EXAMINATION OF CONCUSSIONS AND THEIR EFFECT ON FUNCTIONAL MOVEMENT SCREEN SCORES IN COLLEGIATE ATHLETES

by

Sarah A. Roger

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Exercise Science

Spring 2018

© 2018 Sarah A. Roger
All Rights Reserved
EXAMINATION OF CONCUSSIONS AND THEIR EFFECT ON
FUNCTIONAL MOVEMENT SCREEN SCORES IN COLLEGIATE
ATHLETES

by

Sarah A. Roger

Approved:
Thomas W. Kaminski, Ph.D., ATC, FNATA, FACSM, RFSA
Professor in charge of thesis on behalf of the Advisory Committee

Approved:
John J. Jeka, Ph.D.
Chair of the Department of Kinesiology and Applied Physiology

Approved:
Kathleen S. Matt, Ph.D.
Dean of the College of Health Sciences

Approved:
Ann L. Ardis, Ph.D.
Senior Vice Provost for Graduate and Professional Education
ACKNOWLEDGMENTS

This project could not have been complete without the help and support of many people over the past two years. First, I would like to thank my committee chair and advisor, Dr. Thomas Kaminski, as well as my Ph.D. Mentors Bethany Wisthoff and Kelsey Bryk for their extensive time, support, and guidance through this process. This project would not have been complete without their assistance through all aspects of this project including its development, and especially the writing process. Additional thanks are in order for Dr. Joseph Glutting for his extensive assistance with the statistical analysis process as well Dr. Thomas Buckley for all of his help with how to approach and manage the data diving process.

I would also like to thank Ted Perlak and the Strength and Conditioning Staff as well as Dan Watson and the entire Athletic Training Staff for all of their assistance with gathering of data and records. Additionally to Nikki Lounsberry for her endless support and mentorship of my aspirations over my time here, as well as my fellow Graduate students for their words of encouragement and friendship throughout these two years. Finally I would like to thank my Family and Friends not only for their constant support through the difficult times but for pushing me to stick to my goals and motivating me to be my best everyday.

I would lastly like to recognize all of the student-athletes from the University of Delaware who agreed to have their information included in this project thereby making this study possible.
# TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................ vi
LIST OF FIGURES ...................................................................................................... vii
ABSTRACT .................................................................................................................. viii

Chapter

1  INTRODUCTION .................................................................................................. 1

2  METHODS .............................................................................................................. 6
   2.1 Experimental Approach to the Problem ......................................................... 6
   2.2 Participants ..................................................................................................... 6
   2.3 Procedures ..................................................................................................... 8
   2.4 Statistical Analysis ....................................................................................... 10

3  RESULTS ............................................................................................................... 11
   3.1 Concussion vs. FMS Scores .......................................................................... 11
   3.2 Concussion vs. Control .............................................................................. 12
   3.3 Concussion History vs. FMS ...................................................................... 13

4  DISCUSSION ......................................................................................................... 15
   4.1 Concussion vs. FMS Scores .......................................................................... 15
   4.2 Concussion vs. Control .............................................................................. 16
   4.3 Concussion History vs. FMS ...................................................................... 18
   4.4 Limitations ................................................................................................... 20
   4.5 Conclusion ................................................................................................... 20

REFERENCES ......................................................................................................... 22

Appendix

A  LITERATURE REVIEW ...................................................................................... 28
   A.1 Introduction .................................................................................................. 28
   A.2 Epidemiology & Pathology ......................................................................... 29
   A.3 Assessment and Diagnosis ......................................................................... 30
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.4 Deficits in Postural Control</td>
<td>30</td>
</tr>
<tr>
<td>A.5 History of Concussion</td>
<td>34</td>
</tr>
<tr>
<td>A.6 Injury Risk</td>
<td>36</td>
</tr>
<tr>
<td>A.7 Return-To-Play</td>
<td>37</td>
</tr>
<tr>
<td>A.8 Functional Movement Screen</td>
<td>39</td>
</tr>
<tr>
<td>A.9 Conclusion</td>
<td>47</td>
</tr>
<tr>
<td>A.10 References</td>
<td>49</td>
</tr>
<tr>
<td>B IRB DOCUMENTS</td>
<td>56</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.1: Demographic Information ................................................................. 7
Table 2.2: Concussions by Sport ......................................................................... 8
Table 3.1: FMS Scores for Concussion Group Across Time Points ..................... 11
Table 3.2: FMS Scores Across Groups .................................................................. 12
Table 3.3: FMS Scores Across Concussion History Groups ............................... 13
LIST OF FIGURES

Figure 3.1: FMS Composite Score Across Concussion History Groups.................. 14

Figure A.1: Example of a Stepwise Progression for RTP Following a SRC$^3$ ............ 39
ABSTRACT

It is estimated that between 1.6 and 3.8 million concussions are sustained annually in the United States from sport and recreational activity alone, with 3.9% of National Collegiate Athletic Association (NCAA) athletes experiencing a concussion each year. While impairments in postural control, including static and dynamic balance, are known acute effects of a concussion, there has been evidence in recent studies hypothesizing that these deficits may persist beyond the initial 5-10 day recovery stage. One commonly used measure of overall movement quality in collegiate athletics involves the Functional Movement Screen (FMS) however its’ use in concussion management has not been thoroughly examined. Therefore, the purpose of this study was to retrospectively compare FMS scores in a group of concussed and non-concussed student-athletes. Concussion injury history as well as FMS baseline data from the 2015-2017 academic years, were retrospectively analyzed. Concussion history and baseline FMS scores were derived from a large database. The FMS composite score (ranging from 0-21) as well as the individual component scores (ranging from 0-3) were derived for each subject. The independent variables were group status: concussed vs. control, previous concussion history, and baseline 1 (B1) vs. baseline 2 (B2) FMS test time points. The dependent variables were the FMS component and composite scores. Our results showed no statistical differences between FMS composite scores from B1 to B2, or between groups. Interestingly, the
deep squat component score was significantly different within the concussion group, actually showing improvement from B1 to B2. The results of our study provide further evidence in support of the current literature suggesting that FMS scores have little to no ability to detect lingering functional movement deficits up to one year post concussion. Those responsible for athlete performance and wellbeing may need to look at other measures of functional movement such as the tandem gait task, or other balance and strength measurements; to better recognize potential movement deficiencies, that may pose potential risks for student-athletes returning to sport.
Chapter 1

INTRODUCTION

It is estimated that between 1.6 and 3.8 million concussions are sustained annually in the United States from sport and recreational activity alone, with rates reported as high as 0.45 concussions per 1000 athlete exposures. Recently, concussion has become a major public health concern in the United States and although significant advances have been made in the understanding and education of concussions, long term physiological recovery is not well understood. While concussion pathophysiology is still not fully understood, past research on animal models has hypothesized that the energy deficit, and resulting cell death that occurs in the brain following a concussion, may be the cause of slowed cognition and reaction time. New research has been examining causal linkages between the acute and chronic pathophysiological changes that may result in long-term deficits.

Prior research has demonstrated an increased risk for musculoskeletal injury (MSK) in individuals with a prior history of concussion. Lynall et al. in 2015 demonstrated an increased risk post-concussion within one year compared to before concussion and matched controls (1.97x and 1.67x increase respectively) in a cohort of division I (D-I) college athletes. In addition, Nordström et al. in 2014 found that not only does injury risk increase acutely post-concussion, but also continues to increase within one year of concussion for subsequent injury. The authors reported that from the six month to one-year period there was a 3.69x increase risk for acute injury, and a 7.94x increased risk for gradual onset injury. Similarly, Gilbert et al. in
2016 identified that athletes who sustained a concussion were more likely to sustain a musculoskeletal injury than those who don’t with odd ratios ranging from 1.6 to 2.9 increased odds.\textsuperscript{11} Overall, current research speculates that post-concussion motor control deficits may predispose athletes to lower extremity MSK injuries.\textsuperscript{12}

While impairments in postural control, including static and dynamic balance, are known acute effects of a concussion,\textsuperscript{2,4,13–15} there has been evidence in recent studies that these deficits may persist beyond the typical 5-10 day recovery stage.\textsuperscript{2,13,16–18} Similarly, research examining post-concussion gait has suggested the presence of compensatory movement strategies occurring in individuals with a history of concussion.\textsuperscript{14,15,17,19,20} It has been proposed that these conservative strategies are adopted because of increased postural instability following a concussion thereby decreasing the risk of instability during less stable phases of gait.\textsuperscript{20–22} These previously undetected impairments in movement patterns suggest that the brain, as well as potentially the vestibular, visual, and motor systems may not be fully healed or that compensatory strategies are being utilized, which may play a role in the increased risk of injuries seen in athletes post-concussion.\textsuperscript{9–11,23–26}

The ability to recognize and potentially reduce these movement deficiencies is of great importance in the sports medicine community in order to decrease the risk of athletes returning-to-play before they are fully recovered and decrease subsequent injury rate.\textsuperscript{4,13,23} Best practice currently recommends that all athletes undergo a multifaceted post-concussion assessment including but not limited to the evaluation of mental status/ cognition, oculomotor function, gross sensorimotor function, coordination, vestibular function and balance prior to finalizing a return-to-play (RTP) decision.\textsuperscript{4,5,13,24,27} While there are a number of tests currently used to evaluate
neurocognitive function, clinical tests used to assess functional movements and coordination are limited to the use of the Balance Error Scoring System (BESS) test and, more recently, the tandem gait task (TGT).\textsuperscript{13,23,28} These assessment tools used post-concussion may not provide enough information to assist clinicians in determining whether an individual is clinically prepared to RTP. Despite being one of the most commonly used tests in college athletics,\textsuperscript{29} the BESS test has been shown to return to baseline values within 3-5 days post injury and has a low sensitivity of 0.34.\textsuperscript{30,31} Additionally, the test has been shown to be greatly influenced by the environment in which it is performed, as well as demonstrated a large learning practice effect along poor intra-rater and inter-rater reliability.\textsuperscript{32–34} In contrast, the TGT has been shown to identify the presence of compensatory movement strategies up to two weeks post concussion when comparing single versus dual task completion.\textsuperscript{35} While the test does have a small learning effect over multiple trials and moderate sensitivity, it does not seem to be affected by concussion history, sport, or gender.\textsuperscript{36,37} Since the TGT is a novel post-concussion assessment, literature is limited and the test is not yet widely used throughout the medical community.

Unlike current movement assessment tools, the Functional Movement Screen (FMS), a seven-part screening tool, assesses gross movement patterns, flexibility, and range-of-motion. Limitations and asymmetries can be identified by placing the individual in extreme positions where weaknesses and imbalances become apparent due to deficiencies in mobility and motor control.\textsuperscript{38,39} Each of the seven components are scored individually on a 0-3 scale with a total possible score of 21.\textsuperscript{39} This tool is common place among strength and conditioning specialists (CSCS) and athletic trainers to assess changes over the course of a season/athletic career, and as an
indicator for RTP readiness following injury.\textsuperscript{40-44} Due to it’s reported ability to identify deficiencies in movement patterns, there has been a surge in research involving the FMS over the last ten years concerning it’s ability to identify individuals with a risk for a MSK injury with the majority of studies indicating conflicting and limited evidence.\textsuperscript{40,41,45-47} Hegedus et al. concluded that in NCAA D-I athletes, poor hip stability, active motion and motor control as assessed by physical performance tests such as those evaluated with the FMS, predicted injury.\textsuperscript{48} Similarly, a study published by Boyle et al. suggested that both adolescents and adults who had undergone ACL reconstruction scored below the cut off composite score of 14 for injury risk, despite having passed all other objective tests and being fully cleared for RTP participation from their health care providers and/or sports medicine teams.\textsuperscript{49} Dorrien et al. were the first to assess the relationship between FMS and concussion history and identified no relationship.\textsuperscript{44} The authors concluded that the FMS was not an effective tool to identify postural control deficits, if present, in a collegiate population. However, to our knowledge, there is no study that examines the effect of a concussion on FMS scores compared with baseline data.

Therefore, the aims of the current investigation were tri-fold. Firstly, to determine the changes in FMS scores over a one-year period when a concussion was experienced between baselines. We hypothesized that there would be a significant difference in FMS composite and component scores for the concussed group of individuals at the annual baseline testing compared to the previous year. Our second aim was to examine if a difference in FMS scores exist between collegiate athletes who have experienced a concussion during the academic year to their matched controls. We hypothesized that there would be a significant difference in composite
and component FMS scores between the concussed and control groups. Thirdly, we examined the effect previous concussion history had on FMS composite and component scores. In agreement with the results of Dorrien et al., we hypothesized that there would be no significant differences amongst both composite and component FMS scores across all concussion history groups (0, 1, 2, 3 or more).
Chapter 2

METHODS

2.1 Experimental Approach to the Problem

This retrospective cohort study analyzed component and composite FMS scores obtained at the start of each academic year, for subjects that sustained a concussion between two FMS baselines when compared to a non-concussed control group.

2.2 Participants

Subjects for this study were identified from a pool of 600+ male and female student-athletes (SA) from a local NCAA D-I institution. Regardless of academic year, those who are or were previously participating in varsity sports during the 2015-2017 seasons were included. Subjects with a history of concussion were invited to participate if their concussion was experienced between baseline FMS tests collected in the fall of 2015, 2016, and 2017. Control subjects were SA’s that were identified if they matched a concussed SA for sport, sex, and if possible, age and position. Prior concussions that occurred before the initial FMS baseline testing (B1), for SA’s in either the concussed or control group, were not considered for exclusion criteria. All potential subjects identified for inclusion were at least 18 years of age at the time of FMS baseline testing and provided informed consent (UD IRB # 990857-1).

Student-athletes were excluded from either the control or concussed group if they met any of the following exclusion criteria: those that had no baseline FMS scores, any individual that experienced a significant upper or lower extremity injury
(surgery or time loss of greater than one month) within 6 months of baseline testing, any individual who had not been cleared for full RTP at the time of baseline FMS screening. Additionally, control subjects were excluded if they were diagnosed with a concussion between FMS baseline collections.

A total of 88 concussions were experienced by 81 SAs over the course of the two-year study period. Of these, 42 SAs were missing baseline FMS data while 5 were excluded due to not being fully cleared for RTP at the time of FMS testing (due to date of concussion, surgery or significant upper or LE injury). A total of 65 subjects (23 males, 42 females) were included in this analysis (Table 2.1). Four control subjects were matched to multiple concussed subjects resulting in 70 total observations.

Table 2.1: Demographic Information

<table>
<thead>
<tr>
<th>Sport</th>
<th>Subjects</th>
<th>Age (Y)*</th>
<th>Height (cm)*</th>
<th>Mass (Kg)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concussed</td>
<td>34</td>
<td>19.6 ± 1.1</td>
<td>173.7 ± 9.1</td>
<td>75.7 ± 20.9</td>
</tr>
<tr>
<td>Control</td>
<td>31</td>
<td>19.6 ± 1.0</td>
<td>174.1 ± 11.0</td>
<td>73.4 ± 19.6</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>19.6 ± 1.0</td>
<td>173.9 ± 10.0</td>
<td>74.6 ± 20.2</td>
</tr>
</tbody>
</table>

* Values are represented as means ± standard deviations

Three of the subjects suffered two concussions in a one-year time period while one subject experienced a concussion during both years of the study. In the event a SA experienced multiple concussions between baselines, the athlete was not considered multiple times in the outcome variables of the analysis. A breakdown of the number of injuries by sport can be seen in Table 2.2.
Table 2.2: Concussions by Sport

<table>
<thead>
<tr>
<th>Sport</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseball</td>
<td>3</td>
</tr>
<tr>
<td>Football</td>
<td>4</td>
</tr>
<tr>
<td>M Lacrosse</td>
<td>4</td>
</tr>
<tr>
<td>M Tennis</td>
<td>1</td>
</tr>
<tr>
<td>Field Hockey</td>
<td>2</td>
</tr>
<tr>
<td>W Rowing</td>
<td>2</td>
</tr>
<tr>
<td>Softball</td>
<td>1</td>
</tr>
<tr>
<td>W Swimming &amp; Diving</td>
<td>2</td>
</tr>
<tr>
<td>W Track &amp; Field</td>
<td>2</td>
</tr>
<tr>
<td>W Volley Ball</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

M= Men’s; W=Women’s

2.3 Procedures

Data concerning concussion history were collected through the SA’s annual concussion baseline assessment completed prior to their season as part of the university’s standard concussion care plan. In addition, concussion and MSK injury history were tracked and monitored through SportsWare Online (SWOL), which has been used to monitor athletic-related injuries diagnosed by a certified athletic trainer. Annual FMS composite and component scores were obtained through the data collection efforts associated with this study.

*Functional Movement Screen*

FMS testing was conducted in August, at the beginning of each academic year, from 2015-2017, by level-1 FMS certified CSCS. A reliability analysis was completed separately, prior to data analysis, on ten, random subjects who were consented and recruited to complete FMS testing and were filmed during this analysis. Two raters
(CSCS) conducted all pre and post-testing on each subject. Each rater independently scored the 10 subjects prior to repeating the process through video recording one week later in a random order. This process was then repeated another week later for a total of three scores per subject per rater. A high intra-rater reliability was determined for both CSCS evaluated with rater 1 demonstrating an Interclass Correlation Coefficient (ICC) of 0.975 (95% CI: 0.93-0.99) and rater 2 with an ICC of 0.967 (95% CI: 0.90-0.97). Additionally, the inter-rater reliability of the FMS demonstrated a high reliability with an ICC of 0.972 (95% CI: 0.93-0.99).

In this study, all SAs were screened on all seven components of the FMS, creating a composite score ranging from 0-21. The seven components of the FMS include the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and the rotary stability test as described by Cook et al.\textsuperscript{38,39} Each of the seven FMS components were individually scored from 0 to 3 with specific criteria for each maneuver consistent with FMS protocols. A “3” is awarded if the participant met all movement criteria, a “2” given if the student-athlete is unable to meet all of the given criteria, while a “1” was given if the participant is unable to complete the movement at all. Finally, a “0” was scored anytime a participant reported pain regardless of movement performance.\textsuperscript{38,39} Three clearing exams were performed at the end of the shoulder mobility, trunk stability push up, and rotary stability as per standard testing procedures. These movements are not scored; the tests are simply performed to observe a pain response. If pain is produced, a score of zero is given for the test. These clearing exams are necessary as shoulder impingement and back pain can go undetected during regular movement screening.
2.4 Statistical Analysis

Statistical analyses were performed using Statistical Package for Social Sciences (IBM SPSS Statistics, version 24.0, Armonk, NY: IBM Corp) with significance set a priori at $p<.05$. The independent variables were: group (concussed vs. control), previous concussion history, and time of Baseline 1 vs. Baseline 2 (B1 vs. B2). The dependent variables were the seven component FMS scores and FMS composite score. For the first aim, a paired dependent t-test was run to determine the difference between FMS scores across baselines for the concussed group.

For the second aim, a two-group growth curve was performed to determine the difference between FMS scores in those that have versus have not experienced a concussion during the academic year for both component and composite scores. Covariates included: matched control group, sex, height, weight, and age.

For the third aim, a one-way ANOVA was used to determine the effect of previous concussive history on FMS composite and component scores. All subjects were categorized based on the number of previous concussions experienced (0, 1, 2, 3 or more) at the most recent FMS baseline (B2). Only the most recent FMS baseline was accounted for with the one subject who experienced a concussion during both years of our study. Descriptive statistics were calculated to determine normality of the data.
Chapter 3

RESULTS

3.1 Concussion vs. FMS Scores

There were no significant differences in FMS composite scores between baseline time points (p=0.865, t=-0.172). The deep squat score was significantly different between the two baselines, (B1: 1.47 ± 0.51, B2: 1.82 ± 0.73, p=0.029). There were no significant differences between the remaining component scores. FMS raw data are provided in Table 3.1.

Table 3.1: FMS Scores for Concussion Group Across Time Points

<table>
<thead>
<tr>
<th></th>
<th>Baseline 1</th>
<th>Baseline 2</th>
<th>p-value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite FMS</td>
<td>15.0 ± 1.8</td>
<td>15.1 ± 2.0</td>
<td>0.865</td>
<td>(-0.73, 0.62)</td>
</tr>
<tr>
<td>Deep Squat*</td>
<td>1.5 ± 0.5</td>
<td>1.8 ± 0.7</td>
<td>0.029</td>
<td>(-0.67, -0.41)</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>1.8 ± 0.4</td>
<td>1.9 ± 0.4</td>
<td>0.431</td>
<td>(-0.43, 0.19)</td>
</tr>
<tr>
<td>In-Line Lunge</td>
<td>1.9 ± 0.4</td>
<td>1.9 ± 0.6</td>
<td>0.718</td>
<td>(-0.28, 0.40)</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>2.4 ± 0.6</td>
<td>2.1 ± 0.9</td>
<td>0.172</td>
<td>(-0.14, 0.73)</td>
</tr>
<tr>
<td>Active Leg Raise</td>
<td>2.6 ± 0.5</td>
<td>2.7 ± 0.5</td>
<td>0.718</td>
<td>(-0.40, 0.28)</td>
</tr>
<tr>
<td>Push-Up</td>
<td>2.7 ± 0.5</td>
<td>2.6 ± 0.8</td>
<td>0.431</td>
<td>(-0.19, 0.43)</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>2.0 ± 0.0</td>
<td>1.9 ± 0.2</td>
<td>0.332</td>
<td>(-0.07, 0.18)</td>
</tr>
</tbody>
</table>

Values are represented as means ± standard deviations
* = Significant difference between baseline time points, p<0.05
Composite FMS Scores N=35, B1 component scores n=20, B2 component scores n=28
The average number of days from initial FMS testing to concussion was 147.1 ± 88.3 days with a minimum of 12 days and maximum of 273 days. Time from concussion injury to follow up FMS testing was on average 208.9 ± 95.9 days with a minimum of 15 days and maximum of 354 days.

3.2 Concussion vs. Control

The overall mean FMS composite score across all subjects in this study was 15.19 ± 1.7. The mean FMS composite score was 15.0 ± 1.9 for concussed individuals and 15.3 ± 1.5 for healthy controls. Component and composite FMS scores for both groups are provided in Table 3.2.

Table 3.2: FMS Scores Across Groups

<table>
<thead>
<tr>
<th></th>
<th>Concussed</th>
<th>Control</th>
<th>p-value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B1</td>
<td>B2</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td>Composite FMS</td>
<td>15.0 ± 1.8</td>
<td>15.1 ± 2.0</td>
<td>15.5 ± 1.5</td>
<td>15.2 ± 1.5</td>
</tr>
<tr>
<td>Deep Squat</td>
<td>1.5 ± 0.5</td>
<td>1.8 ± 0.7</td>
<td>1.7 ± 0.7</td>
<td>1.9 ± 0.6</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>1.8 ± 0.4</td>
<td>1.9 ± 0.4</td>
<td>2.0 ± 0.2</td>
<td>2.0 ± 0.5</td>
</tr>
<tr>
<td>In-Line Lunge</td>
<td>1.9 ± 0.4</td>
<td>1.9 ± 0.6</td>
<td>2.0 ± 0.0</td>
<td>2.1 ± 0.5</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>2.4 ± 0.6</td>
<td>2.1 ± 0.9</td>
<td>2.5 ± 0.7</td>
<td>2.6 ± 0.6</td>
</tr>
<tr>
<td>Active Leg Raise</td>
<td>2.6 ± 0.5</td>
<td>2.7 ± 0.5</td>
<td>2.5 ± 0.6</td>
<td>2.5 ± 0.5</td>
</tr>
<tr>
<td>Push-Up</td>
<td>2.7 ± 0.5</td>
<td>2.6 ± 0.8</td>
<td>2.6 ± 0.5</td>
<td>2.5 ± 0.6</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>2.0 ± 0.0</td>
<td>1.9 ± 0.2</td>
<td>2.0 ± 0.0</td>
<td>1.8 ± 0.4</td>
</tr>
</tbody>
</table>

Values are represented as means ± standard deviations
* = Significant difference between baseline time points, p<0.05
Composite FMS Scores N=35 B1 component scores n=20, B2 component scores n=28

Within both the concussion and control groups, 15 subjects were missing FMS component data at B1, while 7 subjects were missing data for B2. No significant
interaction was found between the concussed individuals and their matched controls for composite FMS score. Furthermore, there was no significant difference between the concussion group and control group on any of the individual composite scores.

3.3 Concussion History vs. FMS

64 subjects were categorized into groups based on prior concussion history (0, 1, 2, 3+). Twelve subjects did not have individual component scores. The sample sizes reported in Table 3.3 are the total number of subjects analyzed in each group.

Table 3.3: FMS Scores Across Concussion History Groups.

<table>
<thead>
<tr>
<th>Hx</th>
<th>0 (n=26)</th>
<th>1 (n=26)</th>
<th>2 (n=7)</th>
<th>3 or More (n=5)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite FMS</td>
<td>15.1 ± 1.5</td>
<td>14.9 ± 1.9</td>
<td>15.3 ± 2.0</td>
<td>15.4 ± 2.0</td>
<td>0.902</td>
</tr>
<tr>
<td>Deep Squat</td>
<td>1.9 ± 0.6</td>
<td>1.8 ± 0.7</td>
<td>1.7 ± 0.8</td>
<td>2.0 ± 0.0</td>
<td>0.869</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>2.0 ± 0.5</td>
<td>2.0 ± 0.6</td>
<td>2.2 ± 0.4</td>
<td>2.0 ± 0.0</td>
<td>0.834</td>
</tr>
<tr>
<td>In-Line Lunge</td>
<td>2.1 ± 0.6</td>
<td>2.0 ± 0.6</td>
<td>2.2 ± 0.8</td>
<td>1.8 ± 1.0</td>
<td>0.739</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>2.7 ± 0.6</td>
<td>2.4 ± 0.8</td>
<td>2.0 ± 0.9</td>
<td>2.8 ± 0.5</td>
<td>0.133</td>
</tr>
<tr>
<td>Active Leg Raise</td>
<td>2.5 ± 0.5</td>
<td>2.5 ± 0.5</td>
<td>2.7 ± 0.5</td>
<td>2.8 ± 0.5</td>
<td>0.637</td>
</tr>
<tr>
<td>Push-Up</td>
<td>2.5 ± 0.6</td>
<td>2.4 ± 0.8</td>
<td>2.7 ± 0.5</td>
<td>2.5 ± 1.0</td>
<td>0.843</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>1.8 ± 0.4</td>
<td>1.9 ± 0.3</td>
<td>1.8 ± 0.4</td>
<td>1.8 ± 0.5</td>
<td>0.749</td>
</tr>
</tbody>
</table>

Values are represented as means ± standard deviations
Hx = Prior Concussion History

A range of 0-4 prior concussions was reported for the concussion group while a range of 0-1 was present in the control group. There were no significant differences in FMS composite score between the groups (Figure 3.1). Additionally, there were not
differences in individual component FMS scores between the concussion history groups.

Figure 3.1: FMS Composite Score Across Concussion History Groups.
Chapter 4

DISCUSSION

4.1 Concussion vs. FMS Scores

The overarching theme of this project was to investigate the long-term effects of concussion on FMS scores within a cohort of NCAA division I student-athletes (SA). The FMS has previously been used to identifying movement pattern deficits in an athletic population which may or may not help to identify increased risk for injuries.\textsuperscript{39,41,47,50} We hypothesized that the FMS might be a useful tool in identifying lingering movement deficits in some athletes, up to one-year post concussion.\textsuperscript{9–11,14,16,20,51} Our results however, suggest that the FMS is unable to identify deficits if present, in adequate functional movement patterns which may affect a safe RTP, in our cohort of SAs.\textsuperscript{9–11,49}

Our first aim was to determine the changes in FMS scores over a one-year time point when a concussion was experienced between baselines. We hypothesized that there would be no difference in FMS composite or component scores in the concussed SAs at the annual baseline testing time point compared to the previous year. Our results demonstrated no significant difference between B1 and B2 in support of our hypothesis. Even though the deep squat component score was significantly different within the concussed group, (Table 3.1) the cohort actually improved at the second time-point, however, this improvement was not clinically significant (1.5 to 1.8 out of 3) in that an overall average score below a 2 indicated SAs were still unable to meet all movement criteria. This increase might be explained by the common focus placed upon proper double-leg squat form in traditional strength and conditioning lifting
sessions throughout the course of a sport season. Supporting this, an increase was additionally seen within our control group (1.7 to 1.9) despite the increase not being significantly different.

The absence of significant change in the majority of FMS component scores and FMS composite score suggests that SAs may be able to maintain their gross functional movement patterns post-concussion, over the one year period, despite previous research demonstrating changes in the smaller motions of postural control with more precise assessment tools.\textsuperscript{15,19,51,52} It is important to note that all of our athletes were cleared for RTP post concussion. Alternatively, this test may not be sensitive enough to detect the long-term balance and gait problems/deficiencies that have been shown to arise following a concussion in SAs.\textsuperscript{14,17,53,54}

One restriction of the current FMS, is the broad range of conditions that would cause an individual to score a value of “2” in each of the component tests. The wide range of faults that can lead to a score of “2” makes it so there may be inconsistencies between subjects scoring a “2”. While the multi-joint nature of most of the component tests exposes the subject weaknesses and imbalances, thereby to a lower score, the deficiencies may not be substantial enough to limit the athlete from doing the movement entirely and being scored as “1”. This would lead to similar group scores across participants and could greatly affect the ability of the screen to pick up in changes of movement quality.

4.2 Concussion vs. Control

The second aim of our study was to examine differences in FMS scores between collegiate athletes that have experienced a concussion during the academic year to their matched controls. We hypothesized that there would be no significant difference
between the composite FMS scores of the concussed and control groups. Our results support this hypothesis showing no significant interaction between our two groups between baselines for component or composite FMS scores.

Our concussed group had a mean composite score of 15.0 while our healthy-control group had a composite score of 15.3. These numbers differ slightly from previous research by Kiesel et al. and Warren et al. comparing pre-baseline FMS composite scores of MSK injured vs. non-injured athletes.46,55 For the injured group both Kiesel et al. and Warren et al. reported an FMS value of 14.3, slightly lower than that found in our study with an average of 15.0 in our concussed group. In the non-concussed control group, our score of 15.3 fell between the scores of 14.1 and 17.4 reported by Warren et al. and Kiesel et al. respectively.

In 2015, a report by Mayer et al. compared FMS scores of cleared vs. not cleared individuals following anterior cruciate ligament (ACL) reconstruction surgery at the 6-month follow-up.56 The authors reported that patients in the cleared group exhibited a similar score on the FMS compared with the non-cleared group.56 They point to the fact that while no standardized RTP guidelines exist after ACL reconstructive surgery in the athletic population, clinical impairment measures do not appear to be related to measured functional ability. Despite concussions having very specific RTP guidelines, these results compare closely to our report demonstrating no significant difference in FMS scores between concussed and control individuals at re-baseline testing. Similar with the results of the first aim, this lack of difference between groups may indicate that post-concussion, individuals are still able to maintain proper movement patterns.
4.3 Concussion History vs. FMS

Our third aim examined the effects of previous concussion history on FMS composite and component scores. We hypothesized that there would be no significant differences in either composite and component FMS scores across all concussion history groups (0, 1, 2, 3 or more), which was supported by our results. The overall mean FMS score in this study (15.2 ± 1.7) was similar to previously reported mean composite scores of college aged SAs (13.7 to 16.9)\textsuperscript{44} and was consistent across concussion histories.

In 2015, Dorrien et al. were the first to assess the relationship between FMS and concussion history in collegiate club athletes. The authors reported no relationship between prior concussion history and either composite or component scores;\textsuperscript{44} which supports the results of our study. Interestingly and in contrast with our data, their data appeared to be approaching significance for the Hurdle Step and Trunk Stability. The lack of relationship identified has one of two explanations: there were no motor deficits present during performance of the FMS by concussed individuals, or the FMS tool lacks the sensitivity to identify the changes, either subtle or gross, associated with concussion history both within, and greater than a one-year timespan. Given the findings of studies which used more sophisticated assessment techniques in which individual’s with a history of concussion demonstrate a slower, more conservative gait strategy as well as increased sway, it is reasonable to conclude that the FMS tool lacks the sensitivity to identify these deficits.\textsuperscript{14,51,53} Our results, similar to those found in other studies, suggest that the FMS is not a sensitive enough tool to identify any movement deficiencies caused by changes in neuromuscular control post-concussion in our cohort of SAs.
Although the FMS composite score was one of the few variables approaching significance between groups in our study, the use of the FMS composite score has been questioned given the nature of one number being potentially misleading of an overall individual’s functional movement. Instead, it has been proposed that using the individual component scores when analyzing FMS performance may be preferable.\textsuperscript{40,57} Interestingly, in their description of the FMS, Cook et al. state, "The use of a total FMS™ score for predicting injury risk should be avoided, as the individual components of the test are not correlated with one another and are therefore not measuring the same underlying variable."\textsuperscript{39}

Additionally, the FMS scoring criteria has fallen under scrutiny due to the inability of the test to be precise with only a 0-3 scoring range and corresponding total of 21 possible points. Therefore a 100 point FMS (using the same seven components) has been proposed, with promising inter/intra-rater reliability.\textsuperscript{41,44,58} Based on the results found in our study we agree that the utilization of a 100 point FMS scoring scale may be more beneficial in helping to identifying potential injury-risk cut-off values, and changes pre/post injury. Clinicians and CSCS using the FMS should be aware of and understand these inherent limitations of the current FMS model when analyzing results of SA screens. Current literature does not support the use of the FMS as a post-concussion assessment tool, or injury predictor.

Recent literature looking at other assessment tools such as the TGT has shown promising results in the ability to identify lingering movement deficits/ compensation patterns up to one-year post concussion injury.\textsuperscript{35,36,53} These tools, which were designed to be used post-concussion may be more beneficial to the clinician in helping with
RTP decisions than the FMS which was never intended to be used as an indication for injury risk/prediction.

4.4 Limitations

It is important to recognize some limitations associated with our study. Unfortunately, multiple subjects were missing component FMS score data thereby limiting our total subject pool. Additionally, we acknowledge the fact that time from testing to concussion injury was variable as well as having an unequal sport distribution across subjects. As no previous literature has discussed the change in FMS scores post-concussion, we are unable to know if a significant difference might be identified between those individuals one-year post injury and those perhaps just three-months post injury at B2. Finally, our study was not able to control for prior concussion history in our control match subjects, and was subject to the potentially poor accuracy of self-reported history.

4.5 Conclusion

The results of our study provide further evidence in support of the current literature suggesting that FMS scores lack the ability to detect lingering functional movement deficits up to one-year post concussion. Those responsible for athlete performance and well-being may need to look at other measures of functional movement such as the TGT, or other balance and strength measurements; to better recognize potential movement deficiencies, that may pose risks for SAs returning to sport. In agreement with the current literature, we contend that additional research is needed to examine the efficacy of the FMS and its usefulness in sport performance assessment. Until that time, we recommend using the FMS solely to assess for overall
REFERENCES


9. Lynall RC, Mauntel TC, Padua DA, Mihalik JP. Acute Lower Extremity Injury


40. Moran RW, Schneiders AG, Mason J, Sullivan SJ. Do Functional Movement


49. Boyle MJ, Butler RJ, Queen RM. Functional Movement Competency and


Appendix A

LITERATURE REVIEW

A.1 Introduction

Mild traumatic brain injuries (mTBI) have become a large public health concern across the United States. On average, 1.4 million people are treated annually in emergency departments for traumatic brain injuries (TBIs).1 This does not include those injuries not seen or treated in other settings. Concussions specifically have become a household concern for sport and recreation especially given the increased negative attention in the media. Despite this, a study conducted by Qualey et al. in 2014 found that only 7% of TBIs treated in the emergency department are sports related.2 Research on the pathophysiology of concussions has shown that the neurological, cognitive, and motor deficits seen shortly after impact reflect a functional disturbance in the brain and therefore no change is seen in structure on typical neuroimaging.3,4 As such, concussion diagnosis occurs through clinical assessment and decision making by healthcare professionals such as certified athletic trainers and physicians.3–5 Typical recovery of clinical and cognitive features occurs within a 5-7 day period post impact with an average return-to-play (RTP) around the 10 day time-point.6,7 Recent research however, has demonstrated long-term deficits well past this 10 day time-point in individuals experiencing a concussion, with much of current research focusing on lasting deficits in postural control and dynamic motor control.3,4,8–14
A.2 Epidemiology & Pathology

According to the most recent consensus statement from the 5th International Conference on Concussion in Sport held in Berlin in 2016, “concussion is a traumatic brain injury induced by biomechanical forces,” most commonly a hard blow to the head or body that results in movement of the brain against the skull.\(^3\)

It is estimated that between 1.6 and 3.8 million concussions are sustained annually in the United States from sport and recreational activity alone,\(^{15}\) with 3.9% of National Collegiate Athletic Association (NCAA) athletes experiencing a concussion each year.\(^{16}\) Recently, concussion rates have been reported as high as 0.45 concussions per 1000 athlete exposures (AE).\(^{6,12,17}\) With specific sports such as wrestling and football having rates of 0.89/1000 AE and 0.75/1000 AE respectively.\(^{18}\)

This mTBI typically results in the rapid onset of acute impairments in neurological function as well as the manifestation of clinical signs and symptoms, which may or may not result in the loss of consciousness.\(^3,12\) A concussion is also an evolving injury in the initial stages, with rapidly changing clinical signs and symptoms.\(^3\)

While research of the pathophysiology of concussion is still extremely limited, past research has hypothesized that the energy deficit, and resulting cell death that occurs in the brain during a concussion, may be the cause of slowed cognition and reaction time.\(^{19,20}\) Giza et al. in 2014 discussed “The new neurometabolic cascade of concussion” which breaks down what is currently thought to occur in the brain after a concussive impact, and includes increases in potassium and calcium over 400% of normal levels disturbing homeostasis in the brain cells. New research has been examining casual linkages between the acute pathobiology and chronic progressive changes that may result in long-term deficits.\(^{20,21}\)
A.3 Assessment and Diagnosis

Currently, no gold standard or perfect diagnostic test exists for medical professionals in the diagnosis of concussions. Therefore, concussion diagnosis is a clinical decision made by medical professionals such as certified athletic trainers and physicians, looking at observable signs, reported symptoms, cognition, memory, and balance. According to a recent systematic review by Patricios et al., current sideline screening tests for concussions are all extremely poor at identifying individuals with concussions and are not supported by current evidence for use clinically. Therefore, in agreement with the current international consensus statement, the authors concluded that diagnosis of a concussion is a clinical decision involving a multifaceted approach to assessment. Similarly, Broglio et al. found that no single testing component exceeded a sensitivity of 70%, while a multifaceted concussion assessment is 89%-96% sensitive in acutely identifying a concussion compared with baseline data.

A.4 Deficits in Postural Control

One of the known acute physical complications following concussion are deficits in postural control. However, whether or not these deficits persist after the initial injury has become a widely researched subject. While there has been many recent research studies looking into the long term effects of concussions involving psychological and social implications, less has been done looking at the lasting physical and functional effects.

A study by Sosnoff et al. in 2011 looked to determine whether postural-control deficits seen acutely following mTBI and SRCs persist beyond the acute stage. They investigated 224 individuals of which 62 had at least 1 previously diagnosed mTBI by assessing their performance using the NeuroCOM Sensory Organization Test (SOT)
postural-assessment battery. The researchers concluded that individuals with a history of mTBI exhibited altered postural dynamics compared with individuals without a history of mTBI supporting the notion that changes in cerebral functioning that affect postural control may persist long after acute injury resolution.\(^{25}\) Similarly, Degani et al. compared 11 individuals with a history of mTBI with 11 healthy controls and found that participants with a past history of mTBI presented a larger, slower, and more random body oscillation pattern compared to controls indicating that postural control/balance deficits can be recognized as a lasting effect of mTBI.\(^{26}\)

Merritt et al. in 2016 however, compared 45 student-athletes with prior history of SRC with 45 matched controls with no prior SRC while completing static and dynamic balance tests using the BESS and the Y-Balance Test – Lower Quarter, two tests commonly used by clinicians during the acute and RTP time-point assessments. Interestingly, they found no significant difference between groups and concluded that clinicians lack practical tools for assessing dynamic balance post SRC when using current assessment tools in the field.\(^{27}\)

**Dynamic Postural Control and Gait**

Currently, the assessment of gait after concussion has been limited to laboratory-based studies.\(^{14}\) Recent research has focused on expanding basic postural control assessments post-concussion, to look at dynamic postural control, most commonly using dual-task testing. Dual-task testing involves assessing an individual’s gait strategies, often during tandem gait, while they complete some form of cognitive task. The cognitive task completed often consisted of one of three verbal tests: (1) spelling a five-letter word backwards, (2) serial subtraction from a randomly given two-digit
numeral by 6s or 7s, in order to avoid practice effects related to subtracting from the same number repeatedly, or (3) reciting the months in reverse order, starting with a random month. Research in the past 10 years has shown that individuals post concussion present with an altered gait strategy that is not present in healthy controls.

Parker et al. in 2006 was one of the first to look at the effect of concussion on dynamic motor function. They compared 15 subjects with a concussion and 15 healthy controls. Both groups were assessed within 48 h of injury (for the concussed group) and again at 5, 14, and 28 days post-injury. They found that several aspects of gait stability were compromised in the concussed group for up to 4 weeks after injury. They noted that the concussion group were found to walk significantly slower during dual tasks on all testing days when compared with the uninjured controls and were also found to have greater sway and sway velocity than controls when attention was divided for up to 28 days post-injury.

Similarly, Howell et al. almost a decade later compared concussed individuals completing both single and dual task gait testing acutely post concussion with healthy controls. They found that concussion participants tend to display greater gait instability characteristics across the two-month time-point post-injury. Specifically, they found that concussed individuals walked significantly slower than controls at 72 hours post concussion with single task gait assessment. More significantly, while assessing dual-task gait, they found these individuals continued to walk slower than controls at the 1-week, and 2-week post concussion time-points. They also found that the cadence for concussion participants was significantly lower compared to controls across the two-month time-point post-injury despite displaying greater center-of-mass
Gait Termination and Initiation

Similar research has proposed that gait termination and initiation are better able to detect these altered movement patterns due to the increased need for postural control during transitional movements. Buckley et al. in a study published in 2013 found that gait termination specifically was able to detect both acute and lingering motor control strategy alterations following concussion. The authors examined changes in gait velocity and as well as peak propulsive and braking forces in concussed individuals on day 1 and 10 post injury as opposed to healthy controls. Interestingly, they found that all of the concussion participants demonstrated continued alterations in propulsive and braking forces despite achieving baseline values on all other standard concussion clinical tests.

Oldham et al. assessed planned gait termination performance between baseline and post-concussion individuals with comparison to healthy individuals from D-1 schools. They found an altered center of pressure displacement and velocity during both the braking and transitional phases of planned gait termination within the post-concussion group compared with baseline and matched controls. The authors concluded that concussions may acutely alter the motor component, but not the stabilization components of planned gait termination.

Similarly, Buckley et al. in 2017 looked at impairments in dynamic postural control during the transitional stage of gait initiation acutely post-concussion. They found that 97.6% of participants with a concussion demonstrated a reduction in posterior displacement and velocity during the anticipatory postural adjustment phase.
Similar to previous studies they also found that 76.2% of concussed individuals demonstrated a decrease in initial step length, and 69% a decrease in initial step velocity. The authors concluded that acutely post concussion, individuals demonstrate impairments in the planning and execution of gait initiation, a motor task identified as highly stable in healthy participants.32

A.5 History of Concussion

Interestingly, altered dynamic postural control patterns have been shown to be present in individuals who are no longer suffering from a concussion but who have a previous history.

A study by Martini et al. compared individuals with and without prior history of concussion during both single and dual task assessments. They noted that participants with a history of concussion spent significantly more time in a double-leg stance and significantly decreased time in a single-leg stance and had slower gait velocity. In agreement with previous studies, they concluded these findings suggest that persons with a history of concussion adopt a more conservative gait strategy.33

The authors went on to evaluate the possible long-term effects of high school concussions on gait performance across the lifespan in 2016. 77 participants with and without a history of concussion were grouped into 20-year-old (yo), 40yo, and 60yo age groups prior to completing a normal walking task, a dual task walk, an obstructed walk, and an obstructed, dual task walk. Gait was analyzed using optical motion capture. While the authors found a significant interaction between groups amongst the obstructed walk condition, no significant differences within age was found between those with concussion history and the control group. The authors concluded that an adolescent concussion history has a non-observable effect on gait across the lifespan.10
Similarly, in 2015 a study by Buckley et al. then looked into the effects of a history of multiple concussions on gait stepping characteristics. 63 participants were divided into three groups based on past concussion history (≥3 concussions, 1–2 concussions, and 0 concussion). They found that those with a past history of concussion, presented with a significantly smaller step length compared with those individuals with no prior history of concussion. The authors concluded that subtle impairments in postural control during gait were present in individuals with a prior history of concussion and that these findings suggested a conservative gait strategy.\(^\text{13}\)

Additionally, a cumulative effect of concussions has been shown to increase effects on dynamic motor function. Martini et al. in 2011 found a significant decrease in the amount of time spent in the single-leg stance in those individuals with a history of more concussions than in those with less instances of mTBI.\(^\text{33}\) Similarly, a study by Howell et al. in 2016 compared the gait characteristics of 31 individuals with no prior history of concussion, 15 recovering from their first lifetime concussion, and 22 recovering from their second or more lifetime concussion. The results of the study showed that individuals recovering from their second or greater lifetime concussion had smaller stride lengths during dual-task walking compared with the healthy controls. The authors concluded that there may be a cumulative effect of concussions in worsening dual-task dynamic motor function.\(^\text{34}\)

It has been hypothesized that these altered gait strategies in which individual’s steps are both shorter and slowed down arise in attempt to minimize COM sway in order to minimize threat of falling/instability during less stable gait phases.\(^\text{25,30,32,35}\) However, in doing so, individuals restrict their motor performance. It can be deduced
therefore that this altered gait strategies may pose increased risk to athletes returning to sport.\textsuperscript{36–39}

In agreement with this theory, it has been shown that having a previous history of concussion increases the risk for prolonged recovery, as well as risk for future concussions.\textsuperscript{6,12,23} O’Connor et al. reported 2.9\% of concussed individuals experiencing recurrent concussions.\textsuperscript{40} A National Collegiate Athletic Association (NCAA) study in 2003 found that individuals who have experienced 3 or more concussions having a 3x increased risk for future concussions.\textsuperscript{6} The same authors found that over 90\% of recurrent concussion occurred within 10 days of the initial concussion indicating the likelihood of increased risk for injury acutely post concussion.

A.6 Injury Risk

While no research has been done on the presence of altered strategies in functional sport-specific movements, multiple studies have shown an increased risk for injury in individuals post concussion.\textsuperscript{41–43} Gilbert et al. examined the association between concussion and lower extremity musculoskeletal injury rates at the conclusion of collegiate student-athlete’s athletic career. The authors found significant associations between concussion history and lateral ankle sprains, knee injuries, and muscle strains. They concluded that post-concussion motor control deficits may predispose athletes to LE injury.\textsuperscript{41}

Lynall et al. looked at injury rates for individuals who experienced a concussion at the 90-day, 180-day, and 356-day time-points post-injury and compared this with injuries occurring in the year prior to the concussion. They found a 1.97x increased risk for LE MSK injury one-year post concussion prior to the year before.
Additionally, they found a 1.64x increased risk one-year post concussion compared with matched control subjects. More significantly, Nordström et al. found that the injury risk in the year following concussion for gradual onset injuries, such as tendinopathy continues to increase over time with a 7.92x increased risk at the 6-12 month time-point post concussion. The ability to recognize and potentially reduce these movement deficiencies is of great importance in the sports medicine community in order to decrease the risk of athletes returning to play before they are fully recovered and decrease subsequent injury rate.

A.7 Return-To-Play

As previously stated, the majority of individuals RTP around the 10-day post injury time-point. Current best practice for RTP participation after an SRC follows a graduated stepwise rehabilitation strategy in which the athlete slowly progresses in exertion levels without a recurrence of concussion-related symptoms. An example of this progression can be seen in Figure 1.1 taken from the consensus statement developed at the 5th International Conference on Concussion in Sport. However, determining when an athlete should begin this step-wise progression is a greatly debated topic with current practice beginning once an athlete is symptom free, however, this does not address possible dysfunctions that may still be present. Notably, Kamins et al. reported that physiological dysfunction may outlast current clinical measures of recovery and that no biomarkers currently exist to identify the time-point of full recovery in concussed individuals. This concept supports current practice of gradually increasing activity before full RTP in order to allow for a buffer zone.
Best practice currently recommends that all athletes undergo a multifaceted post-concussion assessment including but not limited to the evaluation of mental status/cognition, oculomotor function, gross sensorimotor function, coordination, vestibular function and balance prior to finalizing a RTP decision. While there are a number of tests currently used to evaluate neurocognitive function, clinical tests used to assess functional movements and coordination are limited to the use of the Balance Error Scoring System (BESS) test and, more recently, the tandem gait task (TGT). These assessment tools used post-concussion may not provide enough information to assist clinicians in determining whether an individual is clinically prepared to RTP. Despite being one of the most commonly used tests in college athletics, the BESS test has been shown to return to baseline values within 3-5 days post injury and has a low sensitivity of 0.34. Additionally, the test has been shown to be greatly influenced by the environment in which it is performed, as well as demonstrated a large learning practice effect along poor intra-rater and inter-rater reliability.

In contrast, the TGT has been shown to identify the presence of compensatory movement strategies up to two weeks post concussion when comparing single versus dual task completion. While the test does have a small learning effect over multiple trials and moderate sensitivity, it does not seem to be affected by concussion history, sport, or gender. Since the TGT is a novel post-concussion assessment, literature is limited and the test is not yet widely used throughout the medical community.
Functional Movement Screen

Current evidence indicates that asymmetries in various performance variables such as balance, strength, proprioception, muscle endurance, flexibility, and mobility, all aspects of function commonly affected post concussion, also put athletes at risk for injury. The ability to recognize and improve upon these deficiencies is of great importance in the sports medicine community as despite all sports requiring different movements and posing large variation of demands on the body, there are common fundamental aspects of human movement that occur throughout all athletic activities.

There is a believe that despite large amounts of training by modern day athletes in endurance, flexibility, strength and power, many athletes continue to be insufficient in their fundamental movements patterns. This inefficiency in functional movement can lead to body compensations in daily movement tasks and poor biomechanics that can eventually decrease performance and increase risk for injuries.

The current practice following a concussion or injury is for individuals to undergo performance and sport-specific tests at the conclusion of “formal

<table>
<thead>
<tr>
<th>Stage</th>
<th>Aim</th>
<th>Activity</th>
<th>Goal of each step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Symptom-limited activity</td>
<td>Daily activities that do not provoke symptoms</td>
<td>Gradual reintroduction of work/school activities</td>
</tr>
<tr>
<td>2</td>
<td>Light aerobic exercise</td>
<td>Walking or stationary cycling at slow to medium pace. No resistance training</td>
<td>Increase heart rate</td>
</tr>
<tr>
<td>3</td>
<td>Sport-specific exercise</td>
<td>Running or skating drills. No head impact activities</td>
<td>Add movement</td>
</tr>
<tr>
<td>4</td>
<td>Non-contact training drills</td>
<td>Harder training drills, eg. passing drills. May start progressive resistance training</td>
<td>Exercise, coordination and increased thinking</td>
</tr>
<tr>
<td>5</td>
<td>Full contact practice</td>
<td>Following medical clearance, participate in normal training activities</td>
<td>Restore confidence and assess functional skills by coaching staff</td>
</tr>
<tr>
<td>6</td>
<td>Return to sport</td>
<td>Normal game play</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: An initial period of 24–48 hours of both relative physical rest and cognitive rest is recommended before beginning the RTS progression. There should be at least 24 hours (or longer) for each step of the progression. If any symptoms worsen during exercise, the athlete should go back to the previous step. Resistance training should be added only in the later stages (stage 3 or 4 at the earliest). If symptoms are persistent (eg. more than 10–14 days in adults or more than 1 month in children), the athlete should be referred to a healthcare professional who is an expert in the management of concussions.
rehabilitation” to attempt to determine the readiness and preparedness of the athlete to RTP.\textsuperscript{4,5,12} However it is the belief of this author that standardized screenings may not provide enough information to determine whether or not an individual is physically prepared to RTP as they do not provide individualized, fundamental analysis of an individual’s movements and whether movement discrepancies may are present. Currently no tests to assess movement function are used in determining RTP timelines post concussion.

The Functional Movement Screen Test, also known as FMS is a seven part clinician-run screening tool looking at an individual’s overall quality of movement. It aims to identify limitations and asymmetries with function movement in the uninjured athlete in order to allow for individualized workout programs that target their “weak link” and allow for overall improved movement patterns.\textsuperscript{53,54} It does not aim to identify why a condition is present, but simply to identify to deficiencies in movement that could infer a potential problem or issue.

The seven components are as follows:

1) Deep Squat

![Deep Squat Image]
2) Hurdle Step

3) In-Line Lunge

4) Shoulder Mobility
5) Active Straight Leg Raise

6) Trunk Stability Push Up

7) Rotary Stability
Each of the different components requires a mix of balance and mobility (including neuromuscular/motor control) designed to provide observable performance of basic locomotor, and stabilizing movements. The tests are designed to place the individual in extreme positions where weaknesses and imbalance become noticeable if appropriate stability and mobility is not utilized. Unlike other performance tests, the FMS testing is not concerned with determining if someone is moving “perfectly” but whether or not they are able to move above an established minimal standard. Component and composite scores should be used to tell clinicians when an individual requires more investigation or assessment and help to give an overall profile of that individual’s movement patterns.53,54

**Scoring**

Each of the seven FMS components are individually scored from 0 to 3 based on specific criteria with three being the best possible score. A “3” is awarded if the individual meets all of the movement criteria listed for a given test with no compensations. A “2” is given if the individual is able to meet some but not all of the given criteria or able to complete the movement but must compensate in some way to perform the fundamental movement. A “1” is given if the individual is unable to complete the movement or is unable to assume the position to perform the movement. Finally a “0” is scored anytime an individual reports pain regardless of movement performance. These 7 scores are then combined to give a total overall composite score ranging from 0-21. The majority of the seven components evaluate both the left and right sides with the lower score of the two sides being recorded and counted toward the total composite score and imbalances between the right and left noted.
Tips for testing given include scoring the subject low when in doubt, waiting till the test is complete to interpret final score, and to view the individual from multiple angles. The FMS also includes three additional clearing tests: shoulder impingement, spinal flexion, and spinal extension. These movements are not scored; the tests are simply performed to observe a pain response. If pain is produced, a score of zero is given for the test. These clearing exams are necessary as shoulder impingement and back pain can go undetected during regular movement screening.\textsuperscript{53,54}

**Reliability**

Since its development, lots of research has been conducted to assess the reliability and validity of the FMS. McCunn et al. in 2016 found that currently, there is no consensus available on the definition of movement quality making analysis of validity of this test extremely difficult.\textsuperscript{58} Through their research they concluded that the FMS has consistently demonstrated good reliability with 16 studies that evaluated either the intra- or inter-rater reliability; 8/8 of those studies reporting an intra-rater ICC of >0.74, and 12/16 reporting an inter-rater reliability of >0.75. Cook et al. reported similar results stating that the FMS has fair to excellent inter-rater reliability for total scores and fair to good reliability for individual test scores.\textsuperscript{53,54}

It is important to note that Shultz et al. found low inter-rater reliability but concluded that improved rater training may fix this, noting the difference between years of experience and the number of tests a rater has administered.\textsuperscript{59} Gribble et al. similarly showed that intra-rater reliability did vary greatly depending on the experience of raters looking at Athletic training students versus Certified athletic trainers with no experience and certified athletic trainers with minimum of 1 year of
FMS training experience. Four other studies however suggested that the experience of the rater did not influence the inter-rater reliability. The literature also currently shows no difference between live versus video recorded grading sessions with reliability between these two of ICC=0.92, however states that the use of which is highly recommended especially in individuals with less FMS experience.

Interestingly, McCunn et al. found that participants who were assessed prior to and after having the criteria for a perfect score on each component score explained to them, demonstrated significantly different scores. Those who had the “perfect score” requirements explained showed substantial improvements in scores compared with those with no explanation.

Injury Risk

This tool is common place among strength and conditioning specialists (CSCS) and athletic trainers to assess changes over the course of a season/athletic career. Due to it’s reported ability to identify deficiencies in movement patterns, there has been a surge in research involving the FMS over the last ten years concerning it’s ability to identify individuals with a risk for a MSK injury with the majority of studies indicating conflicting and limited evidence. A prospective study conducted by Hegedus et al. concluded that poor hip stability, active motion and motor control as assessed by physical performance tests in NCAA division I athletes predicted injury. They determined that five distinct constructs required further investigation as part of a battery of tests comprising a preseason screen: active motion, power, hip stability, flexibility and motor control. With the exception of power, all of these areas are assessed in the FMS.
Kiesel et al. in 2007 was the first to set an initial total composite score cut of value of 14 which would indicate an individual with increased risk for injury. Since then, a large portion of the literature has been devoted to studying the associated injury risk found through various composite and component FMS scores. At least seven articles have since replicated the finding that individuals achieving an FMS composite score of below 14 have an increased likelihood of experiencing an injury; however, the degree of the relationship varies between studies. These studies have also found that the converse is not true, at total score greater than 14 does not mean lower relative risk for injury. Interestingly, in their description of the FMS, Cook et al. states, “The use of a total FMS™ score for predicting injury risk should be avoided, as the individual components of the test are not correlated with one another and are therefore not measuring the same underlying variable.” Despite this, a wide array of association levels have been found between the FMS and injury risk depending on the research article. Multiple published systematic reviews and meta analysis from the last five years however, have concluded that the current literature provides very weak evidence to support the use of the Functional Movement Screen as a predictor for injury risk. It has also been thought that individual component scores might do a better job at predicting injury risk. A systematic review published by Whittaker et al., in 2016 looking at 17 studies on the FMS found that there was a lack of consistent high-quality evidence to support nominating any particular movement quality outcome as a LE injury risk factor and determined that much more research still needs to be done.
A.9 Conclusion

Notwithstanding current evidence indicating that the FMS should not be used as a predictor for injury, it still widely used as a screening tool across college campuses and professional sports as a way to identify weaknesses and deficiencies in individual’s movement patterns.

In 2015, a report by Mayer et al. compared FMS scores of cleared vs. not cleared individuals following anterior cruciate ligament (ACL) reconstruction surgery at the 6-month follow-up. The authors reported that patients in the cleared group exhibited a similar score on the FMS compared with the non-cleared group. They point to the fact that while no standardized RTP guidelines exist after ACL reconstructive surgery in the athletic population, clinical impairment measures do not appear to be related to measured functional ability. In contrast, a study published by Boyle et al. in 2015 found that both adolescents and adults who had undergone ACL reconstruction, scored below the injury-risk cut off of 14, despite having passed all other objective tests and being fully cleared for RTP from their health care providers and/or sports medicine teams prior to enrolling in the study. The importance of this study in highlighting deficiencies in athletes who were otherwise cleared for full participation exposes the need for additional study of the FMS test and its clinical use as a possible RTP screening tool.

Dorrien et al. in 2015 was the first to assess the relationship between FMS and concussion history and found no relationship post concussion. Interestingly, despite the large amount of literature available on post-concussive effects of SRC, research has not provided data about the effect of SRCs and FMS scores as compared with baseline data. Currently no movement screen protocol is used post concussion thereby identifying a possible gap in the evaluation process. If athletes who display...
'poor' movement patterns have a greater risk of injury than those who display 'good' movement patterns, then screening protocols may be an important component of post concussion assessment strategies in order to prevent returning athletes to participation too soon.
A.10 References


Appendix B

IRB DOCUMENTS

University of Delaware Human Subjects
Informed Consent Form

Title of Project: Examination of Concussions and their Effect on Functional Movement Screen Scores in Collegiate Athletes
Principal Investigator: Sarah Roger, B.S., ATC
Other Investigators: Thomas W. Kaminski, PhD. Bethany Wisthoff, MS, ATC.

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will be asked to do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything we have not made clear before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?
The purpose of this study is to examine the relationship between sport-related concussions and Functional Movement Screen (FMS) scores completed as part of your annual strength and conditioning baseline testing. A concussion is a mild traumatic brain injury that can occur following a blow to the head or body, which commonly causes disorientation, headaches, balance problems, and occasionally memory loss, which usually resolves within several weeks.

WHY ARE YOU BEING ASKED TO PARTICIPATE?
You are being asked to participate because you are a current student-athlete at the University of Delaware and have been identified as having a history of sport-related concussion or you’ve been selected to serve as a matched control subject for a teammate whose been diagnosed or has a history of sport-related concussion(s).

WHAT WILL YOU BE ASKED TO DO?
There is no time involvement required for participation in this project. You’re consenting enables us to access data obtained as part of two ongoing studies at the University of Delaware involving student-athletes: NCAA/DoD Grand Alliance: Concussion Assessment, Research and Education (CARE) consortium-longitudinal clinical study core (UD-IRB
#740790-2) and the Ankle Injury Assessment and Tracking in an Athletic Population study (UD-IRB #131714-12).

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?**
The research team does not expect your participation in this study will expose you to any risks (different from those you would encounter in daily life).

**WHAT ARE THE POTENTIAL BENEFITS?**
You will likely receive no direct benefit for participating in this study, however you will be provided your results, once calculated, if you so request.

**WHAT IF NEW INFORMATION BECOMES AVAILABLE ABOUT THE STUDY?**
During the course of this study, we may find more information that could be important to you. This may include information that may cause you to change your mind about participating in the study. We will notify you as soon as possible if any new information becomes available.

**HOW WILL CONFIDENTIALITY BE MAINTAINED?**
If you choose to participate in this study, you can be assured your information is kept confidential. For this study, you will be identified only by your subject number. Records of this information will be kept on electronic file, available only to those directly associated with the research. This consent form will be the only document with your name and personal information. This consent form and data collected will be stored indefinitely. The consent form will be locked in a file cabinet in the Athletic Training Research Lab (Room 160 of the Human Performance Laboratory). No personal information will be shared when the results of this study are reported.

Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law. All of the data will be kept confidential. Aggregate (cumulative) data from this study will be shared with the sports medicine staff here at the University of Delaware. In addition, records of any athletic-related injuries that you experience while participating as an intercollegiate athlete will be shared with the research team. Your information will be assigned a code number. The list connecting your name to the code number will be kept in a locked file. When the study is completed and the data have been analyzed, that list will be destroyed, but the coded data will be kept indefinitely on a secured electronic file device.

**WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?**
There will be no costs related to your participation in this study.

**WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?**
There will be no compensation for participation.

**WHAT IF YOU ARE INJURED DURING YOUR PARTICIPATION IN THE STUDY?**
N/A
DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware, coaching staff, playing time/opportunities, or the sports medicine staff.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator or Advisor:

Principal Investigator – Sarah Roger @ sroger@udel.edu or 802-522-8699
Advisor – Thomas W. Kaminski @ kaminski@udel.edu or 302-831-6402
Doctoral Mentor – Bethany Wisthoff @ bwisthof@udel.edu or 219-380-9792

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

CONSENT SIGNATURES

Your signature on this form means that: 1) you are at least 18 years old; 2) you have read and understand the information given in this form; 3) you have asked any questions you have about the research and those questions have been answered to your satisfaction; 4) you accept the terms in the form and volunteer to participate in the study. You will be given a copy of this form to keep.

_________________________        _________________________________        __________
Printed Name of Participant             Signature of Participant             Date

_________________________        _________________________________        __________
Principal Investigator                  Principle Investigator Signature       Date