor in the ability to complete the FMS. Age is negatively correlated with composite score

(r= -.27), and on average decreases .1 units for every year of age (Peate et al., 2007; Perry &

Koehle, 2013). Physical activity is positively correlated to FMS score (r=.26) (Perry & Koehle,

2013). Body Mass Index has been found negatively correlated with FMS in numerous studies,

and has been seen as high as r= -.806 (Duncan & Stanley, 2012; Peate et al., 2007; Perry &

Koehle, 2013). Body weight most highly effects the deep squat and shoulder mobility test with

normal weight children performing much better than those who were obese (Duncan & Stanley,

2012). Together physical activity and BMI score accounted for 60.2% of variance in FMS score

in children (Duncan & Stanley, 2012). Studies assessing past history of injury and current FMS

score have mostly found no significance (Peate et al., 2007; Schneiders et al., 2011). However,

using linear regression as opposed to logistic, significance was found between past history of

injury and composite score in Firefighters (Peate et al., 2007). Further, after accounting for age

there was a 1.68x greater risk for scoring below 16 in Firefighters with a past history of injury

(Peate et al., 2007).

One limitation of the FMS is the lack of participant knowledge on grading criteria during the

time of testing. One group of firefighters first performed the FMS without any prior knowledge

and then a second time immediately after receiving the FMS grading criteria (Frost et al., 2013).

Once the participants knew what was being graded the group scores improved on average 2.6

points (Frost et al., 2013). Significant improvements were noted in 4 of the 7 tests: Deep Squat, Hurdle Step, In-line Lunge, and Shoulder Mobility Test (Frost et al., 2013). These findings raise question on what the most accurate methods of obtaining true functional ability is.

Despite its design as a screen for risk of injury, the FMS has also been studied for predicting on field performance. Currently research debating this application both supports and denies the FMS's role in performance evaluation. Parchmann et al found no correlation to FMS test and performance in golfers on field tests such as: 10 meter sprint, 20 meter sprint, vertical jump height, agility t-test, and club head velocity during swing (Parchmann & McBride, 2011). Similar findings discovered that the In-Line Lunge test has no correlation to maximal jump height, 36.6 meter sprint time, and COP measures (Hartigan et al., 2014). A longitudinal study with track athletes found that those with FMS scores above 14 points positively correlated with improved performance (Chapman, Laymon, & Arnold, 2014). An interesting alternative finding was that athletes with a bilateral asymmetry did not improve as well as those without (Chapman et al., 2014).When looking at the kinematic and kinetic differences between individuals who score 1-3 on the Deep Squat movement, clear range of motion and force production variations exist between groups (Butler, Plisky, Southers, Scoma, & Kiesel, 2010). Individuals who score below a 3 on the deep squat have overall lower ankle dorsiflexion, knee flexion, and hip flexion ranges of motion during the test (Butler et al., 2010). Not only do they possess lower functional ranges, but the force production is higher in areas such as peak ankle plantarflexion, and lower in knee and hip extension. Individuals scoring a 3 on the deep squats had the highest peak force production in their quadriceps out of all scoring groups (Butler et al., 2010). This may show that individuals scoring a 3 truly do have greater functional range of motion and stability. Lastly, unlike COP, FMS score has been seen to remain consistent between pre to post exertion testing

(Clifton, Harrison, Hertel, & Hart, 2013). This shows that exertion does not affect FMS testing ability (Clifton et al., 2013).

   In conclusion, concussion is a complex devastating injury in the United States with many possible lingering deficits such as late life neurological and motor complications. Currently, only laboratory type assessments are useful in detecting motor changes post-concussion. This leaves the need for a low cost sensitive assessment tool. Currently, no study has been done assessing if these motor changes put individuals at a higher risk for future musculoskeletal injury. Although the FMS is not a perfect test, it is validated in predicting an increased risk for injury by assessing gross movement patterns. Further, because gross dynamic movement requires a large amount of sensory feedback and motor response from the brain the FMS may serve as a valuable tool in assessing changes in complex movements. No current studies have been done using the FMS as an identifier of risk or as an assessment of dynamic postural and motor control in individuals with a history of concussions compared to those without.

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APPENDIX C

TABLES AND FIGURES

Table 1. Movement Grading Criteria

Movement	"3"	"2"	"1"	"0"
Deep Squat	-Upper torso remains parallel with the tibia or toward vertical - Femur is below horizontal - Knees remain aligned over feet - Dowel stays aligned over feet	-Upper torso remains parallel with the tibia or toward vertical - Femur is below horizontal - Knees are aligned over feet - Dowel is aligned over feet -Heels are elevated	- Tibia and upper torso not parallel - Femur is not below horizontal -Knees are not aligned over feet - Lumbar flexion is noted	-The individual receives a score of zero if pain is associated with any portion of this test.
Hurdle Step	-Hips, knees and ankles remain aligned in the sagittal plane -Minimal to no movement is noted in lumbar spine -Dowel and hurdle remain parallel	-Alignment is lost between hips, knees and ankles -Movement is noted in lumbar spine -Dowel and hurdle do not remain parallel	-Contact between foot and hurdle occurs -Loss of balance is noted	-The individual receives a score of zero if pain is associated with any portion of this test.
Inline Lunge	-Dowel contacts maintained -Dowel remains vertical -No torso movement noted -Dowel and feet remain in sagittal plane -Knee touches board behind heel of front foot	-Dowel contacts not maintained -Dowel does not remain vertical -Movement noted in torso -Dowel and feet do not remain in sagittal plane -Knee does not touch behind heel of front foot	-Loss of balance is noted	-The individual receives a score of zero if pain is associated with any portion of this test.
Shoulder Mobility Test	-Fists are within one hand length	-Fists are within one-and-a-half hand lengths	-Fists are not within one and half hand lengths	- The individual receives a score of zero if pain is

				associated with any portion of this test.
Active Straight Leg Raise	-Vertical line of the lateral malleolus passes past the dowel that is placed equidistant from the patella and ASIS -The non-moving limb remains in neutral position	-Vertical line of the lateral malleolus passes the patella of the non-moving limb, but does not pass the dowel -The non-moving limb remains in neutral position	-Vertical line of the malleolus resides below patella -The non-moving limb remains in neutral position	- The individual receives a score of zero if pain is associated with any portion of this test.
Trunk Stability Push-Up Test	-Men perform a repetition with thumbs aligned with the top of the head -Women perform a repetition with thumbs aligned with the chin - there is minimal trunk sway -The body lifts as a unit	-The body lifts as a unit with no lag in the spine -Men perform a repetition with thumbs aligned with the chin -Women with thumbs aligned with the clavicle	-Men are unable to perform a repetition with hands aligned with the chin -Women unable with thumbs aligned with the clavicle	- The individual receives a score of zero if pain is associated with any portion of this test.
Rotary Stability Test	- To flex and extend the hip and shoulder on the same side over the board - minimal trunk sway noted	- Participant can perform a diagonal touch with opposite elbow and knee - The elbow and knee must touch over board	- Inability to perform a diagonal repetition	- The individual receives a score of zero if pain is associated with any portion of this test.

Table 2. Descriptive Statistics

Descriptive Statistics

	Mean	Std. Deviation	N
Composite	15.7636	2.36458	55
Concussion	1.0364	1.10493	55
BMI	27.2731	6.44567	55
Age	20.0364	1.49026	55
DS	2.0000	.72008	55
HS	2.2545	.47990	55
ILL	2.4909	.60470	55
SMT	2.4000	.76012	55
ASLR	2.3636	.64875	55
TSPU	2.4364	.73946	55
RST	1.7818	.53371	55

Table 3. Correlationn

	Composite	Concussion	BMI	Age	DS	HS	ILL	SMT	ASLR	TSPU	RST
Composite	1	.131	-.546**	.055	.642**	.478**	.588**	.600**	.395**	.452**	.472**
Sig. (2-tailed)		.341	.000	.690	.000	.000	.000	.000	.003	.001	.000
Concussion	.131	1	.178	.224	.047	.227	-.027	.071	.007	.252	-.049
Sig. (2-tailed)	.341		.194	.100	.736	.096	.844	.609	.959	.063	.722
BMI	-.546**	.178	1	.260	-.350**	-.330*	-.467**	-.432**	-.122	.056	-.384**
Sig. (2-tailed)	.000	.194		.055	.009	.014	.000	.001	.377	.685	.004
Age	.055	.224	.260	1	-.035	.013	-.164	.069	-.014	.305*	.033
Sig. (2-tailed)	.690	.100	.055		.802	.927	.231	.618	.920	.024	.808
DS	.642**	.047	-.350**	-.035	1	.268*	.298*	.237	.079	.139	.289*
Sig. (2-tailed)	.000	.736	.009	.802		.048	.027	.082	.565	.311	.032
HS	.478**	.227	-.330*	.013	.268*	1	.136	.122	.173	.099	.221
Sig. (2-tailed)	.000	.096	.014	.927	.048		.323	.376	.206	.474	.105
ILL	.588**	-.027	-.467**	-.164	.298*	.136	1	.250	.009	.258	.166
Sig. (2-tailed)	.000	.844	.000	.231	.027	.323		.066	.950	.058	.226
SMT	.600**	.071	-.432**	.069	.237	.122	.250	1	.113	.079	.310*
Sig. (2-tailed)	.000	.609	.001	.618	.082	.376	.066		.413	.566	.021
ASLR	.395**	.007	-.122	-.014	.079	.173	.009	.113	1	.049	-.034
Sig. (2-tailed)	.003	.959	.377	.920	.565	.206	.950	.413		.722	.805
TSPU	.452**	.252	.056	.305*	.139	.099	.258	.079	.049	1	-.083
Sig. (2-tailed)	.001	.063	.685	.024	.311	.474	.058	.566	.722		.548
RST	.472**	-.049	-.384**	.033	.289*	.221	.166	.310*	-.034	-.083	1
Sig (2-tailed)	.000	.722	.004	.808	.032	.105	.226	.021	.805	.548	.000

Figure 1. Informed Consent

<u>**College Of Health And Human Services**</u>

<u>**Department Of Health and Kinesiology**</u>

<u>INFORMED CONSENT</u>

1. My name is Jordan Dorrien, and I am the Graduate Assistant Athletic Trainer for Campus Recreation and Intramurals. I am also working towards my Master's Degree in Kinesiology-Athletic Training at Georgia Southern University.

2. The purpose of this study is to assess the prediction of risk with concussive, and non-concussive injury using the "Functional Movement Screen". The Functional Movement Screen, or FMS, has been used to identify individuals at risk for injury, and we would like to assess its prediction in concussions as well. Furthermore, we wish to assess how functional movement scores may change following the incident of a concussion.

3. All individuals who participate in this study will be asked to complete a health history questionnaire before initial baseline FMS testing. The test entails 7 movements: Deep Squat, In-Line Lunge, Rotary Stability Test, Stability Push-Up, Shoulder Mobility Test, Hurdle Step, and Active Straight Leg Raise. This test will take 15 minutes to administer to each participant. All participants will be monitored, and asked to report to Lead Investigator or CRI Athletic Training Staff with any injuries or concussions sustained over the course of the season. Recognition of a concussion will be determined by initial evaluation and assessment from a CRI Athletic Trainer or overseeing Athletic Trainer if in Georgia Southern University Athletics, followed by evaluation of a physician who will make ultimate diagnosis. Upon recognition of concussion, participant will undergo 3 additional test administrations: 1) within 48 hours of injury 2) upon return to play and 3) 30 days post concussion. However, initial 48 hour testing following recognition of a concussion may be done prior to physician diagnosis. Inclusion of this data into research will be pending physician diagnosis. FMS testing will not be used as a standard of care, assessment for, or to grade the severity of a concussion. All information gathered by testing will be used solely for the purposes of this research. Any participant who does not sustain a diagnosed concussion will not be asked to complete testing beyond initial baseline. All testing will be conducted at the Recreational Activities Center. I, if chose to participate in this study, understand that all testing will be video recorded for further analysis in this study. This analysis will be used to determine validity of the on-site scoring, and will be kept confidential by Lead Investigator. These videos will be safely stored, and no personal identifiers will be associated with them.

4. As a participant in this study, I understand that this research poses minimal risk, due to its administration of bodyweight movements. Although challenging to perform correctly, these movements are functional in nature and closely resemble activities commonly done by an athletic population. However, there is potential for risk of falling when performing movements such as hurdle step, in line lunge, and deep squat post concussion, which require a certain level of balance

and coordination. These risks do not exceed that of common concussion assessment protocols for balance. However, to reduce potential risk during testing, the tester will closely monitor subject within a "spotting" distance in order to intervene in a case of extreme loss of balance. As the inability to complete a movement or maintain balance is part of the grading, each movement in the test must be attempted. If at any time during the test, the participant does not wish to continue testing they may notify the Lead Investigator (Jordan Dorrien) and discontinue their participation.

"I understand in the event of injury resulting from research that medical care is available. However, neither financial compensation nor free medical treatment is provided. All necessary medical expenses are at the responsibility of me the subject. Should medical care be required, I may contact Health Services at (912) 478 – 5641.

5. As a participant in this study, I understand that as a benefit of participating in this research, I have upon request, access to my FMS scores after the conclusion of this research study. These scores can help direct training to reduce risk of future injury. I understand that the Lead Investigator, Jordan Dorrien ATC-LAT, can make training recommendations based off these results that may benefit my risk for injury. I understand that as a team, my coaches will receive a group averaged score which may prove helpful in their decisions for future strength and conditioning.

6. As a participant in this study, I understand that initial baseline testing will take approximately 15 minutes to administer. Furthermore, I understand that I will communicate to the CRI Athletic Training Staff, and Lead Investigator, on injuries or concussions sustained during the season. Upon incident of concussive injury, participant will complete a series of 3 additional tests which may increase the duration of time spent to 1 hour of total testing. I also understand that due to the last testing day being 30 days post concussion, additional time may be spent if school or sport is not in session.

7. As a participant in this study, I understand that all data concerning myself will be kept confidential and available only upon my written request to Jordan Dorrien ATC-LAT. I understand that any information about my records will be handled in a confidential (private) manner consistent with medical records to the extent permitted by law. My identity on all records will be indicated by a case number. I will not be specifically mentioned in any publication of research results. However, I understand that research records may in some cases be inspected by appropriate government agencies or released pursuant to a law or other legal directive. All information and research records will be kept for a period of five years after the termination of this investigation.

8. As a participant in this study, I have the right to ask questions and have those questions answered. If I have questions about this study, contact Jordan Dorrien ATC-LAT at (973)-879-5172, or the researcher's faculty advisor John Dobson, Phd., whose contact information is located at the end of the informed consent. For questions concerning my rights as a research participant, I can contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843.

9. There is no compensation associated with participation in this study.

10. As a participant in this study, I understand that I do not have to participate in this project and my decision to participate is purely voluntary. At any time I can choose to end my participation by telling the primary investigator, Jordan Dorrien.

11. As a participant in this study, I understand that I may terminate participation in this study at anytime without prejudice to future care or withholding of benefits of knowing my initial test results. Investigator may in his/her absolute discretion terminate the procedures and/or investigation at any time

12. As a participant in this study, I understand that there is no deception in this study.

13. As a participant in this study, I certify that I am 18 years of age or older and that I have read the preceding information, or it has been read to me, and understand its contents. Any questions I have regarding the research have been, and will continue to be, answered by the investigators listed at the beginning of this consent form or at the phone numbers given (973) 879 – 5172.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H14231.

Title of Project: The Role of the Functional Movement Screen in the Risk and Assessment of Concussion

Principal Investigator: Jordan Dorrien ATC-LAT

Injury Prevention and Care- Campus Recreation and Intramurals

(973) 879-5172 Jd05907@georgiasouthern.edu

Other Investigator(s): John Dobson, Phd

Hollis Building – Room 1103B

(912) 478-8541 jdobson@georgiasouthern.edu

 Faculty Advisor: John Dobson, Phd

Hollis Building – Room 1103B

(912) 478-8541 jdobson@georgiasouthern.edu

_____   _____

Participant Signature   Date

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

_____   _____

Investigator Signature   Date

Figure 2. Participation Health Questionnaire

Participation Health Questionnaire

| Subject Code: _____ | | Sport:_____ |
| Age:_____ | Gender:_____ | Height:_____ Weight:_____ |

1) Have you ever had a concussion?   Yes   No

     If so, when was your last concussion _____

2) How many total concussions have you had? _____

3) Have you sustained a concussion in the past 4 weeks?   Yes   No

4) Outside of a diagnosed concussion, have you ever been knocked out while

   playing your sport?   Yes   No

     If yes, how many times has this happened? _____

5) Outside of a diagnosed concussion, have you ever suffered from Amnesia

   (memory loss) after being struck in the head?   Yes   No

6) Have you ever had your "bell rung" or "dinged" following a hit to the head while

   playing your sport that did not lead to the diagnosis of a concussion? Yes   No

7) Have you ever suffered from:

Spinal Injury		Yes	No
Shoulder Injury	Left	Right	Yes
No			
Elbow injury	Left	Right	Yes	No
Ankle Injury	Left	Right	Yes	No
Knee Injury	Left	Right	Yes	No
Hip Injury	Left	Right	Yes	No

If yes, please explain your injury/injuries with date of occurrence:

_____

_____

_____

____

    Does the injury still limit your balance?   Yes   No

    Does the injury still limit your strength?   Yes   No

    Does the injury still limit your flexibility?   Yes   No

    Did you receive surgery for injury, and when?   Date:_____   Yes   No

8) Are you currently suffering from an injury?   Yes   No

    If so, what is the injury? _____

    Is this injury resulting in loss of activity or sport?   Yes

        No

9) Have you ever been diagnosed with;

    A balance disorder?   Yes   No

    Metabolic disorder?   Yes   No

    Neurological Disorder?   Yes   No

    Vestibular Disorder?   Yes   No

10) Do you have any medical condition that may prevent you from participating in this

    study?   Yes   No

11) Do you currently take any medications that effect your balance?   Yes   No

    If yes to any of the prior three questions, please briefly describe condition and or medication.

_____

_____

_____

_____

I, the undersigned, agree that the above is complete and to the best of my knowledge.

_____   _____

Participant Signature   Date
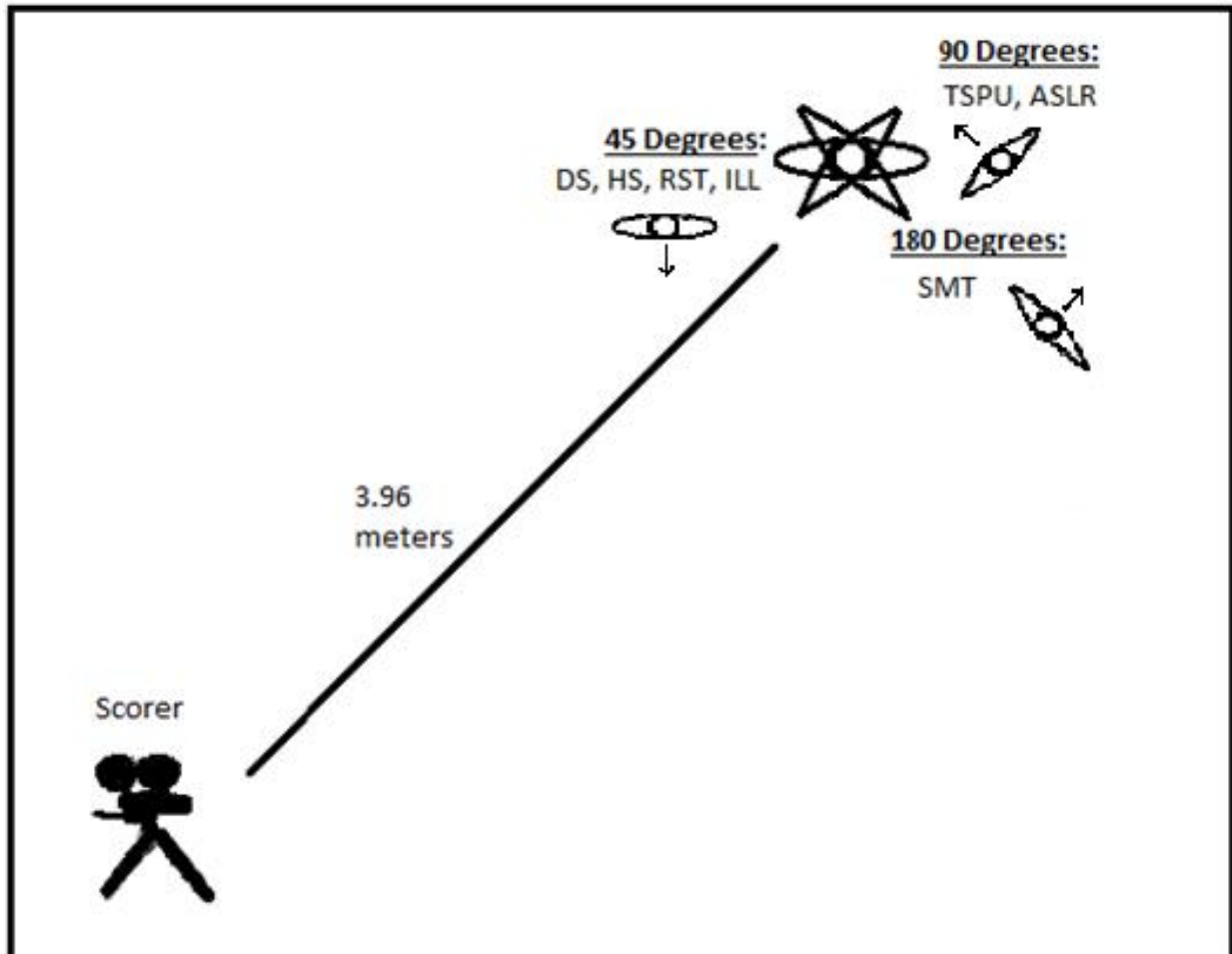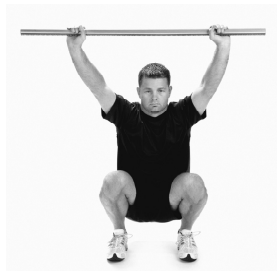
Figure 4. Testing Display

Figure 3. Description of Movements

A. When performing the deep squat the participant places the instep of their feet in alignment with their shoulders. With the dowel overhead the participant is asked to descent into a deep squat with the heels on the floor and feet facing forward.


Modification: If any of the criteria for a score of three are not achieved, ask the individual to perform the test with the board from the earlier described FMS kit under the heels.

B. When performing the hurdle step the hurdle step cord is placed at the height of the tibial tuberosity. With the dowel across the back and toes touching the base of the hurdle, the participant with a tall spine steps over the hurdle with one leg and touches the back of the heel to the floor then returns to starting position.

C. Place the dowel behind the back, touching the head, thoracic spine and sacrum. The client's hand opposite the front foot should be the hand grasping the dowel at the cervical spine. The other hand grasps the dowel at the lumbar spine. The dowel must maintain its vertical position throughout both the downward and upward movements of the lunge test. To perform the inline lunge pattern, the client lowers the back knee to touch the board behind the heel of the front foot and returns to the starting position.
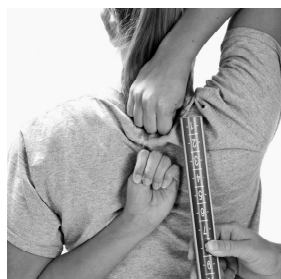
D. Determine the client's hand length by measuring the distance from the distal wrist crease to the tip of the longest digit. The client will stand with the feet together, and make a fist with each hand, thumbs inside the fingers. The client then simultaneously reaches one fist behind the neck and the other behind the back, assuming a maximally adducted, extended and internally rotated position with one shoulder, and a maximally abducted and externally rotated position with the other.

E. Find the point between the anterior superior iliac spine (ASIS) and the joint line of the knee, and place a dowel at this position, perpendicular to the ground. Next, the individual lifts the test limb while maintaining the original start position of the ankle and knee. The opposite knee should remain in contact with the board; the toes should remain pointed upward in the neutral position, and the head remains flat on the floor. Once reaching the end-range, note the position of the upward ankle relative to the non-moving limb.
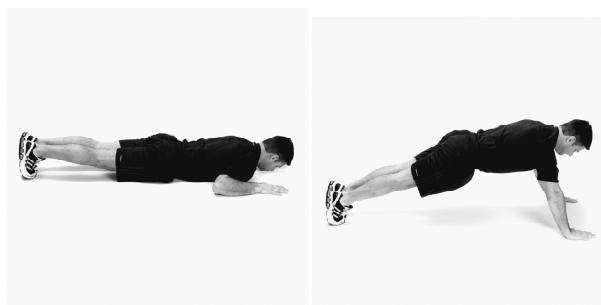
F. The individual assumes a prone position with the arms extended overhead. During this test, men and women have different start positions. Men

begin with their thumbs at the top of the forehead, while women begin with their thumbs at chin level. The thumbs are then lowered to the chin or shoulder level per the scoring criteria. The knees are fully extended, the ankles are neutral and the soles of feet are perpendicular to floor. The individual then performs the push-up in specified position. The body should be lifted as a unit; there should be no sway in the spine during this test. If the individual cannot perform a pushup in the initial position, the hands are lowered to an easier position.

 G. The individual assumes a quadruped position with a board, either the FMS kit board or one of similar size, on the floor between the hand and knees. The board should be parallel to the spine, and the shoulders and hips should be 90 degrees relative to the torso, with the ankles neutral and the soles of the feet perpendicular to the floor. Before the movement begins, the hands should be open, with the thumbs, knees and feet all touching the board. The client should flex the shoulder while extending the same-side hip and knee, and then bring elbow to knee while remaining in line over the board.
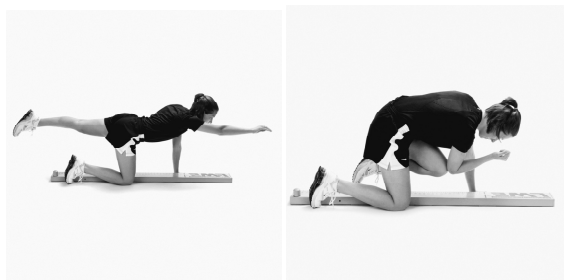
 Modification: If a score of three is not attained, have the person perform a diagonal pattern using the opposite shoulder and hip in the same manner described above. During this diagonal variation, the arm and leg need not be aligned over the board; however, the elbow and knee do need to touch over it.