Validation of Physical Activity as a Functional Outcome Measure Following a Concussion

A thesis presented to
the faculty of
the College of Health Sciences and Professions of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Science

Shannon J. Nickels
June 2012

©2012 Shannon J. Nickels. All Rights Reserved.
This thesis titled
Validation of Physical Activity as a Functional Outcome Measure Following a Concussion

by

SHANNON J. NICKELS

has been approved for
the School of Applied Health Sciences and Wellness
and the College of Health Sciences and Professions by

________________________________________
Brian G. Ragan
Assistant Professor of Athletic Training

________________________________________
Randy Leite
Dean, College of Health Sciences and Professions
ABSTRACT

NICKELS, SHANNON J., M.S., June 2012, Athletic Training

Validation of Physical Activity as a Functional Outcome Measure Following a Concussion

Director of Thesis: Brian G. Ragan

Diagnosis and management of concussions rely heavily on impairment and the presence of symptoms, with little emphasis placed on function. The World Health Organization defines function as a person’s movement within their environment. A person’s movement is also considered physical activity which can be measured using an accelerometer. **Purpose:** To validate physical activity counts/day (AC) and steps/day (SC) as measures for assessing function following a concussion. **Interventions:** 25 participants (14 concussed; 11 control) wore an ActiGraph GT3X+ accelerometer on right hip either after sustaining a concussion or being identified as a healthy control for over a week.

**Results:** A statistically significant difference in AC ($t_{23} = -2.252; p < 0.05$) was found between symptomatic days of the concussed in comparison to healthy controls.

**Conclusions:** Physical activity, more specifically activity counts/day, in conjunction with current concussion assessment tools and symptom questionnaires, can provide an objective method of measuring function following a concussion.

Approved: _____________________________________________________________

Brian G. Ragan

Assistant Professor of Athletic Training
ACKNOWLEDGMENTS

This thesis could not have been accomplished without the love and support of the following individuals. Thank you, Mom, for the many conversations on my drive home. Without hearing your voice of reason and support, I might not be where I am today. Thank you, Steven and Ted, for being great big brothers and supporting me in all my endeavors. Thank you to all my friends, both old and new, for the great memories. Thank you, Cooper, for the many hugs, all of which brought a smile to my face and took the stresses of life off my shoulders even for a brief second. Chelsea, words cannot describe how thankful I am for you. You have supported me through all my ups and downs and gladly pursued this adventure with me. Without your never-ending love and support, I would not be close to the person I am today.

Thank you to my committee for your support and direction. Dr. Ragan, thank you for having faith in me and persuading me not to give up on this. Dr. Howe, thank you for gladly taking another thesis under your belt and providing me with the great feedback I needed. Thank you, Dr. Starkey, for not only helping with my thesis, but by giving me an opportunity to explore and become the Athletic Trainer I’ve always known in time I would be.
TABLE OF CONTENTS

Abstract .......................................................................................................................... 3
Acknowledgments ......................................................................................................... 4
List of Tables .................................................................................................................. 9
List of Figures ............................................................................................................... 10
Chapter 1: Introduction ............................................................................................... 11
  Statement of the Problem ........................................................................................... 12
  Purpose ....................................................................................................................... 12
  Significance of the Study ........................................................................................... 12
  Research Questions .................................................................................................... 13
  Null Hypotheses ......................................................................................................... 14
  Delimitations of the Study ........................................................................................ 14
  Limitations of the Study ............................................................................................ 14
  Definition of Terms .................................................................................................... 15
Chapter 2: Review of Literature .................................................................................. 16
  Concussion ................................................................................................................ 16
    Definition ................................................................................................................ 16
    Concussion Signs and Symptoms ........................................................................... 18
    Long-Term Consequences ....................................................................................... 18
    Prevalence in Athletics ............................................................................................ 19
    Return to Play Guidelines ....................................................................................... 19
Current Assessment Techniques .......................................................... 21
  Computerized Neuropsychological Tests ........................................... 21
  Sideline Administered Tests .............................................................. 23
    Standardized assessment of concussion ........................................... 23
    Balance error scoring system ....................................................... 23
    Sport Concussion Assessment Tool 2 ............................................. 24
Functional Outcome Measurement ....................................................... 25
  World Health Organization International Classification of Function ...... 25
Physical Activity ................................................................................. 27
  Definition .......................................................................................... 27
  Recommendations ............................................................................ 28
Measurement Tools ............................................................................. 30
  Criterion-Based Measurements ......................................................... 30
    Calorimetry .................................................................................... 30
    Physical activity diaries and questionnaires .................................... 31
  Field-Based Measurements ............................................................... 32
    Pedometers .................................................................................... 32
    Accelerometers ............................................................................... 32
Physical Activity as a Health Outcome ................................................. 33
  Overall Health Differences ............................................................... 33
  Disease Progression in Recovery ....................................................... 34
Specific Aims ....................................................................................... 36
Chapter 3: Methods

Overview

Study Design

Participants

Power Analysis

Inclusion and Exclusion Criteria

Instruments

Injury History Form

Concussion Symptom Questionnaire

Accelerometer

Study Feedback Questionnaire

Data Collecting Procedure

Initial Injury

Recovery

Data Processing Procedure

Data Analysis

Chapter 4: Results

Wear Time Validity

Research Question 1

Research Question 2

Research Question 3

Conclusion
LIST OF TABLES

Table 1: Computerized Neuropsychological Tests Domains.................................22
Table 2: Classification of Adult Activity Level Based Upon Total Steps/Day.............29
Table 3: Pilot Data Effect Size............................................................................38
Table 4: Activity Count and Step Count of the Concussed at Symptomatic and
         Asymptomatic and Healthy-Matched Controls.............................................48
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>World Health Organization Disablement Model</td>
<td>27</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Accelerometer</td>
<td>42</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Accelerometer placement on participant</td>
<td>42</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Data collection procedure</td>
<td>43</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Data processing procedure</td>
<td>46</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Mean AC for concussion group at symptomatic compared to healthy control</td>
<td>49</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Mean SC for concussion group at symptomatic compared to healthy control</td>
<td>50</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Mean AC of each concussion participant at symptomatic compared to corresponding healthy controls</td>
<td>51</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Mean SC of each concussion participant at symptomatic compared to corresponding healthy controls</td>
<td>51</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Mean AC for concussion group at symptomatic and asymptomatic</td>
<td>53</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Mean SC for concussion group at symptomatic and asymptomatic</td>
<td>53</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Mean AC of each concussion participant at symptomatic &amp; asymptomatic</td>
<td>54</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Mean SC of each concussion participant at symptomatic &amp; asymptomatic</td>
<td>54</td>
</tr>
<tr>
<td>Figure 14</td>
<td>AC of compliant participant</td>
<td>60</td>
</tr>
<tr>
<td>Figure 15</td>
<td>SC of compliant participant</td>
<td>60</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

Concussions are a biomechanically induced transient disturbance of neurologic function (Giza & Difiori, 2011). Over the past decade, concussions have been recognized as severe injuries that need to be quickly identified, easily evaluated, and promptly treated. Unfortunately, every concussion presents itself differently, making the management process exceptionally difficult.

According to the Congressional report on concussions or mild traumatic brain injuries presented in September 2003, 1.5 million traumatic brain injuries occur annually in the United States with sport-related injuries being a fifth of that total (National Center for Injury Prevention and Control, 2003). Of the 306,000 sport-related brain injuries, 12% required hospitalization, 55% received out-patient care, and 35% received no medical attention (Sosin, Sniezek, & Thurman, 1996).

Diagnosis and management of concussions rely heavily on the identification of signs and symptoms associated with impaired cognitive and neurological functions. Based on current practice patterns of concussion assessment and management, 95% of athletic trainers reported using clinical examinations and 85% used symptom checklists to assess concussions (Notebaert & Guskiewicz, 2005). Additionally, athletic trainers reported using clinical examinations, return to play guidelines, symptom checklists, and player self-reports to make a return to activity decision. Return to activity following a concussion is based on the progression back to baseline while asymptomatic. Although these outcome measures are useful in assessing concussions, they focus on impairment with little emphasis on function, making effective management difficult.
The World Health Organization (WHO) defines function as a person’s movement and interaction within their environment. Physical activity is any bodily movement produced by skeletal muscles that requires energy expenditure (World Health Organization, 2012). Physical activity is an important tool for identifying the healthiness, willingness, and readiness for an individual after suffering a neurological impairment. By measuring physical activity, a person’s function level can be determined.

Physical activity can be measured using a variety of tools. Pedometers, accelerometers, 7-day physical recalls, doubly labeled water, and questionnaires all give insight into function, more specifically, physical activity. Accelerometers are commonly used to measure both intensity of acceleration (activity counts, AC) and quantity (step counts, SC) of movement to justify health status. Physical activity counts and step counts have been validated as rehabilitation outcomes in stroke victims (Shaughnessy, Michael, Sorkin, & Macko, 2005).

Statement of the Problem

Today, concussions are being managed based on cognitive and balance impairments and presence of signs and symptoms with little emphasis on function.

Purpose

The purpose of this research study was to validate AC and SC collected by accelerometers as functional outcome measures following a concussion.

Significance of the Study

To provide optimal patient care, an extensive understanding of each situation is needed. Current concussion assessment tools analyze impairments in cognitive function
and assess the presence of signs and symptoms. These measurement tools have poor
reliability, display inaccuracies in domains measured, and only allow the practitioner to
evaluate the subject’s impairments, not their function level. Despite these limitations,
these tools are routinely used to make return to play decisions. This lack of insight into
function establishes the need for athletic trainers to have a functional outcome
measurement tool to aid in return to play decisions.

This study attempts to improve concussion management by incorporating AC and
SC collected by accelerometers as more accurate functional outcome measures.
Providing a functional outcome measure could aid in proper management and treatment
options following a concussion.

Research Questions

The following research questions for this thesis were:

1. Is there a significant group mean difference in AC and SC between concussed at
symptomatic and healthy matched controls?

2. Within the concussion group, is there a significant difference in AC and SC as
participants progress from symptomatic to asymptomatic?

3. Is there a relationship between concussion symptoms and physical activity over
time?
Null Hypotheses

The following hypotheses for this research study were:

$H_{01}$ There is a significant group mean difference in AC and SC between concussed at symptomatic and healthy matched controls.

$H_{02}$ Within the concussion group, there is a significant difference in AC and in SC participants as they progress from symptomatic to asymptomatic.

$H_{03}$ There will be a relationship between concussion symptoms and physical activity counts over time.

Delimitations of the Study

Delimitations of the study include:

1. All participants were college-aged (18-24).
2. All participants were involved in intercollegiate sports.
3. Participants were not able to participate in this study if they experienced a concussion in the last six months, were not physically able to wear the device or have a history of learning disability, seizure disorder, attention deficit disorder or other mental/physical disability that would hinder their participation in this study.
4. All participants had to wear the device for at least 10 hours.

Limitations of the Study

Limitations of the study include:

1. Small rural college setting.
2. Participant compliance.
Definition of Terms

Accelerometer. A small electronic device used to measure physical activity.

Activity count (AC). Total acceleration or change in speed detected per day.

Concussion. A biomechanically induced transient disturbance of neurologic function.

Function. A person’s movement and interaction within their environment

Impairment. Any disorder in structure or function resulting from anatomic, physiologic, or psychologic abnormalities that interfere with normal activities (Mosby’s Medical Dictionary, 2009)

Physical activity. Intensity of any bodily movement produced by skeletal muscles requiring energy expenditure accumulated throughout the day.

Step count (SC). Total vertical movement of the hips detected per day.

Symptom. The subjective deviation from normal function or feeling, indicating the presence of a disease or abnormality.
CHAPTER 2: REVIEW OF LITERATURE

The purpose of this literature review is to highlight the underlying issues of concussion management and the role of physical activity as it relates to concussion recovery. This review begins with a brief history of the ever-evolving definition of concussions, signs and symptoms associated with it, and the short-term and long-term consequences. The next section discusses the increasing prevalence of concussions in athletics followed by the reliability and accuracy of current concussion assessment techniques. Lastly, the role of physical activity in measuring functional outcome is addressed with the purpose of using the measurement as a more reliable and effective means of making return to play decisions.

Concussion

Definition

The terms concussion or mild traumatic brain injury (mTBI) can be used interchangeably, however, the definitions of these terms have changed over the course of the last 35 years. In 1966, the Congress of Neurological Surgeons defined concussion as a “clinical syndrome characterized by immediate and transient impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc., due to mechanical forces” (Boden, 2012, p. 10). This definition was initially well received. Over time it was noted that the definition failed to include common clinical features associated with a concussion (e.g., headache, nausea).

In 1997, the American Academy of Neurology defined concussion as a “trauma induced alteration in mental status that may or may not involve loss of consciousness”
classifying confusion and amnesia as the “hallmarks of concussion” (Kelly & Rosenberg, 1997, p. 2). The American Academy of Neurology also included the use of a grading scale to clarify severity on a scale of 1 to 3. A Grade 1 score consisted of transient confusion with symptoms resolving in less than 15 minutes, a Grade 2 score involved transient confusion with symptoms lasting longer than 15 minutes, and a Grade 3 score classified by any loss of consciousness.

Seven years later, the National Athletic Trainer’s Association (NATA) revised the 1966 definition to include clinical, pathologic, and biomechanical constructs stating that “1) concussions may be caused by a direct blow to the head or elsewhere on the body from a force transmitted to the head, 2) concussions may cause an immediate or short-term impairment of neurologic function, 3) concussions may cause neuropathologic changes, however the acute symptoms largely reflect a functional disturbance rather than a structural injury, and 4) loss of consciousness may or may not be involved” (Aubry, Cantu, & Dvorak, 2002, p. 6).

Most recently, at the Third International Conference on Concussion in Sport in Zurich, Germany, the Zurich Guidelines defined concussion as a “complex pathophysiological process affecting the brain, induced by biomechanical forces” (McCrory, 2009, p. 756). The same clinical features mentioned in the NATA Position Statement were included; however, the concussion severity grading scale was removed. It can be concluded that while there is no universal consensus on the definition of a concussion, the features and constructs of a head injury have been widely agreed upon throughout history.
Concussion Signs and Symptoms

With the exception of loss of consciousness as a determinant, the recognized signs and symptoms of concussions have stayed relatively constant. The common signs of a concussion are vacant stare, delayed verbal and motor responses, confusion, disorientation, slurred speech, gross incoordination, uncontrollable emotions, and memory deficits (Kelly & Rosenburg, 1997). Common symptoms that could arise immediately following a concussion include dizziness, nausea, headache or lack of awareness of surroundings. Symptoms common over the course of the next few days or weeks could include persistent headache, light-headedness, poor attention and concentration, easy fatigability, irritability, intolerance of bright lights or loud noise, depression or sleep disturbance (Kelly & Rosenburg, 1997). The presence of any of these signs or symptoms throughout history has shown to be consistent with the presence of a concussion.

Long-Term Consequences

The short-term effects of concussions discussed in the signs and symptoms section of this review usually subside within 1 to 7 days. The long-term consequences of repeated concussions are the underlying issue. Studies have found that athletes who have a history of two or more concussions have a greater deficit in verbal memory and reaction time compared to those who did not have a history of concussions (Covassin, Stearne, & Elbin, 2008). Traumatic and mTBI have also been linked to premature onset of Alzheimer’s disease, Parkinson’s disease and other neurodegenerative diseases in both human and animal subjects (Kiraly & Kiraly, 2007).
Prevalence in Athletics

Head injuries in athletics have become more prevalent throughout the past decade. An epidemiological report in 2001 noted that 18% of head injuries submitted to the National Head Injury Association were sustained during athletic competition (Echemendia & Julian, 2001). The American Association of Neurological Surgeons (2011) reported that in 2009 the number of sport-related mTBI almost reached 450,000. Also, according to an epidemiology report on collegiate injuries, the injury rate for concussions has increased by 7% annually (Hootman, Dick, & Agel, 2007) Based on these figures, occurrence of concussions are highly prevalent. With such a high injury rate, the chances of mistakes in return to play decisions are more likely. This information supports the need for a universally accepted guideline for return to play decisions.

Return to Play Guidelines

Return to play following a concussion is the most critical issue of all and, as such, various health care organizations have established different methods of determining return to participation status. The American Academy of Neurology states that the guidelines for return to play are not based on physical exertion testing, but instead on a set number of weeks based on the grade of the concussion and whether loss of consciousness occurred (Kelly & Rosenberg, 1997). The position statement from the NATA states that 7 to 10 days post injury warrants full return of participation as long as the athlete is symptom free (Guskiewicz et al., 2004). The Zurich guidelines (McCrory, 2009), which have become the most widely used method of treating concussions, has a
seven day return to play guideline consisting of physical exertion testing. If however, a symptom resurfaces at any time, the seven day process begins again (McCrory, 2009).

These return to play guidelines focus on return of normal cognitive function and the absence of signs and symptoms. Failure to use a more functional outcome measure could lead to quicker return to play yielding further complications including second impact syndrome. The concept of second impact syndrome is that during an initial concussion, the autoregulation of arterial blood pressure in the brain is thrown off track and a surge of catecholamine, a stress response chemical, is released (Wetjen, Pichelmann, & Atkinson, 2010). Without full recovery, a second impact could result, causing a rapid succession of events that produce profound swelling of the brain and, consequently, death. More evidence of this has been shown in juvenile rats who sustained repeated traumatic brain injuries leading to measureable cognitive deficits and memory impairments in the developing brain (Prins, Hales, Reger, Giza, & Hovda, 2010).

Health care professionals utilize multiple concussion assessment tools to aid in return to play decisions. Over 90% of survey respondents in Notebaert & Guskiewicz’s (2005) report of the current trends of concussion management reported using clinical examinations and physician recommendations to make return to play decisions. Roughly 80% of respondents reported using player self-reports and symptom checklists while the most common concussion assessment techniques barely made the chart. Based on these results, it is evident that the current concussion assessment techniques are not the preferred method for returning an athlete back to full participation and that a functional outcome measurement tool is needed to aid in return to play decisions.
Current Assessment Techniques

Baseline testing is recommended for all levels of contact sports due to the frequency of concussions. Baseline testing can be measured by common computerized neuropsychological tests like CogSport, Concussion Resolution Index, and ImPACT as well as immediate sideline administered tests such as the Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), and Sport Concussion Assessment Tool 2 (SCAT2).

Computerized Neuropsychological Tests

Computerized assessments are issued at the beginning of the season to gather baseline scores. After a concussion is sustained, the test is readministered to determine a difference in cognitive functions including reaction time, verbal memory, and impulse control. Table 1 depicts the domains measured by computerized neuropsychological tests. Although successful in targeting these domains, accuracy and reliability of these tests is lacking. CogSport has shown to accurately test reaction time and processing speed, but fails in accurately testing memory (Shatz & Putz, 2006). The Concussion Resolution Index has low to moderate test-retest reliability with figures for intraclass correlation coefficients ranging from 0.15 to 0.66 (Broglio, Ferrara, Macciocchi, Baumgartner, & Elliot, 2007). Additionally, when retested, the intraclass correlation coefficients still displayed low to moderate test-retest reliability with figures of 0.03 to 0.66. ImPACT, like CogSport, accurately tests reaction time and processing speed but not memory (Shatz & Putz, 2006). Also intraclass correlation coefficients for ImPACT showed a low to moderate test-retest reliability with figures of 0.15 to 0.39 from baseline.
to 45 days later and figures of 0.39 to 0.61 five days after the 45-day testing period (Broglio et al., 2007). The inaccuracy and low reliabilities of these tests establishes a need for a more advanced concussion assessment technique.

Table 1

*Computerized Neuropsychological Tests Domains*

<table>
<thead>
<tr>
<th>Neurophysiological Test</th>
<th>Domains Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>CogSport</td>
<td>Simple Reaction Time</td>
</tr>
<tr>
<td></td>
<td>Complex Reaction Time</td>
</tr>
<tr>
<td></td>
<td>One-Back</td>
</tr>
<tr>
<td></td>
<td>Continuous Learning</td>
</tr>
<tr>
<td>Concussion Resolution Index</td>
<td>Reaction Time</td>
</tr>
<tr>
<td></td>
<td>Cued Reaction Time</td>
</tr>
<tr>
<td></td>
<td>Visual Recognition 1</td>
</tr>
<tr>
<td></td>
<td>Visual Recognition 2</td>
</tr>
<tr>
<td></td>
<td>Animal Decoding</td>
</tr>
<tr>
<td></td>
<td>Symbol Scanning</td>
</tr>
<tr>
<td>Immediate Post Concussion Assessment</td>
<td>Verbal Memory</td>
</tr>
<tr>
<td>and Cognitive Testing (ImPACT)</td>
<td>Visual Memory</td>
</tr>
<tr>
<td></td>
<td>Information Processing Speed</td>
</tr>
<tr>
<td></td>
<td>Reaction Time</td>
</tr>
<tr>
<td></td>
<td>Impulse Control</td>
</tr>
</tbody>
</table>

Sideline Administered Tests

**Standardized Assessment of Concussion (SAC).** The SAC has been widely used along with symptom checklists to diagnose concussions immediately on the sideline. The SAC is used to measure orientation, immediate memory, concentration, and delayed recall. Throughout its usage, it has been found that the SAC has a 94% sensitivity and 76% specificity (Barr & McCrea, 2001). Recently, however, it has been reported that the SAC has a weak relationship in comparison with other neuropsychological tests including the Buschke Selective Reminding Test and the Trail Making Test. This weak correlation indicates that different cognitive domains are being tested (Valovich McLeod, Barr, McCrea, & Guskiewicz, 2006). Further scrutiny of the SAC has also yielded troublesome results. An item analysis on the components of the SAC looking at the difficulty, discrimination, and determination of each item resulted in 63% to 70% of the items being “too easy.” Also, all five of the orientation items, as well as 87% to 100% of the immediate memory items, were marked as unacceptable (Ragan, Herrmann, Kang, & Mack, 2009).

**Balance Error Scoring System (BESS).** The BESS is an inexpensive resource used to assess static postural stability following a head injury. It involves the use of a hard and uneven surface to assess balance by requiring the athlete to close their eyes and remain still. If one or more errors are made, a demotion is attributed to the subject’s score. The potential errors include moving the hands off of the iliac crests, opening the eyes, stepping, stumbling, falling, abduction or flexion of the hip beyond 30°, lifting the forefoot or heel off of the testing surface or remaining out of the proper testing position.
for greater than 5 seconds. Interrater reliability has been reported to be 0.57 and intrarater reliability to be 0.74. These reliabilities suggested the total score of the BESS was not reliable and required a change in postural stability score greater than 9.4 or 7.3 points respectively to occur (Finnoff, Peterson, Hollman, & Smith, 2009).

*Sport Assessment Concussion Tool 2 (SCAT2).* The SCAT2 is a diagnostic tool used on sidelines to quickly identify a concussion and incorporates the SAC to measure orientation, immediate memory, concentration and delayed memory. It also includes the BESS to measure postural stability at double leg stance, single leg stance and tandem stance. Symptom evaluation and coordination sections are also included. Although the amount of research data on the validity and reliability of the SCAT2 is lacking, it can be inferred based on the two components that largely make up the test (SAC and BESS) that the SCAT2 lacks the ability to be an accurate and reliable concussion assessment technique.

Based on this information, it is clear that these tests should not be the sole determining factor for making return to play decisions. The computerized neuropsychological tests only look at specific cognitive domains like reaction time and memory with low test-retest reliabilities. The sideline tests like that of the SAC, BESS and SCAT2, although helpful in identifying concussions, fail in providing a concrete, stable assessment tool for return to play decisions. All of these concussion assessment techniques measure impairments and place little emphasis on function when evaluating an athlete’s health status. This information amplifies the notion that incorporating a new
A functional outcome measurement tool to accurately clear an athlete for full participation after sustaining a concussion is necessary.

**Functional Outcome Measurement**

*World Health Organization International Classification of Function*

The World Health Organization (WHO) International Classification of Function, Health and Disability depicts a biopsychosocial approach to a disability with the term disability “representing the dynamic interaction between person and environment” (Rosenbaum & Stewart, 2004). In the updated international classification of function (ICF) disablement model (see Figure 1), an interactive relationship exists between the domains of body structure and function, activity, participation, environmental factors and personal factors. The upper portion of the ICF model examines the domains of body structure and functions, activity and participation while the bottom portion examines both environmental and personal factors (Snyder et al., 2008).

The body structures and functions domain looks at both the mental and physical aspects of health. Body “functions” are the physiologic functions of the body such as breathing, while the “structures” are the anatomical parts. Any changes or deviations from normal are noted and referred to as impairments (Snyder et al., 2008).

The next two domains focus on activity and participation. Both activity and participation are essential in identifying the effects of structural and functional impairments on a person in their environment. Activity is described as a simple task or activity that has meaning while participation is described as an optional activity with
involvement in life situations (Snyder et al., 2008). For example, running would be an activity, but running at practice would be considered participation.

The second part of the ICF model looks at contextual factors including environment and personal factors and their effects on overall function. Environmental factors refer to social, physical and attitudinal environments in which a person lives. This can include relationships, attitudes and services surrounding the individual. Personal factors include but are not limited to age, gender, coping habits and past experiences, all of which have the potential to influence a situation.

In summary, the ICF disablement model reflects disability as a “health condition that leads to dysfunction at the domain levels indicating impairment, activity limitations, or participation restrictions as mediated by both environmental and personal contextual factors” (Snyder et al., 2008, p. 434). With the aid of this model, insight can be gained on the underlying issue is, how it is affecting overall function and what factors are inhibiting recovery.
Physical Activity

Definition

The WHO defines function as movement and interaction within the environment with physical activity being described as that movement in the form of exercise or activity. Physical activity in the form of exercise is a process that results in improvement or maintenance of physical fitness (i.e., muscular strength, muscular power, muscular endurance, cardiorespiratory endurance, flexibility, agility and balance). Activity incorporates all other forms of movement including occupational tasks (e.g., typing on a computer), daily household chores (e.g., dishwashing) and purposeful transportation (e.g., bicycling to the store) (Caspersen, Powell, & Christenson, 1985).
Recommendations

Participating regularly in physical activity has been proven to increase overall health and fitness and reduce the risk of chronic diseases. The Centers for Disease Control and Prevention recommends that adults age 18 to 64 participate in 150 minutes per week of moderate intensity aerobic exercise. Resistance training, including muscle strengthening exercises, is also recommended twice a week targeting all major muscle groups including legs, hips, back, abdomen, chest, shoulders and arms (Centers for Disease Control and Prevention, 2011).

In the early 1960’s, pedometers were first developed and used to measure daily step counts which provided an objective measure of physical activity. In 1965, the Japanese Walking Association determined 10,000 steps/day to be the standard for a healthy adult. Tudor-Locke et al. (2008) evaluated and expanded on the standard daily step count parameters which are depicted in Table 2 (Zhu, 2008).
Table 2  

*Classification of Adult Activity Level Based upon Total Steps/day*

<table>
<thead>
<tr>
<th>Classification</th>
<th>Total step count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>&lt; 5,000</td>
</tr>
<tr>
<td>Low Active</td>
<td>5,000 – 7,499</td>
</tr>
<tr>
<td>Somewhat Active</td>
<td>7,500 – 9,999</td>
</tr>
<tr>
<td>Active</td>
<td>10,000 - 12,499</td>
</tr>
<tr>
<td>Highly Active</td>
<td>&gt; 12,500</td>
</tr>
</tbody>
</table>

Note. These classifications are based upon the findings of Tudor-Locke et al in the 2008 President’s Council on Physical Fitness and Sports Research Digest.

By using accelerometers, changes in movement can be detected. Vertical plane displacement of the hip identifies step counts of individuals while change in speed, detected by the vertical plane or a combination of the triaxial feature on accelerometers, depicts activity counts (Chen, 2005). By totaling activity counts/day, a more accurate depiction of movement patterns can be achieved in comparison to pedometers which only collect total steps/day.

Based on the physical activity recommendations, it can be inferred that physical activity plays an important role in overall health. However, in incidences of injury, an individual is limited and unable to achieve the standards of a healthy adult. This loss of function can be measured through a variety of tools and can be used to determine when an individual is ready to return to participation.
Measurement Tools

Physical activity can be measured utilizing criterion-based or field-based measurement tools. Criterion-based measurement tools include calorimetry, either direct or indirect, and subjective paperwork. Examples of subjective paperwork include physical activity diaries, recalls, and questionnaires. Field based measurement tools involve the use of pedometers and accelerometers to objectively measure the quality, quantity, and intensity of physical activity.

Criterion-Based Measurements

Calorimetry. Calorimetry is a tool for measuring energy expenditure either directly or indirectly. Although measuring energy expenditure is not the primary focus of this research project, it is important to note that the use of calorimetry provides a great depiction of energy expenditure. Direct calorimetry involves the use of a specially sealed metabolic chamber to measure the amount of heat given off from the body. Although it is the most accurate method of measuring calories (energy expenditure), its use is almost unnecessary in most settings. Indirect calorimetry includes the use of doubly-labeled water. This technique involves the ingestion of water labeled with a concentration of stable isotopes of hydrogen and oxygen. As energy is expended, carbon dioxide and water are produced within the body creating an elimination rate of the isotopes. This elimination rate is then used to calculate total energy expenditure. This method has been known as the “gold standard” of measuring energy expenditure and is often used when validating other measurement tools. Doubly-labeled water energy expenditure estimates have been used to validate physical activity questionnaires by finding a strong
relationship between the two (Conway, Seale, Jacobs, Irwin, & Ainsworth, 2002).

However, doubly-labeled water has its disadvantages. Both the materials and the need of
expertise to analyze isotope concentration make this method very expensive. Also, the
inability for calorimetry to segment activity by time provides a damper in data collection.

Because of this disadvantage, the addition of other measurement tools including physical
activity questionnaires and electronic devices such as accelerometers are needed to gain
an idea of a person’s total daily physical activity counts and step counts (Exercise and
Physical Activity Resource Center, n.d.).

*Physical activity diaries and questionnaires.* Subjective measurements of physical
activity include an array of different paperwork including diaries, logs, and
questionnaires. These self-reported documents are a common approach to identifying
physical activity patterns in populations. The technique of using physical activity diaries
allows assessment of habitual activity over time without the unnecessary financial
expenditure of other measurement tools. Physical activity logs are used to immediately
report the intensity and duration of participation in specific types of activities. This
information is then used to calculate the energy cost of that activity and the accumulated
energy expenditure of daily activities. However, it has been shown that diaries and logs
do not provide enough data to accurately estimate energy expenditure on their own
(Ainsworth et al., 2000; Ekelund, Yngve, & Sjostrom, 1999). Another subjective
measurement of physical activity is the use of questionnaires such as the 7-Day Physical
Activity Recall, Global Physical Activity Questionnaire (GPAQ), and International
Physical Activity Questionnaire (IPAQ). These can be disbursed to particular populations
at a low cost to the researcher. The 7-Day Physical Activity Recall has shown that in comparison to doubly-labeled water, it provides a better energy expenditure estimate than physical activity diaries (Irwin, Ainsworth, & Conway, 2001). However, like the physical activity diaries and other established self-reports, these questionnaires do not provide enough data on energy expenditure to stand alone (Craig et al., 2003). Although affected by many limiting factors including recall error, floor effects and compliance, many of these subjective measurement tools can be useful if combined with the objective measurement tools described below.

**Field-Based Measurements**

*Pedometers.* Pedometers provide an inexpensive, low-technological objective method of monitoring physical activity. Evidence of reliability in laboratory conditions has shown a high correlation in test-retest probability. However, when the pedometers are placed in a real-world setting, multiple variables arise. This increases the uncertainty of the data and subsequently, the correlational equivalent decreases as well. Although pedometers have an acceptable accuracy for steps/day, they lack the ability to capture and identify the differences in type, intensity or pattern of physical activity (Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002).

*Accelerometers.* Accelerometers are small, light-weight, easy to use, and measure on multiple planes. They have the capability to capture objective data across the entire range of the physical activity spectrum. Accelerometers can be uniaxial and measure only in the vertical plane, biaxial or triaxial, which allows the device to catch acceleration in up to three dimensions. Armbands, Computer Science Applications (CSA) or TriTrac 3D
all provide energy expenditure readings. The most studied and accurate among these
physical activity monitors are the Computer Science Applications, otherwise known as
the ActiGraph. The most current software of this device allows for triaxial motion
detection, battery charge capabilities up to 30 days and uses an inclinometer to determine
participant position and times when device has been removed. It also has an ambient light
sensor to supply information on the surrounding environment. These technological
advances are significant because earlier versions of this accelerometer underestimated
energy expenditure (King, Torres, Potter, Brooks, & Coleman, 2004). The current
ActiGraph can be a reliable tool in predicting energy expenditure in control conditions
with correlations as high as $r = 0.91$ (Welk, Blair, Wood, Jones, & Thompson, 2000).

*Physical Activity as a Health Outcome*

Patient feedback and clinical evaluations are predominantly used in determining
when a patient can return to participation, however, these means are subjective and can
pose an issue. Physical activity is objectively monitored and has been used in other
patient populations to establish overall health differences, impact of disease on function
and health, and to evaluate recovery from disease or injury.

*Overall Health Differences*

Monitoring physical activity has identified functional differences in many
different populations. Physical activity has been monitored in patients with chronic
obstructive pulmonary disease (COPD) to assess physical activities in daily life. Results
suggest the use of the activity monitors positively reflected all physical activities
completed by the COPD patients (Pitta, Troosters, Spruit, Decramer, & Gosselink, 2005).
The effects of fatigue on physical activity and function in patients with Parkinson’s disease were evaluated to find the more fatigued one was, the less physical activity the subject did (Ewing Garber, & Friedman, 2003). Van Gelder et al. (2004) reported cognitive differences among older participants who walked little compared to those who walked more than three miles per day. Executive functions including “volition, planning, purposive action and response-inhibition” were evaluated in elderly patients suffering from mild cognitive impairment to find that incorporation of light physical exercise improved executive function capabilities (Scherder et al., 2005, p. 232). Physical activity has also been monitored in lower-limb amputees with results indicating an average step count of 3063 ± 1893 steps/day which is far lower than the recommended 10,000 steps/day (Stepien, Cavenett, Taylor, & Crotty, 2007).

Physical activity is sensitive to different health conditions. It is evident that disease or injury has an impact on physical activity and function. This should be true with concussions, however, studies involving measurement of physical activity following a concussion have yet to be evaluated.

*Disease Progression in Recovery*

Increase in physical activity during the recovery process has shown to be an indicator of improved health and function. Changes in physical activity in stroke patients who were monitored for 2 weeks post discharge from in-patient rehabilitation and again 3 months later noted a significant increase of 80% in step-activity monitoring (Shaughnessy et al., 2005). Upper extremity movement in stroke patients were monitored before and after 2 weeks of “constraint-induced movement therapy” to find a significant
increase from pre- to post-testing sessions in the treatment group (mean change; .08 ± .09) compared to control group (mean change; .02 ± .08) as well as a strong test-retest reliability (0.82-0.94) (Uswatte et al., 2005).

Physical activity in participants with health conditions have been compared to healthy controls to observe disease progression in recovery. Fibromyalgia (FM) and chronic fatigue syndrome (CFS) patients reported significantly different peak activity levels for patients with FM/CFS as compared to controls especially when performing high intensity physical activity. Peak activity was defined as the highest level of activity in a five minute period during the entire length of the study. Negative correlations were also found between physical activity and symptoms indicating that lower physical activity levels are related to higher symptom levels (Kop, 2005). People without peripheral arterial disease had significantly higher mean physical activity levels (1109.0 ± 640.1) compared to those with (783.8 ± 426.2) (McDermott et al., 2002). Patients suffering from chronic congestive heart failure when compared to healthy controls were considerably less active based on time of movement-related activities, mean motility and number of walking periods (Berg-Emons, Bussmann, Balk, Keijzer-Oster, & Stam, 2001). Motor fatigue and strength in patients with multiple sclerosis had declines in motor output during sustained contractions and demonstrated excess fatigue during repetitive contractions and ambulation compared to healthy controls (Schwid et al., 1999). With declination in motor output, it can be inferred that physical activity would also be significantly lower in this patient population.
In many patient populations, a positive correlation between an increase in physical activity and recovery exists. Physical activity measurements have been validated in stroke patients to reflect improvement during the recovery process. Also in comparison to healthy controls, physical activity in those suffering from chronic health conditions is significantly less. This pattern of increased physical activity during recovery should be present in other neurological impairments including concussions. For example, an athlete who sustains a concussion and has symptoms will have a significantly less physical activity level than a healthy individual. Once asymptomatic, the injured athlete should start to mimic the physical activity levels of a healthy control. However, physical activity measurements post injury and throughout the recovery process have yet to be collected and evaluated in patients suffering from concussions.

Specific Aims

Based on the increasing prevalence of sport-related concussions and the early return to play decisions of concussed athletes, it can be determined that a functional outcome measure is greatly needed. Current concussion assessment techniques only report back to the practitioner subject’s impairments and do not give insight into the subject’s function level. By measuring AC and SC, function level and overall health status can be determined. The specific aims of this project was to validate physical activity measurements collected by accelerometers as functional outcome measures during concussion recovery in athletes and to determine if there is a relationship between concussion symptoms and physical activity.
CHAPTER 3: METHODS

Overview

The purpose of this study was to validate the use of accelerometers as functional outcome measures following concussions. This study involved two phases of data collection. The first included the observation of physical activity post-concussion while symptomatic. Once asymptomatic, the second phase began which followed the change in physical activity during recovery. This chapter will describe the study design, the participants involved, the instrumentation used, the research procedures, and the data analyses.

Study Design

This study was an observational match-pair design observing athletes following diagnosis of a concussion in comparison to a healthy control matched based on age, sex, athletic position and perceived physical activity.

Participants

A total of 25 participants were recruited for the study; 14 concussed athletes and 11 matched controls. All participants were between the ages of 18 and 24 (mean age ± SD; 19.21 ± 1.1) and a member of a club sports or intercollegiate athletics. At the beginning of the season, participants were asked to sign an approved inform consent form (see Appendix A) before being enrolled in the study and could elect to withdraw at any time. The Ohio Institutional Review Board approved this study (see Appendix B).
Power Analysis

Power analysis was performed based upon pilot data of disability in the upper and lower extremity using Movement and Activity in Physical Space (MAPS) score as a functional outcomes measure. MAPS scores have shown to be a reliable method used to quantify an individual’s interaction with their environment. Physical activity is one of the three components of the MAPS score. The effect sizes to detect change in physical activity counts/day and steps/day are presented in Table 4. The smallest effect size is 1.2, yielding a minimum sample size of $n = 24$ (12 concussed, 12 control). However, due to the inconsistency of concussions, a sample size of $n = 40$ (20 concussion, 20 control) was used for this study. The figures used to calculate sample size include: projected power = 0.8, alpha = 0.05, effect size = 1.2 and Beta = 0.2.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Upper Extremity</th>
<th>Lower Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Activity Counts</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Steps/day</td>
<td>1.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Inclusion and Exclusion Criteria

All participants were between 18 and 24 years old and complied with the following inclusion criteria: a) must be a member of a club sports team or intercollegiate athletics at Ohio University or Marietta College; b) must be diagnosed with a sport-related concussion within the past 48 hours; and c) be physically capable of wearing an accelerometer. Individuals diagnosed with a history of concussion within the past 6 months or display contradicting disabilities (i.e. learning disability, attention deficit disorder, etc.) were excluded from the study.

Once a participant was recruited for the concussed group, a healthy control was chosen matched for age, sex, athletic position, perceived physical activity, and area of academic study. The healthy controls had to meet the same inclusion criteria as the concussed group and were selected shortly after a concussed participant had been recruited.

Instruments

This study used multiple instruments for data collection. All potential participants were asked to sign informed consent forms and complete an injury history form at the start of the study (prior to injury). Once, a participant was recruited for the study, they were given concussion symptom questionnaires along with an accelerometer to collect data. At the conclusion of the study, all participants were asked to complete a study feedback questionnaire to aid in further research endeavors.
**Injury History Form**

The injury history form is a 7-item screening questionnaire (see Appendix C). Demographics including age, height weight, and sex were first collected followed by questions regarding history of concussions or any other cognitive disabilities. Participants were also questioned about their current physical activity levels and given a 5-point Likert scale to rate their overall health status where 1 = excellent and 5 = poor and their general level of physical activity where 1 = not active at all and 5 = extremely active.

**Concussion Symptom Questionnaire**

The symptom questionnaire used for this study was a 22 item survey based on the Theory of Unpleasant Symptoms (see Appendix D). The Theory of Unpleasant Symptoms defines symptoms as having three major components: the symptoms themselves, the influencing factors that cause or affect the nature of the symptoms, and the consequences of the symptoms (Lenz & Pugh, 2003). In this questionnaire, 22 common symptoms following a concussion were listed and concussed participants were asked to rate each symptom based on frequency, severity, and bothersomeness. Frequency was rated on a 4-point Likert scale (0, never; 1, occasionally; 2, often; 3, always), severity was rated on a 3-point Likert scale (0, not at all; 1, somewhat; 2, a great deal), and bothersomeness was rated on a 5-point Likert scale (0, not at all; 1, a little bit; 2, moderately; 3, quite a bit; 4, extremely). Concussed participants were asked to complete the symptom questionnaire everyday until asymptomatic. Participants were given the opportunity to continue to complete the survey by hand or submit the
questionnaire electronically at the link:

https://www.assessmentcenter.net/ac1/Assessments/Concussion_Symptoms

Accelerometer

The ActiGraph GT3X+ is a small (3.8cm x 3.7cm x 1.8cm) and lightweight (27 grams) device containing a tri-axis transducer used to objectively measure physical activity (see Figure 2). The accelerometer records inclinometer, steps, and activity counts. Acceleration detection ranges in magnitude from +/- 3 Gs and the frequency response ranges from 0 to 30 Hz. The GTX3+ has a storage capacity for up to 40 days of raw data and a battery life of approximately 30 days in between charges. The acceleration/deceleration signal is digitized by an analog-to-digital converter and numerically integrated over a preprogrammed epoch interval. An accelerometer count is a summation of accelerations/decelerations measured during a set period of time (epoch). The count represents a quantitative measure of activity over time, and is linearly related to the rate of change in a subject’s physical activity during a cycle period.

The epoch in this study was set at 1-minute intervals. Each participant was asked to wear the device on their right hip at all times except when showering, swimming and sleeping (see Figure 3). A belt clip was attached to the underside of the device encouraging proper device placement and allowing for optimal data collection. Data from the accelerometer was downloaded and analyzed using the ActiGraph software provided by the manufacturer.
Figure 2. ActiGraph GT3X+ accelerometer.

Figure 3. Accelerometer placement on participant.

Study Feedback Questionnaire

The study feedback questionnaire (see Appendix E) addressed the practicality of using the accelerometers. Participants were asked to provide feedback and rate the amount of burden associated with wearing the device in hopes of making future research endeavors more comfortable for participants.

Data Collecting Procedure

Participants were recruited at the beginning of their season as part of their pre-participation exam. At this time, participants were asked to read and sign the IRB approved consent form as well as complete the injury history form. Once a concussion had been diagnosed by a supervising clinician, the researchers at the School of Applied
Health Sciences and Wellness in Grover Center of Ohio University were contacted and scheduled a meeting with the participant to begin the study. A depiction of the data collecting procedure is in Figure 4.

Figure 4. Data collection procedure. The figure illustrates the general data collecting procedure following a concussion. The concussed participant will wear equipment while symptomatic and return equipment once asymptomatic for a newly charged accelerometer to record recovery data. The healthy control will begin data collecting at the same time as the concussed participant and will continue until concussed participant has returned to participation.

Initial Injury

Following the initial injury, data collection lasted approximately 5 to 7 days. It has been found in adult men that only 3 days of data are needed to note a reliability of 0.8 in activity counts, 4 days to attain same reliability with moderate to vigorous activity, and 7 days to achieve 0.8 reliability when looking at inactivity (Baranowski, Masse, Ragan, & Welk, 2008). Because the participant was concussed and should have little to no activity, 5 to 7 days was the standard for this study.
At the first meeting, participants (both concussed and healthy-matched controls) were given instructions on wearing the accelerometer and completing the symptom questionnaire. Participants’ preferred method of contact (email, phone call, or text) for daily reminders was documented at this time. Participants were also encouraged to contact the researchers at any time if issues arose with the equipment.

During this initial injury phase, participants were instructed to place the device upon waking (or immediately after bathing or showering) on the right hip using a belt clip. Per manufacturer recommendations, participants were asked to remove the device during showering/bathing or any other water activities. Participants were also asked to complete a symptom questionnaire every day until asymptomatic. The healthy controls were given one concussion symptom questionnaire at the time of enrollment in the study to verify they were asymptomatic.

Once symptom free, concussed participants were asked to meet with the researchers to return the accelerometer. Concussed participants completed an updated symptom questionnaire to verify being asymptomatic and were given a newly charged accelerometer to begin the recovery phase of data collection.

Recovery

The recovery phase lasted approximately 5 days. This phase occurred once the concussed participant became asymptomatic. The healthy-matched controls were still involved at this time in order to use their data as a comparison for the concussed participant’s activity throughout recovery. The same instructions were given and the participants were asked to meet with the researcher in 5 to 7 days to return the
accelerometer and any other remaining documents to the researcher. The researcher then gave the participants t-shirts as compensation for their time in the study.

Data Processing Procedure

Upon conclusion of the participants’ involvement in the study, the data collected by the accelerometer was downloaded and analyzed by ActiGraph software. The data was examined to verify quality of data and to ensure that participants wore the device for a minimum of 10 hours to be considered a valid day. There is little consensus on how many hours quantify a normal active day. Multiple studies on proper wear time have found that a minimum of 10 hours will ensure participant compliance (Tucker, Welk, 2011) and many studies including the United States National Health and Nutrition Examination Survey consider 10 hours of wear time the standard for a valid measurement day. Most recently, 13 hours of wear time has been validated as an accurate measurement day (Herrmann, 2010). Our goal was to achieve at least 13 hours of wear time; however, based on our target population of college-aged participants who generally sleep for at least 10 hours a day and involve themselves in coursework an additional 3 hours a day, achieving 13 hours of proper wear time was unlikely. Once the data had been downloaded and the quality check was deemed sufficient, physical activity and steps/day were recorded for the duration of the day to get a daily total physical activity and step count. Figure 5 illustrates the data quality check and data processing procedure.
Figure 5. Data processing procedure. The protocol for checking quality data for processing is illustrated in this figure.

Data Analysis

Statistical analysis occurred based upon the following specific aims.

Specific aim 1. To validate the use of physical activity measurements collected by accelerometers as a functional outcome measure during concussion recovery. To determine if there is a significant difference in AC and SC between the concussed group while symptomatic and healthy-matched controls, an Independent t test was used with significance set at 0.05. The sensitivity of AC and SC within the concussion group was demonstrated using a Paired t test to compare symptomatic days to asymptomatic days. Significance level was set a priori at 0.05.

Specific Aim 2. To determine if there is a relationship between concussion symptoms and physical activity over time. This relationship will be assessed using a Pearson Product Moment Correlation. Alpha level was set a priori at 0.05.
CHAPTER 4: RESULTS

The purpose of this chapter is to present equipment wear time validity and to analyze the data collected by the accelerometers in conjunction with my research questions. AC and SC were analyzed to determine a difference between concussed group and healthy-matched controls and within the concussion group itself. Also, the correlation between physical activity measures and concussion symptoms was evaluated.

Wear Time Validity

As previously stated, 10 hours of proper wear time has been a standard for many studies looking at physical activity and based on our target population and participant compliance, 10 hours became a standard minimum for this research project as well. Days that did not meet the minimum requirement were discarded from data analysis.

Research Question 1

The results for research question “is there a significant difference in AC and SC from symptomatic days of concussed to healthy controls” indicated a significant difference in AC ($t_{23} = -2.252; p < 0.05$) but not SC ($t_{23} = -1.191; p > 0.05$). Mean AC and mean SC of both the concussion group while symptomatic and asymptomatic and the control group are depicted in table 4. Mean AC at symptomatic for the concussed group were 282,546 ± 113,295 counts/day at symptomatic and 315,161 ± 131,574 counts/day at asymptomatic. The mean SC while symptomatic were 8,056 ± 3,557 steps/day and 8,726 ± 4,357 steps/day while asymptomatic. The healthy matched control group reflected similar figures as the concussed group at asymptomatic with mean AC of 387,157 ± 118,003 counts/day and mean SC of 9,620 ± 2,825 steps/day. Figure 6 depicts the
significant difference in mean AC with the concussed group at symptomatic and the healthy control group. Figure 7 is a visual representation of the difference in SC between the concussed at symptomatic and the healthy controls. Figures 8 and 9 are displaying AC and SC at an individual level, demonstrating how each concussed participants’ values compare to their healthy-matched control.

Table 4

Activity Count and Step Count of the Concussed at Symptomatic and Asymptomatic and Healthy-Matched Controls (Mean ± SD)

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Concussed symptomatic</th>
<th>Concussed asymptomatic</th>
<th>Healthy control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step Count (steps/day)</td>
<td>8,056 ± 3,557</td>
<td>8,726 ± 4,357</td>
<td>9,620 ± 2,825</td>
</tr>
<tr>
<td>Activity Count (counts/day)</td>
<td>282,546 ± 113295</td>
<td>315,161 ± 131,574</td>
<td>387,157 ± 118,003</td>
</tr>
</tbody>
</table>
Figure 6. Mean AC for concussion group at symptomatic compared to healthy control. Note. AC of the concussed participants’ increases as the participants recover, however, the healthy control is still significantly higher. *Significance was found $p < 0.05$. 
Figure 7. Mean SC for concussion group at symptomatic compared to healthy control. Note that the healthy control had almost 1,000 more steps on average than the concussed group while symptomatic.
Figure 8. Mean AC for concussion group at symptomatic compared to corresponding healthy controls. In comparison to their healthy controls, 9 out of 11 symptomatic concussed participants displayed lower activity counts/day. Note only 14 concussed participants provided usable data and only 11 controls were used.

Figure 9. Mean SC for concussion group at symptomatic compared to corresponding healthy controls. Eight out of 11 controls showed higher step count values then concussed group while symptomatic. Note only 14 concussed participants provided usable data and only 11 controls were used.
Research Question 2

The results for research question “is there a significant difference in AC and SC within the concussion group at symptomatic versus asymptomatic” was not significant for AC ($t_{13} = -0.870; p > 0.05$) and with SC ($t_{13} = -0.673; p > 0.05$) The mean AC at symptomatic were $282,546 \pm 113,295$ counts/day while the mean SC were $8,056 \pm 3,557$ steps/day. As the concussed participants became asymptomatic, AC and SC increased to 315,161 ± 131,574 counts/day and 8,726 ± 4,357 steps/day respectively. Figures 10 and 11 depict the differences in mean AC and SC respectively within the concussed group at both symptomatic and asymptomatic. Figures 12 and 13 provide visual representations of AC and SC at an individual level, demonstrating how each concussed participants’ values compare symptomatic to asymptomatic.
Figure 10. Mean AC for concussion group at symptomatic and asymptomatic. Note Sx=Symptomatic; Asx=Asymptomatic. Chart is depicting the average total activity counts/day for all the concussed participants on days of displaying symptoms and then throughout recovery.

Figure 11. Mean SC for concussion group at symptomatic and asymptomatic. Note. Sx=Symptomatic; Asx=Asymptomatic. Chart is depicting the average total steps/day for all the concussed participants on days of displaying symptoms and then throughout recovery.
Figure 12. Mean AC for each concussion participant at symptomatic and asymptomatic. In 9 out of the 14 concussion cases, activity counts/day increased throughout recovery.

Figure 13. Mean SC for each concussed participant at symptomatic and asymptomatic. In 10 out of the 14 concussions, steps/day increased throughout recovery.
Research Question 3

The results for research question “is there a relationship between concussion symptoms and physical activity” did not identify a significant correlation between AC and concussion symptoms ($r = 0.25$) or SC and concussion symptoms ($r = 0.67$). However, as expected, the correlation between AC and SC was significant ($r = 0.79$).

Conclusion

A significant difference in AC for the concussed group while symptomatic was identified in comparison to healthy controls. A significant difference was not identified in AC or SC within the concussion group between symptomatic days and asymptomatic days. Also, the correlation between AC and SC did exist.
CHAPTER 5: DISCUSSION

The purpose of this thesis was to validate the use of accelerometers to measure physical activity following a concussion. This chapter will describe the interpretation of the results and apply them to clinical practice. Also, limitations of the research study are discussed as well as future research endeavors involving physical activity.

Validity of Physical Activity Between Groups

Capturing objective physical activity levels following a concussion has yet to be researched. Because this is a novel approach, literature involving physical activity and concussions are limited. However, studies involving patients with other diseases like peripheral arterial disease or fibromyalgia, found significant differences in physical activity levels in comparison to healthy controls (Kop, 2005; McDermott, 2002). The results of this study provide evidence for the use of AC as a functional outcome measure during concussion recovery. AC of the concussed at symptomatic were significant in comparison to the healthy controls and AC of the concussed group, once asymptomatic, reflected values similar to healthy controls. Also, although not statistically significant, the increase in AC and SC within the concussion group in comparison to the healthy controls displayed a similar recovery curve to a study on stroke patients that showed an increase in SC following a three month recovery period (Shaughnessy, 2005).

With reference to Figures 8 and 9 in the previous chapter, the main priority of this study was to collect data on the concussed participant as soon as the research group became aware. Because of this, finding a healthy control in some cases did not take precedence and the first three participants shown did not have a healthy control-matched
pair. The inclusion of three more controls could have increased the power to detect true differences between groups with respect to AC and SC.

Validity of Physical Activity Within Concussion Group

Although the results did not suggest significant differences between physical activity levels including AC and SC within the concussion group, positive interpretations can be made. Based on Figure 12 from the results chapter, mean AC of the concussed while symptomatic are dramatically lower than the mean AC while asymptomatic in 9 out of the 14 participants. In the five cases where symptomatic AC was not lower than the asymptomatic AC, noncompliance with the data collecting protocol was the interfering factor. Also, it can be interpreted that once the concussed participant began to feel better, they no longer had the motivation to continue wearing the device. In reference to Figure 13 of the average SC of the concussed at symptomatic compared to average SC while asymptomatic, an increase in SC throughout recovery in 11 out of 14 participants was depicted. The difference in the number of participants with significant changes between AC and SC can be explained based on what is being measured. AC measured the volume of movement occurring every minute while SC measured the quantity of steps taken. Based on this idea, the number of steps can easily be increased, by going on a 30-minute walk for example. However, if the volume of movement throughout the walk day by day does not change, then overall activity count levels maintain at the state of symptomatic or lower.

In reference to Table 4, the concussion group did in fact increase in both AC and SC between symptomatic and asymptomatic. Unfortunately, even though the concussed
group improved, they did not reflect similar values as the healthy controls. The inability
to mimic values of healthy controls could have been a direct result of noncompliance of
the concussed group once they became asymptomatic and more involved in their sport.
Another reason could be the fact that we had three less participants within the healthy
control group than concussed participants yielding higher values. It could also have
been due to the fact that the concussed participants normally have a lower (or different)
activity level than the healthy controls prior to the injury. Since no baseline is available,
this will be impossible to determine. Future studies should incorporate baseline physical
activity levels in athletes as they are recruited into the study, before they are concussed.

Physical Activity Correlation with Symptoms

The results suggested a significant correlation did not exist between AC and
concussion symptoms or with SC and concussion symptoms. The loss of correlation
between symptoms, AC, and SC could be linked to the length of the inclusion window.
Based on the literature, symptom resolution occurs $4.2 \pm 0.4$ days (McCrea et al., 2009)
after a concussion is sustained. This research study had an inclusion window of up to 48
hours. This loss of at least 2 days of symptom scores could have been the key to
achieving similar significant correlations as seen in other patient populations including
fibromyalgia patients (Kop, 2005). However, unlike other diseases, current
recommendations in treating and managing concussions are complete physical and
cognitive rest until all symptoms resolve (McCrory, 2009). Based on these guidelines, it
is understood that since we lost at least 2 days of symptomatic data with our inclusion
window, we were unable to truly relate the amount, frequency and severity of symptoms to participants’ physical activity levels.

Case of Compliance

Although the results indicated AC were significant, compliance was still an issue in this study. Those participants that showed interest and complied with the data collection guidelines resulted in positive reflections of physical activity throughout the recovery curve (see Figures 14 and 15). The participant shown here demonstrated low AC and SC while symptomatic and steadily increased while asymptomatic. A sudden decrease in AC and SC are seen on day three throughout the symptomatic recovery timeline because of their participation as a spectator at a home volleyball game. This increased their symptoms and consequently decreased their physical activity. Once asymptomatic, the participant steadily increased both their AC and SC before plateauing prior to returning to competition. Based on this, it can be inferred that physical activity, with participants’ compliance with data collection guidelines, can serve a purpose as a functional outcome measure following a concussion.
Figure 14. AC of compliant participant. AC while symptomatic increased day by day until participant went to a volleyball game on day three that worsened their symptoms resulting in lower AC on the fourth day. *Note athlete became asymptomatic on a Sunday which has been shown repeatedly to be the day with the lowest physical activity counts. Participant AC increased throughout recovery and plateaued before returning to competition on the 10th day.

Figure 15. SC of compliant participant. SC while symptomatic increased day by day until participant went to a volleyball game on day three that worsened their symptoms resulting in lower SC on the fourth day. *Note athlete became asymptomatic on a Sunday which has been shown repeatedly to be the day with the lowest physical activity counts. Participant SC increased throughout recovery before returning to competition on the 10th day.
Limitations

This study is not without limitations. One limitation was that the sample size was relatively small and comprised of college aged athletes living in small, rural college settings. In past studies looking at physical activity, the participants were observed in more controlled environments and complied more with the research guidelines unlike participants in this study. A total of 19 concussions were reported throughout the two-year study, but only 14 participants provided substantial data. Motivation could be the limiting factor in this case and it could be interrupted that if applied in a clinical setting where the data collected by the accelerometer was used as a return to play tool, athletes would have more desire to wear the device.

Participant compliance was problematic, however, compliance of clinical staff reporting concussions proved to be another limitation in this study. It was estimated that at least 16 concussions were not reported to the research group. This lack of communication between the clinical staff and research staff resulted in a significant loss of data as well as a smaller sample size than originally conceptualized.

Another limitation was manufacturing flaws with the accelerometer. Because the device is not water-proof or resistant to high impact forces, all participants were instructed to remove the accelerometer before involving themselves in any of these activities. This led to a loss of data, however, because the goal of this study is to look at physical activity throughout recovery, it is inferred that concussed athletes would not be involved in these activities until return to play has already been established. (Of course by then their participation in the study would no longer be warranted.)
Final limitations involve the data processing procedure and its availability in clinical settings. In order to properly analyze the data, an understanding of pedometers and accelerometry needs to be established with required training. Also, cost of equipment (i.e., accelerometers and corresponding software, and computers capable of storing and processing data) could be a limiting factor as well as the time constraint needed to collect, process, and analyze data.

Conclusions

Current concussion assessment tools are subjective in nature and focus on cognitive and balance impairments with the presence of signs and symptoms. Physical activity has the potential to fill the void in concussion assessment as a more objective functional measurement tool. Based on the results of this thesis, it can be concluded that physical activity and more specifically, AC can provide a detailed image of function following a concussion. For example, an athlete displaying an increase in physical activity levels throughout recovery after suffering from a concussion, in conjunction with symptom questionnaires and cognitive based measurement tools can assist athletic trainers with return to play decisions following a concussion. Of course, further research addressing the limitations should be investigated in an effort to build a stronger platform for the use of physical activity as a functional outcome measure following a concussion.
REFERENCES


Baranowski, T., Masse, L., Ragan, B., & Welk, G. (2008). How many days was that? We’re still not sure, but we’re asking the question better! *Medicine & Science in Sports & Exercise, 40*(7), S544-S549.


McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., & Cantu, R. (2009). Consensus statement on concussion in sport-The 3rd International Conference...


APPENDIX A: INFORMED CONSENT

Ohio University Consent Form

Title of Research: Development of improved functional assessment for concussions.

Researchers: Brian Ragan, PhD; Shannon David, Melissa Bartholomew, Danielle McElhiney, Shannon Nickels, James Famsworth, Chad Starkey, PhD; Andrew Krause, PhD

You are being asked to participate in research because you participate on an athletic team at Ohio University. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

EXPLANATION OF STUDY

This study is being done to get a better understanding of the injury recovery processes following concussions. The goal of this study is to create and validate an updated symptom checklist as well as validate the use of total activity counts, movement, and physical activity scores (MAPS), for assisting in return to play decisions following Mild Traumatic Brain Injury (MTBI) or concussions.

Upon agreeing to participate in this study, you will first complete a baseline concussion assessment including the Modified Standardized Assessment of Concussions and health history form.

If you experience a concussion or are identified as a match to another participant that has a concussion, you will be asked to complete an online symptom questionnaire daily following a concussion received during the athletic season until you have returned to baseline or asymptomatic, and to wear GPS, and accelerometer devices for a period of five days following injury. Once you become symptom free you will meet with researchers to wear the device for another five days. To help test the accuracy of the instruments you will be asked to fill out a travel diary that discusses where you have traveled, what you did at those locations, and at what times you were at those locations. It will take you approximately 10 minutes each day to fill out the symptom questionnaire, a total of 5 minutes throughout the day to fill out the travel diary. Wearing the GPS and accelerometer takes the same amount of time it takes to clip a cell phone to your waist. You will be asked to meet with researchers a total of five times to receive and return equipment throughout the study. It is also possible that if you do not experience a concussion you might not be asked to serve as a healthy match, which means you have no further participation in the study.

You should not participate in this study if you have experienced a concussion in the last six months, are not physically able to wear a GPS and accelerometer device, or have a history of learning disability, seizure disorder, attention deficit disorder, or other mental/physical disability that would hinder your participation in this study.

Your participation in the study will last approximately 10 days following a concussion or as a healthy matched participant.

Declining or withdrawing from this study will not affect status within the school or on an athletic team.
Risks and Discomforts

The GPS and accelerometer devices are approximately the size of a small cell phone and should not have any effect on your daily activities. You can easily attach the devices to a belt or place them inside your pocket. There are no anticipated risks associated with this study.

Benefits

Through this study the academic community will gain useful information about the reliability of determining when an athlete can return to play. The population that will benefit from this research is wide spread, including, coaches, allied health professionals, and most importantly the athletes. It could help change the way athletes are evaluated for concussions and help determine better protocols for return to play. You will benefit from this study by receiving a physical activity assessment.

Confidentiality and Records

Your study information will be kept confidential by assigning codes to your information. The codes will be matched with a master’s list kept in a locked cabinet. Your personal information will not be used in the study. Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:
* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

Compensation

As compensation for your time/effort, you will receive a t-shirt upon return of the research equipment at the end of the study.

Contact Information

If you have any questions regarding this study, please contact James Farnsworth (919)244-1003, Danielle Mc Elhiney (413)221-3187, Shannon Nickels (904)327-5005, Shannon David (740)593-0935, Melissa Bartholomew (707)372-9786, or Dr. Brian Ragan (740)597-1876

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- You have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- You may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature ___________________________ Date ____________________________

Printed Name ___________________________  

Version Date: 12/15/2010
APPENDIX B: INSTITUTIONAL REVIEW BOARD APPROVAL

The following research study has been approved by the Institutional Review Board at Ohio University for the period listed below. This review was conducted through an expedited review procedure as defined in the federal regulations as Category(ies):

4, 6, 7

Project Title: Development of Improved Functional Assessment for Concussions

Primary Investigator: Brian Ragan
Co-Investigator(s):
  Shannon David
  James L. Famsworth
  Shannon Nickels
  Chad Starkey
  Danielle McElhinney
  Neilsa Bartholomew
  Andrew Krause

Faculty Advisor: Brian Ragan
Department: Athletic Training

Robin Stack, CIP, Human Subjects Research Coordinator
Office of Research Compliance

Approval Date: Oct. 21, 2011
Expiration Date: Oct. 20, 2012

This approval is valid until expiration date listed above. If you wish to continue beyond expiration date, you must submit a periodic review application and obtain approval prior to continuation.

Adverse events must be reported to the IRB promptly, within 5 working days of the occurrence.

The approval remains in effect provided the study is conducted exactly as described in your application for review. Any additions or modifications to the project must be approved by the IRB (as an amendment) prior to implementation.
APPENDIX C: INJURY HISTORY FORM

Injury History Form

Name: _______________________________ Date: __________________

Ht. ________  Wt. ________  Age: ________  Gender:  M  F

1. Do you participate in a club sport or intercollegiate sport at Ohio University? If yes, please list sports in which you participate:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

2. Do you have a history of concussions? If yes please explain: Yes_____ No_____

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

3. Do you have a history or diagnosis of a learning disability, seizure disorder, attention deficit disorder, or other mental disability? If yes, please explain: Yes_____ No_____

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

4. Do you currently have any other injury or condition that limits your activity level or hinder your participation in this study? If so please explain: Yes____ No_____

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

5. Are you currently physically active usually exercising 30 minutes per day, 3-5 days per week?

   Yes____  No____

6. How would you rate your overall health status?

   1 = excellent   2   3   4   5 = poor

7. How would you rate your general level of physical activity?

   1 = not active at all   2   3   4   5 = extremely active
APPENDIX D: CONCUSSION SYMPTOM QUESTIONNAIRE

Symptom Questionnaire

The following questions ask about symptoms that are commonly associated with concussions. For each symptom you will be asked how frequently it occurs (How often you have the symptom), how severe it is (the intensity of the symptom), and how much it bothers you (the amount of distress it causes you). If your response to the frequency of the symptom question as never you may skip the questions regarding the severity and how much the symptom bothers you and proceed to the next symptom. Please consider your experience with each symptom and circle the number that is the best response.

1. **HEADACHE**

   How OFTEN did you experience a **HEADACHE**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

   How SEVERE was your **HEADACHE**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

   How much did your **HEADACHE** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

2. **PRESSURE IN YOUR HEAD**

   How OFTEN did you experience **PRESSURE IN YOUR HEAD**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

   How SEVERE was the **PRESSURE IN YOUR HEAD**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
How much did the **PRESSURE IN YOUR HEAD** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 3. Neck Pain

How **OFTEN** did you experience **NECK PAIN**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was your **NECK PAIN**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **NECK PAIN** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 4. NAUSEA OR VOMITING

How **OFTEN** did you experience **NAUSEA OR VOMITING**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was your **NAUSEA OR VOMITING**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **NAUSEA OR VOMITING BOTHER** you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
5. **Dizziness**

How **OFTEN** did you experience **Dizziness**?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was your **Dizziness**?

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **Dizziness** **BOther** you?

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

6. **Blurred Vision**

How **OFTEN** did you experience **Blurred Vision**?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was your **Blurred Vision**?

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **Blurred Vision** **BOther** you?

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

7. **Balance Problems**

How **OFTEN** did you experience **Balance Problems**?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
How SEVERE was your **BALANCE PROBLEMS**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **BALANCE PROBLEMS** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 8. SENSITIVITY TO LIGHT

How OFTEN did you experience **SENSITIVITY TO LIGHT**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your **SENSITIVITY TO LIGHT**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **SENSITIVITY TO LIGHT** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 9. SENSITIVITY TO NOISE

How OFTEN did you experience **SENSITIVITY TO NOISE**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your **SENSITIVITY TO NOISE**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
How much did your **SENSITIVITY TO NOISE** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

10. **FEELING SLOWED DOWN**

How **OFTEN** did you experience **FEELING SLOWED DOWN**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was **FEELING SLOWED DOWN**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did **FEELING SLOWED DOWN** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

11. **FEELING LIKE “IN A FOG”**

How **OFTEN** did you experience **FEELING LIKE “IN A FOG”**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was **FEELING LIKE “IN A FOG”**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did **FEELING LIKE “IN A FOG”** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
**12. NOT FEELING RIGHT**

How OFTEN did you experience **NOT FEELING RIGHT**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was **NOT FEELING RIGHT**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did **NOT FEELING RIGHT** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**13. DIFFICULTY CONCENTRATING**

How OFTEN did you experience **DIFFICULTY CONCENTRATING**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your **DIFFICULTY CONCENTRATING**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **DIFFICULTY CONCENTRATING** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**14. DIFFICULTY REMEMBERING**

How OFTEN did you experience **DIFFICULTY REMEMBERING**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
How SEVERE was your **DIFFICULTY REMEMBERING**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **DIFFICULTY REMEMBERING** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**15. FATIGUE OR LOW ENERGY**

How OFTEN did you experience **FATIGUE OR LOW ENERGY**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your **FATIGUE OR LOW ENERGY**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **FATIGUE OR LOW ENERGY** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**16. CONFUSION**

How OFTEN did you experience **CONFUSION**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your **CONFUSION**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **CONFUSION** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
17. DROWSINESS

How OFTEN did you experience DROWSINESS?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your DROWSINESS?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your DROWSINESS BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

18. TROUBLE FALLING ASLEEP

How OFTEN did you experience having TROUBLE FALLING ASLEEP?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your TROUBLE FALLING ASLEEP?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your having TROUBLE FALLING ASLEEP BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

19. EMOTIONAL

How OFTEN did you experience being MORE EMOTIONAL?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
How SEVERE were your EMOTIONS?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your EMOTIONS BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

20. IRRITABLITY

How OFTEN did you experience IRRITABLITY?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your IRRITABLITY?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your IRRITABLITY BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

21. SADNESS

How OFTEN did you experience SADNESS?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How SEVERE was your SADNESS?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
How much did your **SADNESS** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**22. NERVOUS OR ANXIOUS**

How **OFTEN** did you experience being **NERVOUS OR ANXIOUS**?

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

How **SEVERE** was your **NERVOUSNESS OR ANXIOUSNESS**?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Somewhat</th>
<th>A Great Deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

How much did your **NERVOUSNESS OR ANXIOUSNESS** BOTHER you?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderately</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
APPENDIX E: STUDY FEEDBACK QUESTIONNAIRE

STUDY FEEDBACK QUESTIONNAIRE

1. Was the GPS receiver or accelerometer difficult to wear?

2. Did the GPS receiver or accelerometer interfere with any of your daily activities?
   Yes    No
   If yes, please explain the interference: ______________________________________

3. Would you do another study if it required you to wear a GPS receiver or accelerometer?
   Yes    No

4. Did you use the bell around a door knob to help remind you to have guests fill out the Guest Log?
   Yes    No

5. Please check which of the following helped remind you to wear the accelerometer (check all that apply):
   □ I did not need a reminder
   □ Yellow reminder cards placed around the house (i.e. bathroom, fridge, etc.)
   □ Call/Text/Email Reminder from lab researcher
   □ Leaving the accelerometer in a designated location (please specify): ______________

6. Please provide any additional comments about the GPS receiver or the study.