Validation of the Rest and Neurocognitive Recovery Concussion Application as a

Physical and Cognitive Rest Measure

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This thesis titled

Validation of the Rest and Neurocognitive Recovery Concussion Application as a

Physical and Cognitive Rest Measure

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Abstract

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Context: Current concussion guidelines call for physical and cognitive managed rest following a concussion. To better treat concussed athletes and evaluate these guidelines, objective monitoring measures are needed. The Rest and Neurocognitive Recovery Application (RNRCA) was developed for the concussed athlete and health care provider to assist in tracking concussion symptoms, daily activities, and overall wellbeing of the athlete. **Objective:** To validate the use of the RNRCA in monitoring physical and cognitive activity when compared to an Activity Diary. **Participants**: Participants who volunteered for the study were college students, intercollegiate athletes, and club sport athletes, all over the age of 18. Concussed participants were diagnosed with a concussion by a licensed athletic trainer during their regular sports season. **Interventions:** The study was 5 days and the AD and RNRCA were completed once every 24 hours. RNRCA logs were sent directly to the primary investigators e-mail and forwarded to the designated team athletic trainer. ADs were collected following completion of the study. Main Outcome Measures: Descriptive statistics, dependent *t*-tests, and intraclass correlations were run for all activities comparing the Activity Diary and RNRCA activity logs. **Results:** No physical, cognitive, or electronic activities showed significance when comparing the two devices that collected activity data. Behavioral activities that were

most highly associated with concussion symptoms were reading, watching television, attending class, and exercising. **Conclusions:** RNRCA successfully collected physical and cognitive activity data in sequence to an Activity Diary. Higher power is needed in order to validate the use of the application with concussed subjects.

Dedication

"The greater the obstacle, the more glory in overcoming it."

— Molière

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Chapter 1: Introduction

Concussion is at the forefront of both the medical literature and media attention.^{1,2} Researchers are currently searching for a more effective way to diagnose the injury, as well as return athletes safely to sport following injury.³ Concussion evaluation tools and methods continue to be analyzed, as there are no direct objective measures for diagnosis of the injury, leading to frustration and difficulties for health care providers.⁴

Concussion may cause physical, cognitive, emotional, and sleep disturbances that can vary from minutes to months in length, and in some cases even years.⁵ Acute concussion symptoms refer to the disturbances noticed by athletes and health care providers, such as headache, difficulty concentrating, and sleep disturbances. Concussion symptoms tend to resolve within 7 to 10 days following injury. However, persistent symptoms (> 10 days) are reported in 10% to 15% of diagnosed concussions and may persist for months to years.⁶ This variability in symptom type and duration dictates the need for individualized injury management for concussed athletes.

The current management protocol for concussed athletes includes physical and cognitive rest until the acute concussion symptoms are resolved.⁶ As previously stated, there is currently no objective tool or device for monitoring the physical and cognitive rest protocol. Because all symptoms are self-reported by concussed patients, it is unknown what triggers concussion symptoms or how much cognitive and physical rest is necessary for a full recovery from a concussion. There is sparse published evidence regarding the effectiveness of rest following concussion diagnosis.⁶

Concussion Monitoring Device

This study tested the feasibility of using a newly developed monitoring device in the assessment of cognitive and physical rest of concussed athletes. The Rest and Neurocognitive Recovery Concussion Application (RNRCA) was developed as a means of communication between the concussed athlete and health care provider during concussion recovery. The application was designed to collect athletes' concussion symptom scores and overall activity level as a means not only to monitor the recovery process objectively but also to assess activities that worsen concussion symptoms.

Using the smart phone application "RNRCA" as means of communication between athlete and health care provider is a realistic and convenient method for high school or college students. Smart phones appear to be a popular means of communication for this generation. In a study completed in 2012, it was found that 95% of college students bring their cell phone to class every day.⁷ Due to cognitive rest protocol, it is unknown if individuals should refrain from cell phone use during concussion recovery because of the demands required to use the device. Refraining from using one's cell phone may require cognitive effort, such as anxiety and stress. It has been shown that monitoring one's cell phone has become an automatic response in college students.⁸ This study will aim to determine if cell phone use exacerbates concussion symptoms during recovery.

In order to validate the new device, an Activity Diary (AD) will be used to monitor participant activity. ADs have been validated to successfully collect energy expenditure data when compared to accelerometers.⁹ The device is commonly used with accelerometry in order to collect more descriptive findings, such as type and intensity of activity.¹⁰

ADs were used in a study measuring children's compliance to rest after being diagnosed with a mild traumatic brain injury.¹¹ The study concluded that patients who were advised to decrease activity had a lower level of energy expenditure, therefore, following the recommendations provided by physicians. The ADs had a 44% compliance rate of diary completion.¹¹ The children's compliance in the rest study had similar methodology to our current study, hypothesizing that an AD will successfully track physical and cognitive activity in the injured population.

Statement of the Problem

Many aspects of the recovery process of a concussive head injury are still unknown. Recent research shows both positive and negative findings when physical and cognitive rest have been prescribed to athletes recovering from concussive injury.^{12, 13} A study of high school and collegiate athletes who were prescribed 1 week of physical and cognitive rest showed improvement on post-concussed assessment testing.¹³ In comparison, a study published in 2013 recommending only cognitive rest showed no significant association between rest and time of concussion symptom resolution.¹²

A recurring problem in these previous studies is the lack of objective measures during the prescribed rest. Without objective monitoring, it is difficult to assess patient compliance and adherence to these rest recommendations, as well as to determine which activities worsen concussion symptoms. Specifically, it is difficult to limit cognitive activity in all its forms. Another challenge is the difficulty achieving consensus among health care providers regarding patient education about concussion. The meaning of "rest" differs among individuals; some health care providers may advise patients to avoid the use of electronics while others will not. If health care providers were able to advise patients consistently on what activities to avoid throughout recovery, patient compliance might increase.

Purpose of the Study

The primary purpose of this study is to validate the RNRCA compared to an AD used by concussed and nonconcussed athletes. The RNRCA is a newly innovated device designed for the purpose of collecting and relaying information from concussed athletes to their health care providers. This is the first study to be completed using an application for this purpose.

There are several secondary reasons for the research project. A secondary purpose is to investigate specific behaviors that worsen or prolong concussion symptoms during recovery. It is hypothesized that certain activities requiring high degrees of cognitive function may aggravate concussion symptoms and extend the recovery process. Cognitive function is related, but not limited, to attending classes, meetings, socializing, or concentrating on a television screen or program. Finally, this study proposed to determine if electronic devices (eg, cell phones, computers, tablets) place cognitive stress or promote ease of stress on the concussed athlete. This will inform health care providers whether electronic devices should be reduced or restricted during recovery in order to limit cognitive function, or if doing so will cause anxiety and stress.

Significance of the Study

The goal of this research study was to implement a monitoring regimen to assist in concussion recovery. A monitoring regimen will help health care providers better understand the recovery period of a concussion and the impact that physical and cognitive rest has on the injury. There are few published works illustrating ways to assist the concussed athlete back to sport participation. The 2012 Consensus Statement on Concussion in Sport states that further research is needed in order to evaluate the effects of rest, including the optimal amount and type of rest.⁶ This research project aims to provide answers to the health care field.

In addition to supplying needed research in the field, the device is also proposed to serve as a clinical tool to objectively monitor athletes as they progress back to sport participation. The application serves to remove communication barriers between athletes and health care providers about symptoms and to promote increased monitored activity throughout recovery.

Research Questions

The research questions guiding this thesis were:

- 1. Is the RNRCA a valid tool when collecting physical and cognitive activity information from concussed athletes?
- 2. Which behavioral activities worsen symptoms during concussion recovery?
- 3. What effect does electronic usage have on cognitive stress during concussion recovery?

Hypothesis

The hypothesis relating to the research questions for this thesis were:

- We believe the RNRCA is a valid tool as indicated by preliminary research studies completed using nonconcussed participants.
- We believe any activities requiring high brain function (> 3 on RPE scale) will worsen concussion symptoms. These activities include participating in classes, doing homework, reading, running, or weight lifting.
- We believe that electronic usage will worsen concussion symptoms due to the highly lit screens, concentration on small words, and the excessive amount of time spent on these devices.

Limitations of the Study

Limitations of the study include:

- 1. The number of participants used in the study was limited.
- 2. Most athletes were collegiate hockey players, limiting the variety of sport.
- 3. The quality of data collected was dependent on the compliance from the athletes.
- 4. The accuracy of subjective data was dependent on the athlete.
- 5. Concussions were diagnosed primarily by certified athletic trainers rather than sports physicians.

Definitions of the Key Terms

Cognitive rest. Decrease in/or lack of activity involving brain function. Decrease in activities involving concentration, memory, and association with others.Concussion. Concussion is defined as a traumatically induced transient

disturbance of brain function and involves a complex pathophysiological process.¹⁴

Objective measure. Unbiased analysis of a task or activity

Physical rest. Decrease in/or lack of activity that stimulates the body's

physiological system. Any type of exercise (walking, biking, running, weight

lifting) increasing heart rate is not recommended or permitted.

Rest. Decrease in/or lack of physical and cognitive activity.

RNRCA. Rest and Neurocognitive Recovery Concussion Application, a device developed to collect information from concussed athletes and relay to health care provider.

Chapter 2: Literature Review

Introduction

Although concussion is at the forefront of both the medical literature and the media, it remains an injury that continues to be investigated due to the lack of effective evaluation and treatment protocols.³ Concussions are caused by direct or indirect forces to the head that result in disturbances of brain function.¹⁵ Athletes need to be aware of the signs and symptoms of a concussion in order to report these symptoms to the athletic trainer or team physician. Currently the intervention of a concussion includes managing the experienced concussion symptoms with cognitive and physical rest.⁶ This may include the avoidance of daily activities such as exercising, attending classes, and socializing with peers.¹⁶ Athletes' adherence to cognitive and physical rest is needed in order to avoid exacerbating concussion symptoms and delaying recovery.⁶

Concussion

A concussion is a functional, rather than structural, injury caused by forces transmitted to the brain tissue. Concussions can have many mechanisms of injury: rotational or angular forces, direct impact to the head, or forces transmitted from diverse body parts to the head.^{6,17} Concussions cause a disturbance in brain function that may result in physical, cognitive, emotional, and sleep dysfunction.⁵ Headache is the most common symptom experienced by concussed individuals; other common symptoms include dizziness, disorientation, and balance disturbance.¹⁵ Lists of commonly reported concussive symptoms are shown in Table 1.¹⁸

Physical	Cognitive	Emotional	Sleep
Headache	Difficulty concentrating	Anxiety	Drowsiness
Blurred vision	Difficulty remembering	Nervousness	Increased sleep
Dizziness, poor balance	Disorientation	Irritable	
Fatigue	Feeling slowed		
Light sensitivity	down		
Nausea			
Noise sensitivity			

 Table 1. Signs and Symptoms of Concussion Head Injury¹⁸

Pathophysiology. When a concussive injury occurs, neural membranes are disturbed resulting in a potassium efflux into extracellular spaces.¹⁵ When potassium levels are altered, the overall pH level inside the cell is altered.² Following the efflux of potassium is an influx of calcium and excitatory amino acids into the cells,¹⁵ followed by further efflux of potassium.¹⁹ This large disruption in pH level suppresses neuron activity in the affected cells. The sodium-potassium pump is enabled to restore the balance within cells; this increases energy requirements of the cells.²

In the acute phase of a concussion there is a paradoxical decrease in cerebral blood flow. This lack of blood flow is prolonged in early adolescent patients when compared to older individuals, creating an increase in metabolic need from the neurons and axons in the surrounding cells.² During an altered period of pH, the mitochondria are unable to function normally.² This prevents them from creating the large amounts of ATP that are needed for cells to function normally, resulting in decreased brain functioning that is noted the first several days following a concussive injury.² This is frequently referred as neurometabolic cascade of a concussive head injury.

Incidence. Concussion frequency varies within athletic age groups. A U.S. epidemiological study in 2007 concluded that concussions represent 8.9% of high school athletic injuries and 5.8% of collegiate athletic injuries.²⁰ Athletes are three to six times more vulnerable to suffer from subsequent concussion if they have sustained previous concussions.²¹ Therefore, by the time athletes have reached the collegiate level the likelihood of having a history of concussions is greater when looking at their risk over time.

An epidemiological study was conducted using the National Collegiate Athletic Association injury database and a variety of collegiate sports from1997 through 2000.²² Over this 3-year study, concussions accounted for 6.2% of all injuries when examining the data of all sports teams.²² The highest concussion incidence included women's lacrosse (13.9%), women's soccer (11.4%), men's ice hockey (10.3%), men's lacrosse (10.1%), men's football (8.8%), and women's basketball (8.5%).²² The researchers concluded that concussion incidence continues to increase for collegiate athletes participating in collegiate football, men's soccer, and men's and women's basketball.²² Covassin, Swanik, and Sachs found that football athletes were 10 times more likely to suffer a concussion during a football game than during practice (2003).²² Similarily,

hockey players are 15.5 times, and soccer players 21.9 times more likely to suffer a concussive injury during a game than during practice. Overall, female athletes were found to be at a greater risk of suffering a concussion during games than male athletes.²² To substantiate these statistics, an article published in 2009 concluded that concussions are most common in contact sports such as hockey and football.²⁰ Concussion incidence in noncontact sports were greatest in: soccer, basketball, lacrosse, and wrestling.²⁰ Conclusively, these statistics provide athletic trainers and sports administrators means for developing prevention plans and help identify which high-risk sports require comprehensive concussion assessment.

Following diagnosis. Acute concussion describes the days directly following injury. Generally, concussion symptoms will present immediately upon injury and will commonly last for less than 72 hours; this is considered the acute phase of a concussion.²³ It is also plausible for concussive symptoms to appear several hours following the injury.¹⁵ Late onset of symptoms does not indicate that the concussion is of a greater magnitude, but athletes need to be aware of the possibility. Concussion symptoms are the deficiencies that are evident to the athlete, such as headache, fatigue, and dizziness.

When relating to the overall impairments of a concussive injury, symptoms are not the only deficiency. Other deficiencies involved are cognitive impairments, such as decreased speed and reaction time. Most concussions (80% to 90%) will be completely resolved within 7 to 10 days.⁶ There are many instances, especially in children and adolescents, in which the time to resolve is longer, which emphasizes the importance of treating each concussion individually.⁶

The literature has shown that there is a difference between concussion patients being symptom free (headache, dizziness, nausea, etc.) versus impairment free (difficulty concentrating, decreased reaction time, etc.). Studies have examined concussion patients who are symptom free; however, neurocognitive testing is not yet standardized throughout health care providers.²⁴ This was evident in a study on high school and collegiate athletes who performed neurocognitive testing (e.g., reaction time and processing speed) on day 7 post concussion compared to age-matched uninjured controls. The study showed that the high school athletes who had suffered a concussion performed significantly worse than the controls 7 days post injury, while the collegiate athletes may no longer be reporting symptoms, they still show a decrease in neurocognitive activity. Factors such as reaction time and processing speed may be better indicators of concussion recovery than simply recovering from symptoms, especially in younger athletes.

Concussion Assessment Tools

Assessment tools are used to diagnosis and monitor the recovery of a concussion.¹⁵ There are several concussion evaluation methods available, including symptom checklists, neuropsychological tests, balance tests, and sideline assessment tools.¹⁵ Loss of consciousness occurs in less than 10% of concussed individuals; however, if loss of consciousness is evident with injury, further imaging should be ordered.²⁵ Imaging, such as radiographic and magnetic resonance, is commonly overused and has little effect on the diagnosis of a concussion. Imaging should strictly be used to rule out more serious brain injuries, such as a skull fracture, intracranial hemorrhaging, and cervical spine injuries.⁶ Plain radiographs have no influence on the diagnosis of a concussion; magnetic resonance imaging acutely can be appropriate for evaluating prolonged deficits.⁵

As more research is completed, concussions are being managed with similar or the same tools with which they are being evaluated. Assessment tools are initially used to evaluate a concussed individual then are used to monitor the injury during recovery. Symptom checklists, neurophysiologic testing, and posture stability testing should all be returned to normal, or baseline, before an athlete begins their return to sport protocol.²⁶

Concussion Interventions

Because there are no specific treatments used for concussed athletes, managing and limiting aggravation of these symptoms is the main treatment protocol.⁶ An athletic trainer's immediate concern should be for their athlete's safety and readiness to resume daily activities. It is important to recognize that student athletes recovering from a concussive injury will face challenges with their academic performance as well as with returning to team events. Until acute symptoms resolve, cognitive and physical rest is used as the cornerstone of concussion management.⁶

Physical rest. The initial management of a concussed individual until acute symptoms resolve should include physical rest. In order to avoid aggravating symptoms and delaying recovery physical rest should be implemented.⁶ The amount of rest needed is unknown at this time; it has been shown that 24-48 hours post-injury rest is appropriate.⁶ As demonstrated in Table 2, physical rest involves more than the absence of team practices and games, because any rise in heart rate above rest can add stress to the

overall bodily functions. Activities that cause or worsen concussion symptoms should be avoided. Table 2 identifies the common activities that may aggravate concussion symptoms. Activities that do not exacerbate symptoms may be performed.⁶

Location	Example of Activity			
Home	Avoid household chores, running errands, stairs, sexual activity, dancing, outside chores			
School	Avoid walking to class, standing for prolonged periods, stairs, rushing between classes, socializing with peers			
Sport	Avoid aerobic exercise (walk, run, bike, swimming), lifting weights, team practices, team fitness or training, team games, pick- up, drills			

Table 2. Physical Rest Recommendations for a Concussion Head Injury¹⁵

Acute exercise has a negative effect on brain recovery immediately following injury when physical rest is needed;²⁷ however studies have shown that moderate exercise following the vulnerable symptomatic phase can have a positive effect on improving cognitive function.^{27,28} During the subacute phase of the injury, once concussion symptoms have resolved, exercise has been shown to contribute safely and constructively to the rehabilitation of concussed patients.²⁷ Some clinicians perceive physical rest to be of limited use following the 7-10 day time period of neurometabolic cascade.²⁹ Low-level exercise following concussive injury may be beneficial; however, the optimal time to wait following injury is unknown.⁶ A study performed in 2011 revealed that 36% of adolescent athletes continued to have decreased cerebral blood flow when compared to nonconcussed controls 1 month after concussive injury.¹⁶ This may support the notion of a prolonged period of rest when relating back to the neurometabolic cascade after concussions in the adolescent athletes.

Cognitive rest. Cognitive activity can lead to exacerbation of concussion symptoms, an indication from the brain that the neurometabolism is being pushed too far.³⁰ In order to avoid exceeding this threshold, athletes recovering from concussion need to limit the amount of cognitive activity in which they partake. It is common for physical rest to be administered in concussion treatment protocols until the athlete is fully asymptomatic; however, cognitive stimuli are more difficult to limit. Mental exertion can be reached by a variety of activities. All actions require some degree of cognitive function; these are highlighted in Table 3. Because it is not realistic to reach a state of no cognitive activity, unless sleeping, athletes need to refrain from cognitive stimulus that re-creates symptoms.³⁰

Location	Example of Activity
Home	Avoid text messaging, computer usage, watching television, attention needed while cooking or performing a task, bright lights, loud sounds
School	Avoid communication with large groups, concentrated or attention needed conversation, concentrating on schoolwork/chalk board/speaker, concentrating on assignments or tests
Sport	Avoid concentrating on plays or drills, being in a loud or bright environment

Table 3. Cognitive Rest Recommendations for Concussion Head Injury¹⁵

The Student-Athlete

Student athletes are unique in the sense that they have two major commitments to uphold when in school: success in education and in sports. In addition to these large commitments, students are subject to a social environment. When concussed, this creates added pressure on the student-athlete. Being taken out of sport due to physical rest requirement is guaranteed; in addition, the student may need to be taken out of class and limit their social interactions.

Implication of studies. When relating back to the pathophysiology of a concussive brain injury, it is evident that both physical and cognitive activity is influenced by the metabolic derangement that occurs in the brain, resulting in reduced energy for the typical demands of the day.² The biggest barrier to the overall well-being of the student is whether or not they should attend classes at time of injury. A study by

Moser and colleagues in 2012 suggested that 1 week of complete cognitive rest during the acute or subacute healing phase may decrease concussion symptoms and assist in athletes' overall cognitive performance.¹³ When relating this practically, if being in class worsens the patient's symptoms, whether it is due to the bright lights, loud sounds, or concentration needed in class, then prescribed absence from class may be a good recommendation for that particular student. As the patient becomes less symptomatic and is able to concentrate for a specific amount of time, for example 30 minutes to 2 hours, then the student can begin integrating class back into their daily schedule. Grady and colleagues (2012) recommend keeping the student-athlete home for 1 to 3 days following injury as this is when the brain is in the greatest dysfunction due to the energy crisis caused by the concussion.² As student-athletes recover from the concussive injury, their tolerance for cognitive activity will increase with recovery.³⁰ A concussion is manageable throughout the education system as long as health care providers, student-athletes, and educators are communicating effectively regarding the well-being and overall health of the student-athlete.

Return to Play

Following a concussion, athletic trainers should monitor their athletes up to and following being asymptomatic at rest. Athletes should be evaluated using the symptom checklists, postural stability tests, and a neurophysiologic test to ensure they have returned to their personal "normal."¹⁵ Once asymptomatic at rest, the athletes can begin to progress through a step-by-step increase in physical exertion levels.³¹ The stepwise exertion protocol is demonstrated in Table 4.

Step	Type of Activity		
1	Asymptomatic at rest		
2	Light aerobic activity (walking, stationary bike). Less than 70% of MHR		
3	Sport-specific activity/training (intervals for football players, skating for hockey)		
4	Non-contact training drills, sport specific		
5	Full-contact practice training		
6	Game play		

Table 4. Stepwise Exertion Protocol to Return to Play from a Concussion Head Injury³¹

Between each exertion phase, a minimum of 24 hours is necessary for the body to react to the increased metabolic demands of the exertion. When athletes are symptom free for at least 24 hours, they are able to proceed to the next step in the return-to-play protocol.³¹ If any concussive symptoms return with this activity, athletes need to rest for 24-48 hours or until asymptomatic before repeating this step.³¹

Rehabilitation Adherence

Concussions relate directly to musculoskeletal injuries when looking at patient adherence. Concussed individuals are commonly asked to attend athletic training and physician appointments, follow instructions, and do home exercise tasks just as an injured athlete would. However, as indicated in the research, the rates of adherence to these tasks are not consistent.³²

A positive association is observed between high adherence to rehabilitation programs and favorable treatment outcomes. There are several predictors that may influence athletes' commitment to a rehabilitation program: personal characteristics, situational characteristics, cognitive responses, emotional responses, and behavioural responses.³² A study by Byerly et al. (1994) revealed that the greatest predictors of adherence to athletic rehabilitation programs were pain management and emotional support.³³ If athletes experience a decrease in pain during or following rehabilitation they are more prone to adhere to their rehabilitation program. In addition, if athletes are supported emotionally by fellow teammates, team medical staff, coaches, or parents, they are more likely to adhere to the rehabilitation program.³³

Monitoring Devices

The National Athletic Trainer's Association, The American College of Sports Medicine, and the latest Zurich concussion consensus statement all generally agree that cognitive and physical rest should be maintained until acute concussion symptoms resolve. ^{6,34,35} However, compliance with these guidelines is solely based on patient report; currently, there are no objective ways of monitoring this compliance. We are unable to determine if athletes are adhering to these recommendations. To date, physicians and athletic trainers have no way to monitor athletes' physical and cognitive rest after concussive injuries.

Accelerometer. In order to develop an objective monitoring device for concussed athletes, both physical and cognitive activity needs to be quantified. By quantifying athletes' activity levels, researchers and health care professionals can correlate these levels with concussion symptoms. Accelerometry can be used to track individuals' physical activity within their living environments.

Accelerometry is a cost effective and easily reproducible way to collect physical activity data with minimal interference with individuals' everyday living.³⁶ The Actigraph GTX3 accelerometer device, is approximately 6x9x2cm in size and 85g in weight.³⁷ Due to the light weight and convenience of the device, individuals should be able to wear the accelerometer discreetly throughout the day.³⁶ Although accelerometers are not recommended for wear during contact sports activity, the device can be worn noninvasively while walking, running, sitting, or laying down. The ActiGraph accelerometer collects motion data on vertical, horizontal (right-left), and horizontal (front-back) axes.³⁸

The accelerometer detects and records body accelerations ranging in magnitude from approximately 0.05g to 2.5g. This output is digitized by a 12-bit analog-to-digital converter at a rate of 30Hz; the signal then passes through a digital filter that changes the frequency range to 0.25-2.5Hz. The filter signal is enhanced over a user-specific interval, known as an epoch. Each epoch stores the amount of activity for that specific time period and then the integrator is reset.³⁹ ActiGraph computes participants' activity in epochs (counts per minute) to the data analyzer.

Reliability of accelerometry. The ActiGraph accelerometer, being an uniaxial device, is one of the most widely used motion sensors in studies involving adolescents.³⁹ In a study done by Vanhelst et al. (2012), a strong reliability was shown between physical activity levels of adolescents and patterns demonstrated by an uniaxial and triaxial

accelerometers. The concordance correlation coefficient between the uniaxial and triaxial accelerometer types was superior to (r = 0.95).⁴⁰ ActiGraph accelerometers have demonstrated the ability to distinguish between different physical activity intensities and modes, showing high reliability in all planes of movement.³⁸ A study by Santos-Lozano et al. (2012) presented intraclass correlation coefficients (ICC) in regards to each axis. The ICC values ranged from 0.92-0.99 for the y-axis, 0.93-0.99 for the x-axis, and 0.98-0.99 for the z-axis.³⁸

One factor that relates to the reliability of the device is the positioning during use. ActiGraph accelerometers are sensitive to the positioning on the body part and the side on which the device is worn; therefore, the accelerometer should be worn over the dominant hip bone at all times during use.³⁸

Validity of accelerometry. A preliminary study was completed using an Actigraph GTX3 accelerometer and an athletic concussion population. The purpose of the study was to demonstrate if the accelerometer would be able to define a difference between the activity level of a concussed athlete and their nonconcussed teammate. The results demonstrated that there was a significant difference in mean total physical activity counts (t(11) = 2.9; p < 0.05) between concussed athletes (Mean \pm SD: 298,158 \pm 116,704 counts) and controls ($450,271 \pm 67,130$ counts.) There was a significant difference in physical activity counts (t(11) = 2.5; p < 0.05) between concussed athletes (224,661 \pm 100,306 counts) and controls ($104,201 \pm 66,297$ counts). The study revealed that accelerometry is sensitive to physical activity changes associated with prescribed physical rest recommendations during concussion recovery. The change appeared relative

to the activities athletes were involved in outside of the home. This provides validity evidence for the use of accelerometry in monitoring adherence to physical rest protocols for concussed athletes.

Relation to study. By using the ActiGraph accelerometer, researchers are able to quantify the amount and intensity of physical activity of an athlete. This is ideal when monitoring concussed athletes who are told to decrease their participation in all types of physical activity. When analyzing the data, the ActiGraph computes athletes' activities into minutes and hours of the day, reflecting when the athlete is most and least active. The purpose of this research study is to produce an objective measure for cognitive activity. When pairing accelerometry with the RNRCA, designed to track cognitive activity, health care professionals will have objective measures for both physical and cognitive rest.

Rest and Neurocognitive Recovery Concussion Application

The Rest and Neurocognitive Recovery Concussion Application (RNRCA) is an Apple application that was developed by the primary investigator (Kristen Wells) to assess physical and cognitive activity. The application can be downloaded through the Apple App Store. The application can be used on an iPhone, iPad, or iPod as long as an internet connection can be reached on the device. The application was developed as an alternative way of collecting cognitive activity data. Activity diaries can be seen as an inconvenience to the millennium student-athlete. An application is thought to be convenient to current collegiate students; in addition, it requires minimal cognitive activity to complete. Because the athlete is in a concussed state, minimal cognitive activity is essential when collecting these data. The app was designed to be a mindnumbing activity to the student-athlete. With the amount of time student-athletes spend on their cellular devices, it is thought that completing the app should not be inconvenient or difficult.

The RNRCA was used in a preliminary study that focused on the validation of the RNRCA when compared to a paper-and-pencil technique of an AD. Results showed that the RNRCA was able to reproduce activity data as an AD would. Correlation ($p \ge 0.07$) between the two devices was evident in the following activities: chores (r = 0.95), rest (r = 0.80), reading (r = 0.93), outside work/job (r = 0.99), exercise (r = 0.95), class (r = 0.98), socializing (r = 0.91), all being significant. There were certain activities, such as sleep (r = 0.61) and eating (r = 0.61) where the correlation was greater than 0.60. Overall, the study was successful when comparing the two types of devices and collecting activity data. This gives us confidence to continue on with our research integrating concussed individuals.

Relation to study. At the current time, there is minimal research to support the amount of rest a concussed athlete should sustain when recovering from injury. The RNRCA aims to find the activities that aggravate concussive symptoms, or the threshold at which a concussed athlete can sustain an activity. In addition, the application summarizes the overall amount of activity athletes can partake in during their days of recovery.

Summary

Our study aimed to use a new innovation to assess cognitive and physical activity of the concussed athlete. A monitoring measure is needed in order for health care professionals to deliver treatment plans to athletes. Without a monitoring device, health care providers and concussed athletes may have different standards of rest. In addition, each concussion should be treated individually. Activities (eg, texting, social media, or computer use) that provoke concussion symptoms in one individual may not trigger symptoms in another athlete. By using a cell phone application, measures are realistic and applicable to collegiate students; therefore, adherence levels of these protocols should be greater. An adherent program is needed in order for health care providers to identify symptom triggering activities and the activity levels that aggravate concussion symptoms. Once these standards are set, concussed athletes will be able to avoid concussion symptom aggravation, leading to a more efficient recovery process.

Chapter 3: Methods

Participants

All participants enrolled in the study were collegiate students. Participants were over the age of 18 and able to consent to participation. The first stage of the research study included non concussed participants. Any individual not currently suffering from a head injury could participate. The second stage of the research study included injured athletes. During the second stage, an inclusion criterion was a concussive head injury that was diagnosed by a licensed athletic trainer or sports physician within the past 48 hours.

Study Design

The study used a cross-sectional design developed to monitor physical and cognitive activity of concussed athletes as they recover from injury. Rest was assessed by an electronic iPhone[™] application (RNRCA) as well as an AD. A primary purpose of the study was to validate the use of the RNRCA in comparison to an AD.

Setting

Participants who consented to the study were collegiate students (phase one) and varsity or club sport athletes (phase two) at a Mid-American University. Throughout phase two, all participating teams that consented for the study were Division 1 or Division 1 club, as recognized by the National Collegiate Athletic Association (see Table 5). **Table 5.** Participating Institutions and Sports into the Rest and Neurocognitive Recovery

 Concussion Application Research Study

Institution	Participating Sport	
Ohio University Intercollegiate Athletics	Women's basketball, women's field hockey, swimming and diving, women's soccer	
Ohio University Club	Men's ice hockey, men's rugby	

Instruments

Development of the application. The RNRCA was designed using iBuild App (www.ibuildapp.com), a website that allows users to design an app free of charge for Apple- and Android-based products. Once the app was designed, an Apple Publisher Certificate was purchased to allow the researchers to publish the application to the Apple Store. For the purpose of this study, RNRCA was made public as a free download.

Rest & Neurocognitive Recovery Concussion Application. The RNRCA was developed as a quick and effective way to monitor concussed athletes through their recovery (see Figure 1). The application assesses cognitive and physical rest while the athlete is experiencing concussion symptoms. The main launch screen of the application is demonstrated in Figure 1a.



Figure 1. Five tabs of the Rest and Neurocognitive Recovery Concussion Application.

Activities tab. The "activities" tab prompts participants to enter the activities they took part in over the past 24 hours (see Figure 1-B). There are two activities tabs, one to record activities performed at home and the other to record activities on campus. The participants use dropdown menus to indicate the amount of minutes they spent on each task, how difficult the task was, and whether or not the task aggravated their concussion symptoms. For example, participants may have input that they went to class for 4 hours the previous day, it was of light difficulty, and the activity did not re-create concussion symptoms.

Intensity. All activities that participants partook in were ranked on a Rating of Perceived Exertion scale (RPE). Participants were asked how difficult the activity was to engage in, using a dropdown menu to choose 0 (no difficulty) through 7 (high exertion). Borg's Rating of Perceived Exertion scale is a valid tool used commonly in physical activity research.⁴¹ The scale quantifies an individual's perception of exertion during activity.

Symptom aggravation. Participants were asked if an activity they partook in caused concussion symptoms. This was an important component of the activities tab because a main purpose of the study was to find behavioural activities that were associated with symptoms. If an activity caused concussion symptoms, it was scored with a value of "1." If no symptoms were reproduced, the activity was scored with a value of "0."

Frequency and intensity. An additional variable (frequency multiplied by intensity) was produced to reflect the activities that caused symptoms. The symptoms value "0 or 1" was multiplied by the RPE scale "0 through 7" to produce the new value.

Once all dropdown answers were complete, the participant clicked "Send Form," which sent the information directly to the researcher.

Well-being tab. The "well-being" tab allowed the participants to communicate their overall feeling of health and well being to the researcher (see Figure 1-C). Participants had several options to choose varying from: "I feel good" to "I'm not feeling well" to "I need to go to a physician." Once placing a check mark in one of the boxes beside the correlating statement the participant clicked on "Send Form" to send the information to the researcher.

Electronics tab. The "electronics" tab asked participants to enter the amount of time they spent using a computer, cell phone, watching television, or talking on a telephone over the same 24-hour period (see Figure 1-D). Similar to the activities tab, participants were asked how difficult the task was (RPE) and if the task aggravated concussion symptoms. If participants had watched approximately 4 hours of television in the past 24 hours, they chose 4 hours from the dropdown menu, rated the difficulty, and chose "yes" or "no" for symptoms arising. After completing all dropdown menus, students clicked "Send Form" to send the information to the researcher.

Symptoms. The "symptoms" tab allowed participants to communicate their daily concussion symptoms to the researcher each day (see Figure 1-E). Participants were presented with dropdown tabs, which allowed them to rate the symptoms they experienced once every 24 hours. The symptoms were rated on a 0-6 scale; 0 being not prevalent, 1 being a level of light discomfort/feeling, and 6 being a high level of discomfort/feeling.

This application was created as a means to communicate with the concussed athlete using the least amount of cognitive activity needed. Electronic communication was the manner chosen by the researcher due to the proximity of the cellular device to the college student. A study done by Tindell and Bohlander in 2012 found that 95% of students bring their cellular phone to class each day.⁷

Activity Diary. The purpose of the AD for participants was to record their activities throughout each day. Participants were given 5 outlined sheets asking for them to document their activities over a 5-day period. Activities could include going to school/work, socializing, sleeping, etc. The AD was completed simultaneously with the RNRCA in order to validate the new application.

Validity. Several studies have used accelerometry to validate the use of an AD in collecting physical activity data.^{42, 9} Strong relationships were found between accelerometers and AD for both activity energy expenditure and total energy expenditure.⁹ In addition, ADs are able to collect more information regarding the type of activity, intensity of activity, and movement patterns of the participants.¹⁰

Activity intensity. In order to better understand participants' behaviors, researchers categorized the events into physical, cognitive, and electronic activities. Previous research collecting activity data used accelerometers and ADs to calculate the mean intensity (counts per minute) of each activity.⁴² Sedentary activities included watching television, using a computer, attending classroom, reading, and eating; all were grouped as low intensity. High intensity activities were sports training, including team practice or an individualized work out.⁴²

Procedures

Institutional review board approval was obtained from Ohio University. The first phase of the study included a nonconcussed population. Collegiate students were recruited from a college campus to complete the 5-day study. The nonconcussed population followed the same protocol as the concussed population described below. The researcher presented the study to various athletic teams to recruit concussed participants. Prior to their athletic season, if athletes were interested in being part of the study, approved consent forms were signed by all interested athletes. The athletes were not concussed at the time of agreement. If consented athletes suffered from a concussive injury throughout their athletic season, they were asked to participate in the study.

When a concussion occurred, licensed athletic trainers at OU contacted the researcher regarding the injury. Any athlete interested in participating in the study began using the application within 48 hours of the concussion diagnosis. If the athlete did not own an Apple device to access the application, the researcher provided an Apple iPad to use for the duration of the study. In addition the researcher met with the athlete to provide the AD.

Participants were asked to complete the study for the next 5 days. It was emphasized to participants that 5 consecutive days is ideal; however, knowing that a concussed individual has memory deficits, they could make up for a forgotten day(s) as long as the overall study was completed within 7 days post-injury. No medical restrictions or instructions were given to participants regarding their injury. The participant had the option of receiving daily text reminders (am or pm, specified by the athlete) from the researcher.

Following the 5-day collection period, the researcher followed up with the participant to collect the Apple iPad, if necessary, and the AD. At that time the RNRCA and AD data were entered into Microsoft Excel workbook for analyzing.

Data Analysis

To answer *research question 1–* "is the RNRCA a valid tool when collecting physical and cognitive activity information from concussed athletes"–descriptive statistics and dependent *t*-tests were run using SPSS. The RNRCA was compared to the AD looking for significant correlations between the two devices. Bonferroni adjustment was used in order to consider the amount of activities being analyzed. Therefore, our alpha level was originally set at $p = \ge 0.05$; however this was adjusted to $p = \ge 0.004$ in order to compensate for the amount of activities being analyzed. In addition, intraclass correlations were run, further identifying the relationship between the two activity devices.

To answer *research question 2*– "which behavioral activities worsen symptoms during concussion recovery"–symptom aggravation and intensity were used from the activities tab of the RNRCA. A frequency by intensity variable was produced for each activity reflecting how difficult an activity was perceived to be, and if the activity caused concussion symptoms.

To answer *research question 3*—"what effect does electronic usage have on cognitive stress during concussion recovery"—symptom aggravation and intensity were considered from the electronics tab of the RNRCA. The data were summed using Excel and the percentage of electronic usage causing concussion symptoms was calculated.

Chapter 4: Results

This chapter presents an analysis of the validity of the RNRCA in relation to an AD. Secondary findings of the study explore whether behavioral and electronic activities were associated with an increase in concussion symptoms.

During the 8 months of data collection, 13 nonconcussed participants (mean age: 23.6 ± 2.6 yrs; females n = 8, males n = 5) and 4 concussed participants (mean age: 20.5 ± 1.1 yrs; males n = 4) participated in the study. The nonconcussed participants were all graduate school students. The 4 concussed subjects who participated were all collegiate club hockey players, 3 forwards, and 1 goalie. Of the concussive injuries, two occurred in practice and two in games.

Validity of RNRCA with a Concussed Population

Dependent *t*-tests were used to compare the two methods for tracking athletes' physical and cognitive data: RNRCA vs. AD. Of the 16 activities accounted for on the RNRCA, 1 activity (meeting) was dismissed from the analysis due to no participation. No activity was documented on the AD from the concussed participants for job/work, phone, or social media so those categories were not included in the analysis. Dependent *t*-test analysis concluded that all activities produced nonsignificant values when comparing the two devices (see Table 6). This finding demonstrates that the RNRCA was able to collect activity data for cognitive, physical, and electronic usage similarly to the AD.

	Time Spent in Each Activity (minutes; mean ± SD)		Dependent t-test
Activity	RNRCA	AD	RNRCA/AD (p = \geq 0.004)
Appointment	8.0 ± 17.8	2.0 ± 7.74	0.27
Chores	15.0 ± 19.5	4.2 ± 16.0	0.19
Class	20.0 ± 43.4	48.0 ± 64.9	0.29
Computer	83.3 ± 75.3	50.0 ± 57.4	0.12
Eat	17.1 ± 19.3	40.7 ± 40.0	0.85
Exercise	18.0 ± 22.1	16.0 ± 27.4	0.83
Job	4.0 ± 15.4	-	-
Phone	10.7 ± 14.9	-	-
Practice	12.0 ± 46.4	6.0 ± 23.2	0.67
Reading	72.8 ± 58.4	79.2 ± 68.2	0.79
Rest	152.1 ± 74.8	138.5 ± 56.2	0.50
Social Media	46.6 ± 27.6	-	-
Socializing	166.0 ± 154.1	164.0 ± 135.5	0.95
Sleep	530.7 ± 146.6	518.4 ± 119.2	0.81
Television	100.7 ± 77.7	102.85 ± 68.3	0.94

Table 6. Comparison of Activity Diary and Rest and Neurocognitive Recovery Concussion Application: The Concussed Participants (n = 4).

AD = activity diary; RNRCA = Rest and Neurocognitive Recovery Concussion Application; SD = standard deviation.

Concussed versus nonconcussed population. As shown in Table 6, there were no activities that resulted in significant findings ($p = \ge 0.004$); the concussed participants entered similar values into both the RNRCA and AD. The nonconcussed population reported comparable results to the concussed participants. There was only one activity,

talking on the phone (p = \geq 0.004), where time spent was significantly different between the two devices (see Table 7).

	Time Spent in Each Activity (minutes; mean ± SD)		Dependent <i>t</i> -test
Activity	RNRCA	AD	RNRCA/AD (p = \geq 0.004)
Chores	40.0 ± 44.1	35.0 ± 50.4	0.63
Class	204.7 ± 216.1	113.8 ± 200.8	0.07
Computer	111.8 ± 102.6	47.2 ± 96.9	0.01
Eat	65.0 ± 48.7	79.3 ± 30.2	0.11
Exercise	41.4 ± 50.0	50.7 ± 50.9	0.26
Job	114.71 ± 186.4	105.0 ± 176.3	0.82
Phone	18.1 ± 21.1	4.5 ± 15.2	0.00*
Reading	96.3 ± 102.7	38.1 ± 80.5	0.01
Rest	90.9 ± 79.8	143.9 ± 115.0	0.04
Social Media	29.4 ± 24.1	0	-
Socializing	192.3 ± 130.0	208.8 ± 123.7	0.42
Sleep	430.9 ± 80.0	465.4 ± 52.0	0.01
Television	78.1 ± 65.3	103.0 ± 121.1	0.29

Table 7. Comparison of Activity Diary and Rest and Neurocognitive RecoveryConcussion Application: The Non Concussed Participants (n = 13)

AD = activity diary; RNRCA = Rest and Neurocognitive Recovery Concussion Application; SD = standard deviation.

*Signifies significance different between RNRCA & AD ($p = \ge 0.004$).

Activity	Concussed	Non Concussed
Chore	0.65	0.89
Class	0.67	0.92
Computer	0.18	0.60
Eat	-0.13	0.58
Exercise	-0.08	0.92
Job	0.00	1.00
Meeting	-	0.97
Phone	0.00	0.21
Practice	-0.05	-
Read	0.00	0.84
Rest	0.36	0.60
Sleep	0.16	0.54
Social	0.47	0.91
Television	-0.06	0.68

Table 8. Intraclass Correlation of Rest and Neurocognitive Recovery Concussion Application and Activity Diary of the Concussed (n = 4) and Nonconcussed Participants (n = 13)

Comparison of devices. Of the 15 activities applicable for participants to choose from on the RNRCA, one activity (phone) was found to be significantly different from the AD in the nonconcussed group. Therefore, both concussed and nonconcussed groups collected similar data, showing that the AD and RNRCA record similar activity levels.

Table 8 demonstrates the intraclass correlation for both the concussed and nonconcussed participants. Nonconcussed participants have a higher intraclass correlation than the concussed participants when comparing the RNRCA and AD.

Compliance in Use of the Devices

Both the RNRCA and AD had very successful compliance rates with the concussed participants. The AD had 100% and the RNRCA had a 92% completion rate over the course of the study with the collegiate athletes. The non concussed participants had slightly lower compliance rates using the devices. Over the 5-day period, 49% of AD data, and 66% of RNRCA data were collected due to variable participant compliance. On day 1 of data collection, 76% of RNRCA and AD was completed and by day 5 only 38% of data were recorded.

Concussion Specific Analysis

Concussion symptoms. The "symptoms" tab of the RNRCA was used to record participants' concussion symptoms each day. Concussed athletes were all symptomatic through day 1 and 2 of concussion recovery, while 50% of athletes remained symptomatic on day 5. Figure 2 demonstrates the symptoms that were experienced by the concussed athletes throughout the 5-day study. The most frequent symptom experienced by the participants was headache (18.1%), trouble falling asleep (16.8%), and irritability (15.5%).



Figure 2. Concussion symptoms demonstrated by frequency and intensity in concussed athletes over 5-day study. Intensity: Rate of Perceived Exertion scale (0 through 7) of an activity with 1 (meaning symptomatic) frequency.

Activities corresponding to concussion symptoms. All concussed athletes had

difficulty completing activities on day 1 through day 4 of recovery, indicating an increased RPE score. Researchers multiplied the RPE level (0 through 7) of an activity with a symptomatic score of 1 (meaning activity caused symptoms) to produce a new value demonstrating frequency by intensity. Using this new variable, Figure 3 depicts the cognitive (47%), physical (23%), and electronic (30%) activities that were associated with concussion symptoms.



Figure 3. Concussed athletes symptomatic activities categorized by type of activity.

When further classifying electronic activities, watching television (53%) was responsible for the greatest symptoms, followed by computer usage (21%) (see Figure 4). Talking on the phone was the only electronic activity measured that did not cause any symptoms, possibly due to the low frequency associated with the concussed athletes and this activity.

Overall, electronic and cognitive activities were among most likely to invoke an increase in concussion symptoms. The behavioral activities that were most highly associated with concussion symptoms were (1) reading, (2) watching television, and (3) attending class.



Figure 4. Electronic activities causing concussion symptoms broken down into specific activity.

Chapter 5: Discussion

There are currently no descriptive guidelines or measures to assist an injured athlete throughout the process of concussion recovery. This is, in part, due to the inaccuracy and the subjective nature of the currently available monitoring tools (eg, AD) used to track athletes' activities during this recovery process. Many aspects of the recovery process remain unknown, specifically, the ideal quantity and quality of rest for a fast and full recovery. If athletes are able to avoid activities that aggravate concussion symptoms, they should recover more efficiently.⁶ The RNRCA was developed to assist health care providers and concussed athletes in the recovery process.

This study sought to validate the use of the RNRCA throughout concussion recovery in comparison to an AD, and to identify the behavioral and electronic activities that worsen concussion symptoms during recovery. The study was completed on healthy collegiate students as well as a subset of concussed collegiate athletes. According to the results of the study, the RNRCA application was able to effectively measure physical and cognitive activity in comparison to an AD. The RNRCA also gathered information regarding problematic activities correlating with symptoms. The behavioral activities that worsened symptoms appeared to be activities requiring higher brain function, such as being in a classroom and reading. Electronic usage was correlated with concussion symptoms as well, particularly watching television and using the computer. The chapter further describes the analysis of the results.

Comparison of Monitoring Tools

The purpose for creating the RNRCA was to develop a more efficient and realistic method for student athletes to communicate with their health care providers in today's technologically advanced society. The RNRCA was designed to have high compliance rates as well as acceptance by collegiate athletes. In comparison to a pen and pencil method of the AD, the RNRCA used direct closed-end questions, intending to encourage the concussed athletes to record accurate and reliable information. Due to concussed athletes commonly having difficulty concentrating and remembering, this element of the application was crucial.⁶

Benefits of the RNRCA. With the AD, participants typically did not comment on their phone usage, use of social media, or texting frequency, even when some of these activities led to concussion symptoms. Therefore, we were unable to analyze the significance between the devices for these activities. However, it was important to gather the information correlating these electronic activities with concussion symptoms.

Ease of use. The RNRCA appeared to be well received by the athletes, used as easily as most iPhone applications. Concussed participants were able to use the RNRCA at their leisure to complete the tabs. In addition, concussed athletes were not required to check in with their athletic trainers everyday in the clinic. The daily, automatic transfer of each athlete's symptom scores and electronic diaries via e-mail to the athletic trainer allowed the athletic trainer to evaluate the athlete's progress from afar.

Although not measured in the current study, there is evidence that electronic diaries are easy and acceptable tools for recording behavior. A study conducted by Lau et

al. (2013) measuring children's physical activity compared accelerometry and two electronic devices (Palm Pilot and Pro-Diaries) for gathering data.⁴³ Parents of the children were responsible for applying the accelerometer and entering the activity information manually into the two electronic devices. Parents indicated that they enjoyed using the electronic devices, specially the Palm Pilot, in favor of the large screen size.⁴³ This relates to the current study, as both used newly developed applications and smart phones to collect activity data, and both had positive findings. Lau et al. (2013) also found that parent's consistently overestimated their child's activity intake, when reporting into the AD. This relates to the current study in that several activities (phone, computer) were overestimated when reported into the application.⁴³

Faults of the AD. The AD has been found to be a reliable and valid tool to collect activity data; however, it is not the most convenient means of data collection.^{9,42} Bringolf-Isler et al. (2009) combined accelerometer, questionnaire, and AD data to estimate the intensity and duration of children's activities throughout the day. Researchers noted that parents responsible for completing the devices were not as detailed in documenting activity changes in the AD.⁴² The quality of the AD depended on the education and nationality of the parents.⁴² In the current study, similar findings were found, relating to electronic activities, and the lack of recorded use.

Compliance to devices. Overall, both the RNRCA and AD had successful completion rates; 75 to 79% completion rate for the AD and RNRCA, respectively. The compliance rates for each of the devices were significantly lower for the nonconcussed (58%) participants than the concussed (96%). This difference between groups may be

because the nonconcussed participants did not have direct supervision from an athletic trainer to complete the devices. The concussed participants were urged to complete the devices in order for their athletic trainer to continue to progress them through recovery, providing them added motivation to do so. Another factor contributing to this difference may be that the nonconcussed group had no restriction on their activities, unlike the concussed group.

Activity data. Of the 14 activities analyzed, the amount of time reported for 1 of the activities was significantly different between monitoring tools. The greatest discrepancy when comparing the two devices was the amount of time spent talking on the phone. When comparing this sedentary activity between RNRCA and AD, nonconcussed participants recorded more minutes talking on the phone (14 min) when using the RNRCA. The discrepancy in recorded time spent in this sedentary behavior may be due to the difficulty of approximating the amount of sedentary time rather than illustrating a discrepancy between the two devices. This discrepancy was similar to the children's physical activity study mentioned earlier in the chapter, concurring that parents overestimated their child's physical activity when recording the time manually. This was particularly true when the children were least active,⁴³ similar to the findings in the current study.

Collegiate Athletes' Concussion Rate

The RNRCA collected not only activity data similar to AD, but also concussion specific data, such as concussion symptoms and their association to activities. This information connected directly to the concussed subjects who participated in the study.

Risk of injury. The study consisted of 120 athletes who consented to participate in the study, 2 men's club sports teams, and 4 women's intercollegiate sports teams. Over the 6-month data collection period, 4 athletes were concussed. All concussed athletes were male ice hockey players. The rate of occurrence and associated sport has been published in previous studies. Flik et al. (2005) found that concussions were the most common injury among collegiate ice hockey players (18.6%).⁴⁴

Activities Causing Concussion Symptoms

The secondary objective of the study was to determine which activities were correlated highly with concussion symptoms. Activities were divided into three main categories based on the amount of intensity needed to complete them. According to the current study, cognitive activities (47%) were associated with concussion symptoms more than physical (23%), and electronic (30%) activities. Of these cognitive activities, those with the highest correlation with concussion symptoms were (1) reading (20%), (2) watching television (17%), and (3) attending class (15%). The positive relationship might be dependent on the level of concentration required during these activities.

It was hypothesized that activities associated with concussion symptoms would be those with an RPE rating higher than 3, out of a 7-point scale. The mean RPE for activities causing symptoms were 2.59 (mode and median = 2). Therefore, our hypothesis was not supported.

Electronic activities. Although electronic monitoring tools have been found easy to use in previous research, the results of this study also found that cognitive activity, including electronic, led to increased concussion symptoms. The analysis reveals that

electronic activities worsened concussion symptoms. Electronic usage was responsible for over 30% of the recreation of symptoms reported by the concussed athletes. Within the electronic activities, those most engaged were computer usage (83.3 ± 75.3 min) and watching television (100.7 ± 77.7). Electronic activities as a whole had an RPE of 0.4; this illustrates that although these were easy tasks for the athletes to complete, they still caused concussion symptoms.

Limitations

The biggest limitation to the study was the number of concussed participants. When dealing with a population that depends on injury rate, it is unknown how many participants the study will be able to recruit. Due to the low injury rate over the course of the season, the study resulted in having low power. In order to validate a new device a high subject count is needed; therefore, more recruitment will need to be done in order to enhance these results.

In addition to the low injury rate, all concussions diagnosed were from one sports team. Ideally, the study would have both males and females from a variety of sports teams. It would be ideal to see the difference between gender activity level as well as the most problematic activities.

Using an AD allowed researchers to have a clear understanding of the activities participants were involved in, however all were completed by patient report. It would be ideal to have more objective measures such as accelerometry for physical activity and a quantitative measure for cognitive activity.

Significance

The primary purpose of the study was to validate the use of the RNRCA compared to an AD in a concussed and nonconcussed population. Our findings showed that the application collected meaningful activity data. The RNRCA is a helpful device for concussed athletes and health care providers. Continuing to collect data to validate the RNRCA and applying the device in a clinical setting should be encouraged.

Secondary findings of the study identified activities that were most highly correlated with concussion symptoms. Health care providers are beginning to encourage concussed athletes to take time away from school during acute concussion recovery. The results of this study verify that classroom attendance and completing homework or readings provoke concussion symptoms. Therefore, precautionary guidelines should include advising students that school should be avoided during the symptomatic stage of recovery.

Clinicians should be aware that watching television was among the activities most highly correlated with concussion symptoms. Athletes are generally told to rest, and many feel that watching television is a low intensity activity that can be allowed. The problem arises when athletes are concentrating on the screen, the loud noises, and the bright light. This corresponds to other electronic devices our participants had difficulty with during recovery.

Electronic activity was the cause of 30% of concussion symptoms during recovery. Health care providers should be aware of these distractions and promote

decreased use of cell phones, computers, and lit screens during the acute stage of concussion recovery.

Future Direction

This study was the first step towards creating a method to monitor progression throughout concussion recovery. Finding that electronic activity worsened concussion symptoms leads to future studies concentrating on the involvement of electronic devices throughout recovery. In addition, using more quantitative measures such as accelerometers within the concussion application would result in more defined results. A large barrier in the research is discovering a quantitative measure for cognitive activity.

Conclusion

The RNRCA was an effective device for measuring physical and cognitive activity. Although all of the measures were subjective reports, the device enables a communication system between injured athletes and health care providers.

The RNRCA can inform health care providers about the recovery process to help improve recovery in the days to follow. Having a daily communication system between athletes and health care providers permits for the return to play protocol to be established as soon as possible.

The RNRCA is able to depict which activities collegiate athletes should deter from and assist health care providers in identifying where problems exist. If athletes continue to have symptoms, health care providers are able to look at their activity log throughout the day, and determine which activities should be avoided. The results of this study emphasize the lack of athlete education regarding concussions. It is apparent that cognitive and electronic activities are not being avoided throughout recovery, as they should. More education is needed regarding the use of electronic devices and avoiding cognitive activities (concentrating, remembering) while symptomatic.

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