Utah State University

DigitalCommons@USU

All Graduate Plan B and other Reports

Graduate Studies

5-2017

Evaluation of Long-term Effects of Mild Traumatic Brain Injury on Visual Motor Control of NCAA Division I Football Athletes

Kathryn DeLost

Follow this and additional works at: https://digitalcommons.usu.edu/gradreports

Part of the Medicine and Health Sciences Commons

Utah State University
MERRILL-CAZIER LIBRARY

EVALUATION OF LONG-TERM EFFECTS OF MILD TRAUMATIC BRAIN INJURY ON VISUAL

MOTOR CONTROL OF NCAA DIVISION I FOOTBALL ATHLETES

By

Kathryn L. DeLost

A plan B research project submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Health and Human Movement

Approved:

_____   _____
Breanna Erin Studenka   Christopher Dakin
Major Professor   Committee Member

_____
Tye Harrison
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah

2017

Abstract

Context: Current concussion evaluation assessments rely largely on static measures that may not detect subtle changes in behavior. Dynamic evaluation, such as visual-motor tracking tasks, may reveal subtle and meaningful changes in motor behavior post-concussion. **Objective:** This study compared measurements of performance regularity over a time series (approximate entropy; ApEn), which was derived from a visual-motor tracking task performed before concussion, post concussion, and at one month, three months, and six months post concussion. ApEn values were compared for number of previous concussions and playing position groups. **Design:** ApEn values were collected from the visual-motor tracking task, and history of concussion and playing position were obtained from an intake questionnaire. Post-test ApEn values were collected from participants who sustained a concussion during the study along with control subjects (matched by age and date of pre-test). **Setting:** Testing occurred in an office in the athletic training room, which matches the typical setting for pre and post-concussion testing.

Participants: Ninety-nine Division I football athletes were baseline tested. Six concussed subjects were pre and post-tested along with 11 control subjects. One of those six was post-tested at one, three, and six months, while two were post-tested at injury, one month, and three months along with one control subject. **Task and Procedure:** The subject was seated at arm's length from a laptop, pressed the distal joint of his index finger against a force plate and traced a line presented on the computer screen. Visual feedback was not displayed on the screen for the no-vision condition. An algorithm calculated ApEn from the output. **Results:** Post-test ApEn values were not significantly lower when compared to pre-test values and values of control participants. There was a significant effect of position

group on ApEn scores, but not RMSE. There was not a significant main effect of previous

number of concussions on ApEn, but ApEn was significantly lower in those with two or

more previous concussions compared to those with one.

Introduction

Concussion is a form of traumatic brain injury that is prevalent in sport. The Center

for Disease Control and Prevention [CDC] reports that an estimated 1.6 to 3.8 million

concussions occur annually in the United States alone (Langlois, Rutland-Brown, & Wald,

2006), costing an estimated 60 billion dollars in health care costs and lost player hours

(Corso, P., Finkelstein, Miller, T., Fiebelkorn, I., & Zaloshnja, E., 2006). In addition to

financial burden, concussions also can have severe consequences to the players' long-term

health including headaches, trouble concentrating, even death (CDC, 2010; American

Association of Neurological Surgeons, 2017). The most severe consequences of concussion

often arise as a result of a failed diagnosis or return to play too soon, which raises the risk

of a second concussion. A second concussion shortly following the first raises the risk for

second impact syndrome (SIS). SIS is a rare, but often fatal disorder, that occurs when an

athlete sustains a concussion then returns to play and sustains a second concussion before

the first one heals completely (Saunders & Harbaugh, 1984; Cantu, 1998). The signs and

symptoms of SIS are diffuse cerebral swelling, brain herniation, and death (Bey & Ostick,

2009). Playing with residual symptoms can put the athlete at risk for further injury, raising

the risk of another concussion during the same season by three. Because of the severe

consequences of SIS it is imperative that potential concussions are properly detected,

diagnosed and reported so that players can safely return to play (RTP).

Concussions, defined as a "trauma induced alteration in mental status that may or may not involve loss of consciousness" (Broglio et al., 2014), are caused by either direct or indirect forces applied to the skull resulting in rapid acceleration and deceleration of the brain (Broglio et al., 2014). Therefore, by definition, athletes in sports that are more prone to receiving accelerations or impacts sufficient to cause concussion tend to report more concussions. A study of Epidemiology of Sports-Related Concussion in NCAA athletes from 2009-2010 to 2013-2014 found that among 25 NCAA sports, the overall concussion rate was 4.47 per 10,000 athlete-exposures (AEs) (Zuckerman et al., 2015). An *athlete exposure* is a unit of susceptibility to injury, which is defined as one athlete participating in one practice or game where he or she is exposed to the possibility of injury. The men's football rate was 6.71 concussions in 10,000 AEs. While football didn't take the lead in sport-related concussion (SRC) rate when compared to other NCAA sports, it led in annual incidents at 3,417 reported. In particular, football players who experience a concussion are three times more likely to sustain another during the same season (Valovich, Perrin, & Gansneder, 2003).

The incidence of concussions in football is also associated with the primary position than an athlete plays. Skills players, which include wide receivers, defensive backs, running backs, linebackers, and quarterbacks are more susceptible to full-speed hits that result in a higher magnitude impacts, while offensive and defensive linemen endure more frequent, lower impact hits (Baugh et al., 2015). Tight ends can act more as a receiver or offensive lineman, so their exposure often depends on how a program uses them, and special teams players are typically most susceptible to high impact hits. A study by Baugh et al. (2015) found that offensive linemen reported significantly higher numbers of

undiagnosed concussions and what they considered "dings", which is a commonly used term to downplay a head impact that results in concussive symptoms that may quickly resolve. They also found that offensive linemen reported more post-impact symptoms compared to other position groups. Several other studies based on self-reporting have different results, such as one by Guskeiwicz et al (2003) that found linebackers and offensive linemen have the highest rate of concussion per 1000 AE, while Delaney et al. (2002) found tight ends and defensive linemen have the highest rate of diagnosed concussion in college football. The American Medical Society for Sports Medicine (Harmon et al., 2012) has identified playing position, specifically quarterbacks, wide receivers, running backs and defensive backs, as a key risk factor for concussion in professional football and, due to a lack of understanding on this topic, an area for further discovery.

Currently, the most widely used means of identifying a concussion is to compare an athlete's baseline score on one of several concussion tests (described below) with their post-contact score on the same test. Two of the most common clinical tests are the Standardized Assessment of Concussion (SAC) and the Balance Error Scoring System (BESS). The SAC consists of a neurological screening, immediate memory, and delayed recall components (Koscs et al., 2008) and is scored out of 30 points, where a difference of one or more points indicates a potential concussion. The SCAT (Standardized Concussion Assessment Test) and SAC have limitations, however. Both tests can exhibit a learning effect as well as a decrease in score when taken fatigued (Shehata et al., 2009; Koscs et al., 2008). The BESS test evaluates postural control in different stances on varying surfaces and has also exhibited a learning effect, which means that regardless of a healthy or injured individual, practicing the test multiple times may result in an improved score and could

cause bias (Bell et al., 2001; Valovich, Perrin, and Gansneder, 2003; Wilkins, Valovich, Perrin, and Gansneder, 2004). A test score total of two or more points different than the baseline test indicates diagnosis of concussion, which means that non-concussed individuals could be falsely diagnosed with a potential concussion due to fatigue depending on when the test was given (e.g., following practice). In addition, these tests are typically only administered immediately following injury, and not longitudinally to assess progress toward recovery. Concussion diagnosis should be made through several different assessment tools (Broglio et al., 2014, Harmon et al., 2012), and could be aided by the addition of alternative dynamic measures to increase the reliability of the concussion evalutation process as a whole.

Currently, tests using motor behavior to identify the signs/symptoms of concussion, like the BESS test, do not take advantage of all the information that is available to them. Specifically these tests use a single measure to quantify a time-varying behavior which neglects the underlying structure of this behavior. However, the information contained in the structure of the motor behavior may provide a more sensitive and more reliable indicator of concussion-induced impairment of motor behavior. In the past decade, research has suggested that a certain level of variability in a biological system is normal, and necessary for function (Hamill, Heidershceit, Haddad, & Van Emmerick, 2006). Variability can range from completely regular to entirely random with human motor behavior variability falling somewhere in the middle. The complexity of this variability reflects the interaction of multiple physiologic systems, which work together to generate motor behavior (Cavanaugh, Guskiewicz, & Stergiou, 2005) and therefore the structure of this variability is a product of these systems.

The structure of variability can be quantified in a few different ways, including using approximate entropy (ApEn). ApEn is a statistical technique that is used to quantify the amount of regularity and irregularity of fluctuations in a time series (see Figure 1 below). While dynamic measures are commonly used for analysis of postural control, they are also used to evaluate many other physiological systems like respiration, electrical activity in the cerebral cortex, and autonomic nervous system function (Glass & Mackey, 1988; Cavanaugh, Guskiewicz, & Stergiou, 2005). ApEn is one of the most commonly used measures for quantification of the regularity of dynamic data (Cavanaugh, Guskiewicz, & Stergiou, 2005). This analysis has been used previously to identify structural changes in sway, measured by a change of amplitude of center of pressure of the feet (Yardley et. al., 2001), during the division of attention, that would not be easily observable using other analyses of sway such as those used during the BESS test (Cavanaugh, Mercer, & Stergiou, 2007). To date, only a few studies have examined the ApEn values of individuals with a previous history of concussion. Those studies support the notion that current tests to evaluate postural control and neurocognitive function after injury are not sensitive enough to detect subtle declines in cerebral activity that persist for years after injury (Broglio & Martini, 2016).

Less Regular
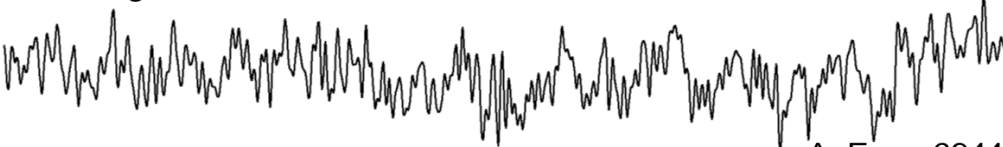
ApEn = .6944

More Regular
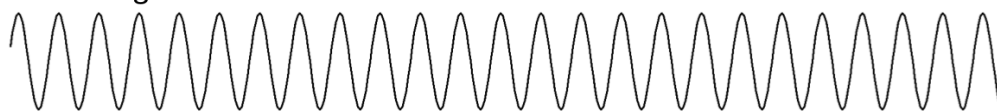
ApEn = .1392

Figure 1. An example of two waveforms with corresponding ApEn values.

Sosnoff, Broglio, and Ferrara (2011) compared a group of previously concussed athletes (average of 2.9 years post-injury) and a group of nonconcussed athletes. No differences were noted in the results of the NeuroCom Sensory Organization Test (SOT), however, the previously concussed group exhibited altered postural dynamics and a decline in complexity of their mediolateral sway indicating that the nonconcussed group had altered control over their movements. A second, similar, study was conducted with individuals six years post-injury, and the researchers found that, when presented with a divided attention task (i.e. stepping over a cone while walking), the previously concussed group demonstrated a more conservative, less complex, gait pattern to protect themselves from falls, which is also common of otherwise healthy older adults (Martini, Sabin, & DePesa et al., 2011). These results support the belief that there are lasting effects of mTBI that persist after acute injury resolution, and present a concern for susceptibility to falls and other postural control related injuries later on in life (Broglio & Martini, 2016).

Aims and Hypotheses

Previous studies suggest that individuals who have sustained a concussion demonstrate lower ApEn in postural sway when compared to their baseline values (Cavanaugh et. Al., 2005; Cavanaugh et. al, 2006). In these studies, post-concussion assessment was completed at 72 hours post-injury. To date, changes in ApEn have not been examined over longer time scales. Therefore, the primary aim of this study was to

compare baseline ApEn values in participants diagnosed with a concussion with ApEn values at the time of injury, one month, three months, and six months after injury. The secondary goal was to compare performance on the visual-motor tracking test in individuals from different football position groups. The tertiary goal of this study was to compare athletes with a history of one and multiple concussions to athletes with no history of concussion to see if there is a relationship between performance on the visual-motor tracking task and concussion history.

We hypothesized that, following concussion, individuals would exhibit lower ApEn values than obtained during baseline testing, and that, over time, ApEn would increase back to baseline by 6 months post concussion. In addition, we hypothesized that, due to the purported number of sub-concussive impacts sustained in daily activity, visual motor tracking of individuals within the offensive and defensive line, and linebacker groups would exhibit lower ApEn (Baugh et. al., 2015). Finally, we hypothesized that individuals with history of multiple concussions would exhibit lower ApEn, which also might be related to the position than an individual plays.

Methods

Participants

A total of 99 Utah State University (USU) NCAA Division I football athletes (All male, Age: M= 21.1, SD=± 2.8) were recruited to participate in this study, with 9 concussions occurring in 8 athletes (see Table 1). Data was collected from 41 subjects to add to a larger data set, which included 58 subjects that were baseline tested in a previous study. Participants were recruited from August 2013 to November 2014 and November 2015 to March 2017. This study was approved by the Utah State University Institutional Review

Board. Each subject signed an informed consent document before they began any testing.

Participant confidentiality was maintained using a subject number code. Participant's data

were encoded and grouped using a numerical code based on their playing position: 1-

offensive line (OL) and defensive line (DL), 2- linebackers (LB), 3- wide receivers (WR) and

defensive backs (DB), 4- running backs (RB) and tight ends (TE), and 5- quarterbacks (QB)

and specialists (SP). In total there were 31 subjects in group 1 (17 OL, 14 DL), 15 in group

2, 28 in group 3 (16 WR, 12 DB), 13 in group 4 (7 RB, 6 TE), and 12 in group 5 (6 QB, 6 SP).

The player grouping is based on suggestions from the AMSSM position statement:

concussion in sports medicine (Harmon et. al., 2012). Their mean ages, number of years of

football played, and number of concussions sustained can been seen in Table 1.

Table 1. Descriptives of individuals from different football position groups.

	OL/DL- 1	LB-2	WR/DB- 3	TE/RB- 4	QB/S- 5
n	31	15	28	13	12
# previous concussions	1.1 ± 1.4	1.3 ± 1.2	1.04 ± 1.3	0.5 ± 0.6	0.4 ± 0.8
age	21 ± 1.6	22 ± 1.6	21 ± 1.7	21 ± 1.9	21 ± 1.7
Years of FB played	10.2 ± 3.2	12 ± 2.8	12 ± 3.0	13 ± 2.6	12 ± 3.9

OL/DL is offensive and defensive lines, LB is linebackers, WR/DB is wide receivers and defensive backs, TE/RB is tight ends and running backs, QB/S is quarterbacks and specialists

Participants who sustained a head injury during the season, completed post-testing

using the visual-motor tracking task, described below, and performed, in alignment with

USU's standard concussion evaluations: a symptom questionnaire, SAC and mBESS tests. If

testing indicated a concussion, the subject entered USU's concussion protocol and

underwent daily follow up SAC and mBESS testing until his scores reached within one point

of his baseline SAC score, and two points of the baseline mBESS score. If his score

improved compared to the baseline (i.e. a higher score on the SAC or lower score on

mBESS), it was accepted as a passed test. Based on USU's injury records, there were nine

concussions during the Fall 2013 season. During the 2015 season, including the post-

season practices and one game, there were a total of seven concussions. The 2016 fall

season produced 10 concussions (Table 2). This study aimed to pre-test 99 football

athletes and post-test 7-10 concussed participants based on data from USU's injury

records. Eight concussed subjects elected to participate in the study, three of whom were

tested at the time of injury, one month, and three months post-injury (M age= 21, STD =

±0.673). Of those three, only one subject had baseline and six-month post test values

captured. Two subjects were post-tested, but did not have pre-test baseline data and have

not reached the six-month mark yet. A total of six concussed subjects (M age= 20.3, STD

age=±1.48) were pre and post-tested. One subject was post-tested in both the 2014 study

and this study due to multiple injuries. A total of eleven control subjects (M age= 20.6, STD

age= ±1.61) were tested (Table 3). A breakdown of injured and control subjects can be

found in Table 4.

Table 2. Utah State University Football Concussion Data

Season (year)	# of Athletes	# of Concussions	% Concussions per athlete

Fall 2013	109	9	8.3%
Fall 2015	104	7	6.7%
Fall 2016	105	10	9.5%

Table 3. Descriptives of individuals in the concussed and control groups.

	Concussed	Control
n	n=6	n= 11
# previous concussions	0.67	0.55
age	20.3 ± 1.48	20.6± 1.61
Years of FB played	9.83 ± 3.63	12.18 ± 2.29

Table 4. Descriptives of baseline and post-testing in all participants.

Subject #	Control/Injured	Age	Position #	Baseline tested	Post-tested	Serial tested
4	Injured	21	2	X	X	
8	Injured	19	3	X	X	
17	Injured	22	4	X	X	
29	Injured	20	3	X	X (2)	
51	Injured	20	3	X	X	1, 3, 6 month
69	Injured	20	1	X	X	
94	Injured	22	2		X	1, 3 month
95	Injured	21	2		X	1, 3 month
1	Control	21	1	X	X	
2	Control	21	3	X	X	
33	Control	20	1	X	X	
36	Control	20	4	X	X	
39	Control	23	5	X	X	
44	Control	22	3	X	X	
45	Control	20	3	X	X	
47	Control	20	3	X	X	
54	Control	22	3	X	X	
63	Control	19	3	X	X	
71	Control	19	4	X	X	
96	Control	23	2		X	1, 3 month

Procedures

Upon entering USU intercollegiate athletics, each athlete was baseline tested using the SAC and mBESS tests in order to compare these scores with the scores from their post-injury tests in the event of a brain injury. This study added a third baseline and post-injury test, which was a visual-motor tracking task. The RMSE and approximate entropy scores from this task were compared to the baseline value to determine if a change in visuo-motor complexity occurred as a result of the brain injury. Two control subjects, who were baseline tested at the same time as the injured subject, were retested at the same intervals to serve as a comparison. The goal was to test the concussed and control subjects at the time of injury, and at one, three, and six months post-injury. The ApEn scores collected from all participants were analyzed to determine if they provide a reliable means to detect behavioral differences following concussion.

Measurements

The visual-motor tracking task consists of a force transducer and a screen. When the program is opened, it prompts the administrator for subject number, whether the participant had a history of concussion or no history of concussion, and what post-concussion session they are being tested on. Testing was conducted in a quiet area to limit distractions. The subject placed their forearm in a pronated position and placed the medial aspect of the distal inter-phalangeal (DIP) joint of the index finger against the transducer. Each subject was instructed to use his right index finger. The subject was seated in front of a table at a comfortable, but close distance from the computer screen. First, the subject had three practice attempts to become accustomed to the program. A target path appeared on the black screen and represented the amount of pressure the subject used to move the

cursor on-screen in order to trace the target path. A lessening of the force used caused the cursor to drop down towards the bottom of the screen, and an increase in force caused the cursor to move vertically toward the top of the screen (see Figure 2). After the practice session was over, the subject began 10 trials, five of which include full vision, and the other five without a visual guide on the screen. In the first condition vision was available, therefore the subject was able to see their cursor on the screen and use visual feedback to update their position relative to the target path. In the second condition, the subject had three seconds of visual feedback to equalize the movement of their cursor and then the visual feedback was removed while he tried to maintain a constant force. Each trial lasted for 20 seconds, and the Root Mean Squared Error (RMSE; average deviation from the target), was displayed after each trial. The data from each testing session was saved and analyzed. The independent variables for this study were the time from injury (pre-test vs. post test, and one month, three months, and six month follow ups), the number of previous concussions (0, 1, 2+), and playing position (1-5). Dependent variables were the ApEn and RMSE values for each trial, averaged over 5 trials for each condition.

Figure 2. A participant performing the visual-motor tracking task with visual feedback.

Data Analysis

The visual-motor tracking data were analyzed with Matlab software (Mathworks, Natick, MA) using a custom written algorithm. The algorithm takes the data and quantifies the disorganization or randomness by finding the patterns of short-sequence data points within a time-series. For ApEn, an error-tolerance is used to determine whether points that are close, remain close once an additional point is compared. The closeness is termed error-tolerance, and is calculated as 2 times the standard deviation of the time series. Points that are adjacent were compared based on previous literature (Yentes, et al., 2013). For each point in the behavioral time series, data points at 2 and 3 points away are compared. A ratio of points that are close in proximity over those that remain close (within the error tolerance) when compared with a subsequent data point, is then calculated. The resulting ApEn value can be between zero and two, and it has no identifying unit. The lower the ApEn value, the more regular the time-series. For example, a sine wave would

have a smaller ApEn score than a randomly generated wave-form (see Figure 1). The

higher the ApEn value, the more random the time-series is. Gaussian noise is indicated by

an ApEn value of two (Cavanaugh, Mercer, and Stergiou, 2007).

The values for ApEn and RMSE were analyzed in three groups of individuals to

address our main aims. For the six subjects who were concussed and had pre-test data,

and the eleven control subjects, an ANOVA for ApEn was run with test (pre vs. post) as a

within subject factor, and group (concussed vs. control) and previous history of concussion

(0, 1, 2+) as between subject factors. Secondly, A one-way ANOVA with position group (1-

5) a a between subjects factor was run for the entire group of ninety-six athletes with pre-

test data Finally, for the entire group of ninety-six athletes with pre-test data, a one-way

ANOVA was run with previous history of concussion (0, 1, 2+) as a between subject factor.

Results

First, we hypothesized that RMSE would be higher and ApEn would be lower in

individuals following injury. We expected ApEn to increase as time from injury increased,

and therefore, did not expect to see differences between 3 months post injury and pre-test

values. A two-way ANOVA was run to determine the effect of concussion on RMSE values

with group (concussed vs. control) as a between subjects factor, and test session (pre-test

vs. post-test) as a within subjects factor. No significant main effects, $F(1, 15) = 3.2$, $p =$

.093, or interactions, $F(1, 15) = .012$, $p = .915$, were found within the full vision condition

for RMSE (see Figure 3). There was also no main effect of group, $F(1, 15) = 1.8$, $p = .20$, or

interactions on the no vision condition. During the no-vision condition, both the concussed

and control groups had lower RMSE scores on the post-test but the difference was

insignificant, $F(1, 15) = 1.2$, $p = .30$. For both the concussed and control group, ApEn

values decreased from pre to post-test (Figure 4), but the difference was not significant (F (1, 15) = .67, p = .42). There was a main effect of group on ApEn scores, F (1, 15) = 8.6, p = .010. No interaction was found, F (1, 15) = .15, p = .71. For the no vision condition, there were no significant main effects of group, F (1, 15) = 1.8, p = .21, and no interactions, F (1, 15) = .056, p = .82. Symptoms and days until full RTP of the six subjects with pre and post-tests can be found in Table 5.

Table 5. *Symptoms and days until full RTP of subjects 4, 8, 17, 29, 51, and 69.*

| Subject #	Days to RTP	Signs and Symptoms
4	4	Anterograde amnesia > 5 minutes, headache, dizziness, confusion
8	14	Blurry vision, pain in face, "flash of black", headache, nausea, dizziness, extreme fatigue, sensitivity to light and sound
17	5	"off balance", head pressure
29	3	Headache, "felt out of it", nausea
51	3	Headache, blurry vision < 1 minute, fatigue
69	4	Headache (returned on day 3), nausea, fatigue, dizziness, slow to respond
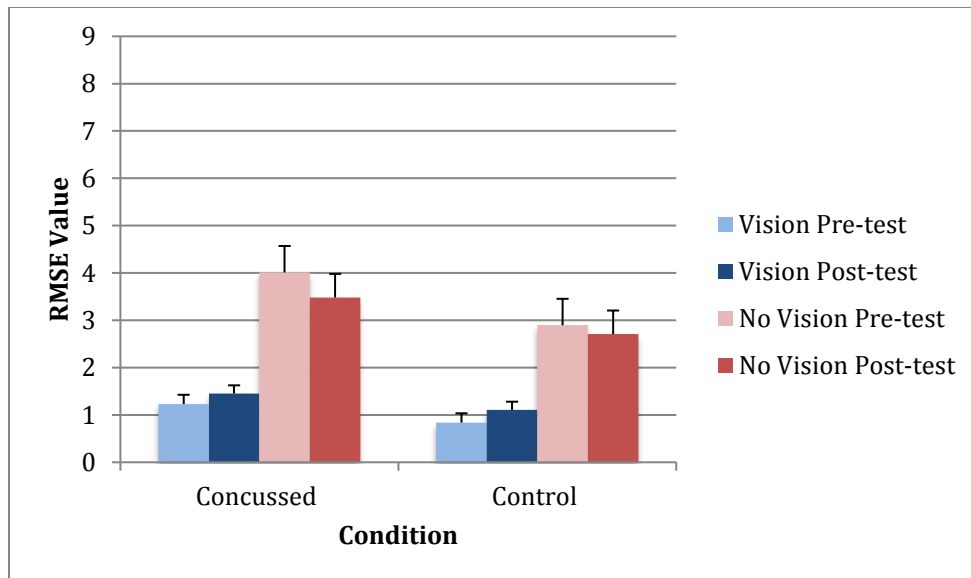
Figure 3. Pre and post-test RMSE values in concussed and control subjects in the vision and no vision conditions. Error bars represent one standard error.
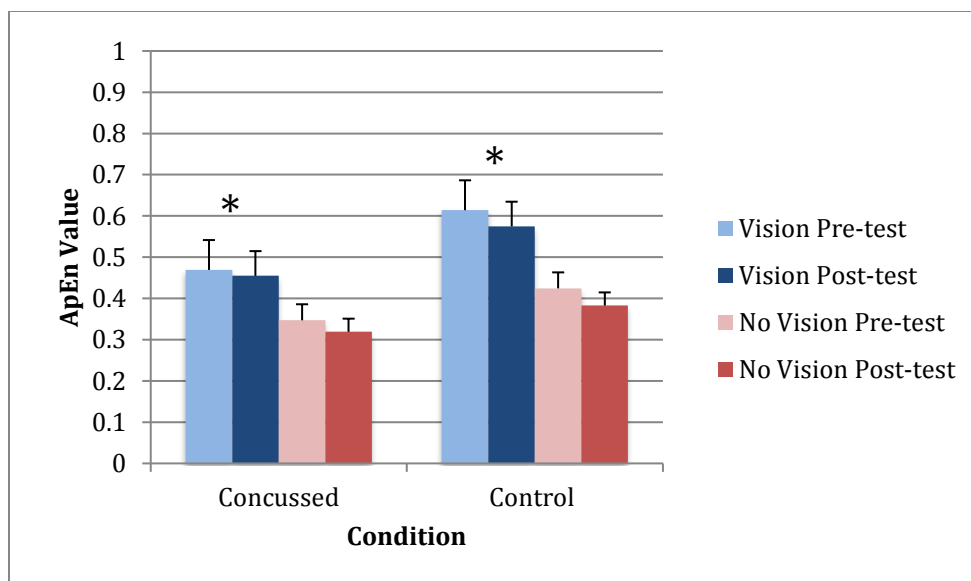

*Figure 4. Pre and post-test ApEn values in concussed and control subjects in the vision and no vision conditions. All error bars represent one standard error. * indicates significant effect between concussed and control groups.*

There was insufficient data to run statistical comparisons for the 3 subjects who underwent serial testing at post-injury, 1 month, 3 months, and 6 months. The following case studies will look at each subject individually. A list of symptoms and days until RTP can be seen in Table 6. Subject 51 was the only participant that completed the 6-month serial testing (see Figure 5). At the time of baseline testing he was 20 years of age, played football for 7 years, was a wide receiver, and had no previous concussions. He sustained a concussion during a game in the Fall 2015 football season. His signs and symptoms included blurry vision that resolved and headache, which he did not report until the day after because he normally had headaches after games. He was cleared to RTP 4 days after the initial injury. Contrary to our hypothesis, his ApEn values during the vision condition were elevated after injury, and decreased each time he performed the task. However, the ApEn value at 3 months was higher than the baseline value in both conditions. At 6 months, the ApEn value was lower than pre-test values in both conditions. RMSE values were also compared (see Figure 6) and we found that the subject committed the least amount of error during the post-injury vision condition test. This indicates that while the ApEn value was the highest for that test, meaning the structure was more random; the subject was able to keep his cursor closest to the guiding line on the screen.

Table 6. *Symptoms and days until RTP of subjects 51, 94, and 95.*

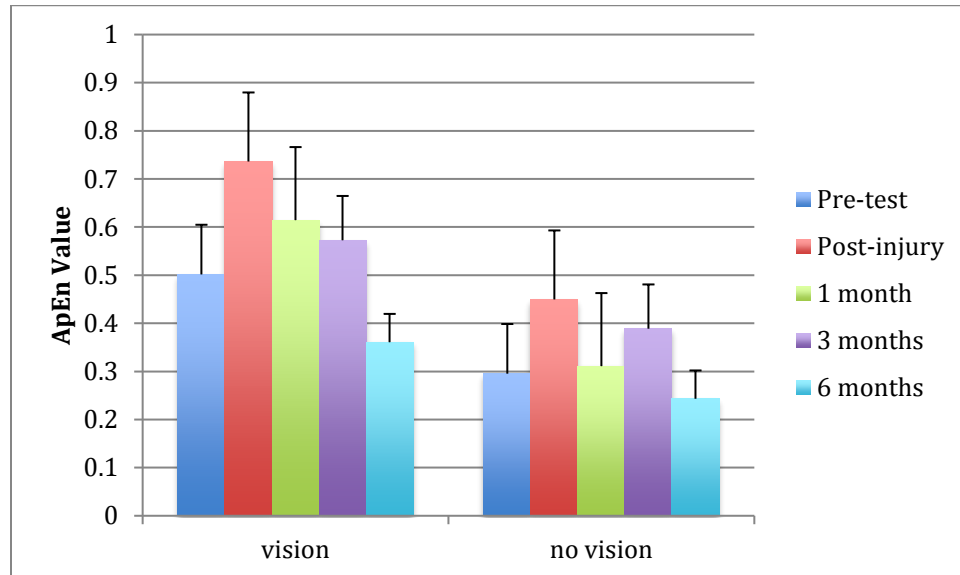| Subject #	Days to RTP	Signs and Symptoms
51	4	Blurry vision <1 minute, headache
94	8	"flash of black", severe headache, dizziness, trouble concentrating for long periods of time
95	3	"flash of black", cervical spasms

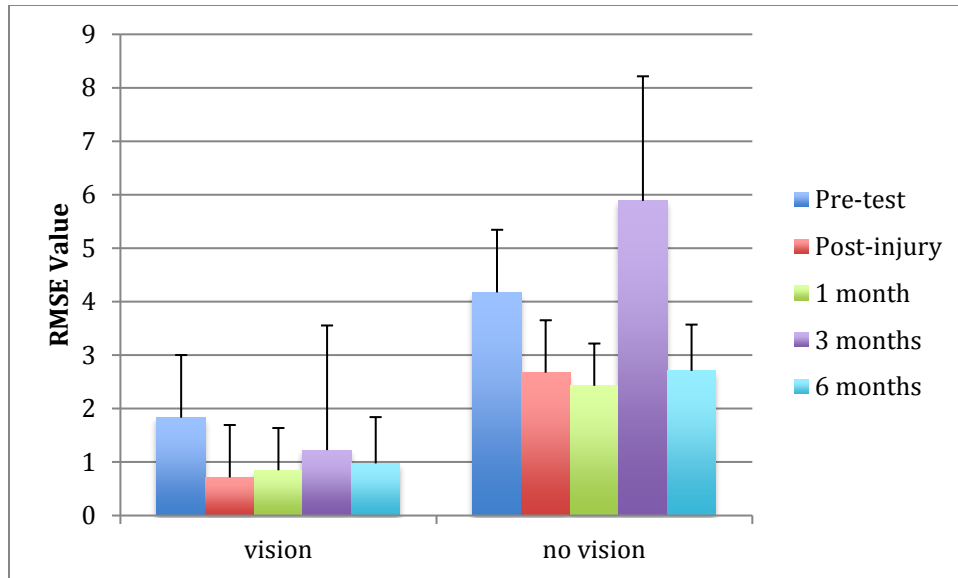*Figure 5. Subject 51 pre-test, post-injury, and serial test ApEn values. Error bars represent one standard error.*

Figure 6. Subject 51 pre-test, post-injury, and serial test RMSE values. Error bars represent one standard error.

Subject 94 was 22 years of age, played football for 12 years, was a linebacker, and had a previous history of one concussion. He sustained a concussion during a practice of the Fall 2016 football season. He reported receiving a helmet to helmet hit and seeing a flash of black, but not being unconscious. He did not initially report the injury and continued to participate throughout the next few plays until ultimately he felt he should not play. Initial symptoms included severe headache and dizziness. The subject had persistent headaches, when trying to concentrate for long periods of time, which lasted 6 days. He was cleared to RTP 8 days after the initial injury. He did not have a baseline test, but RMSE and ApEn values for post-injury, 1-month, and 3-month test days can be seen in Figures 7 and 8, respectively. Contrary to the hypothesis, his ApEn values decreased over time in both the vision and no vision conditions.
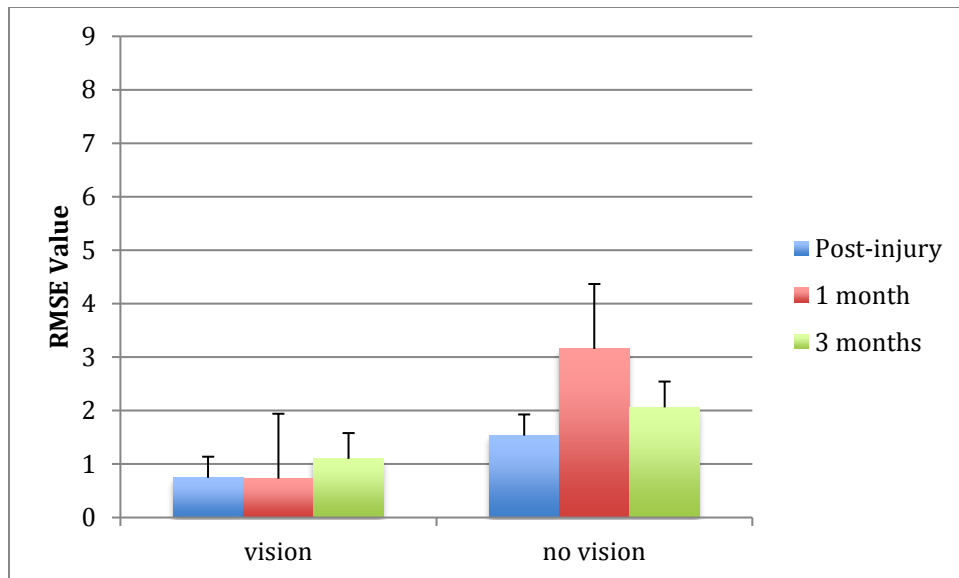
Figure 7. Subject 94 post-injury, 1 month, and 3 months post-injury RMSE values. Error bars represent one standard error.
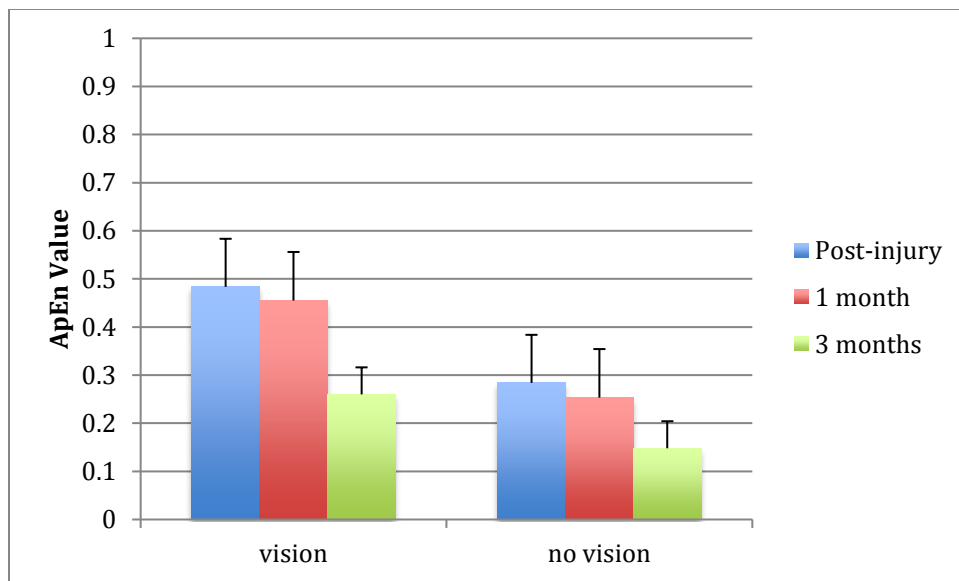

Figure 8. Subject 94 post-injury, 1 month, and 3 months post-injury ApEn values. Error bars represent one standard error.

Subject 95 was 21 years of age, played football for 10 years, was a linebacker, and had a previous history of one concussion. He sustained a concussion during a game of the Fall 2016 season from a helmet-to-helmet hit. He reported seeing a flash of black, but remembered everything that happened. He was pulled from the game immediately after the hit and did not return. He did not have any lingering symptoms, and passed baseline SAC and mBESS testing within 2 days of injury. He was cleared to RTP on the third day after initial injury. He did not have a baseline test, but ApEn and RMSE values for post-injury, 1-month, and 3-month test days can be seen in Figure 9 and 10, respectively. As hypothesized, his ApEn increased from post-injury to 3 months post.
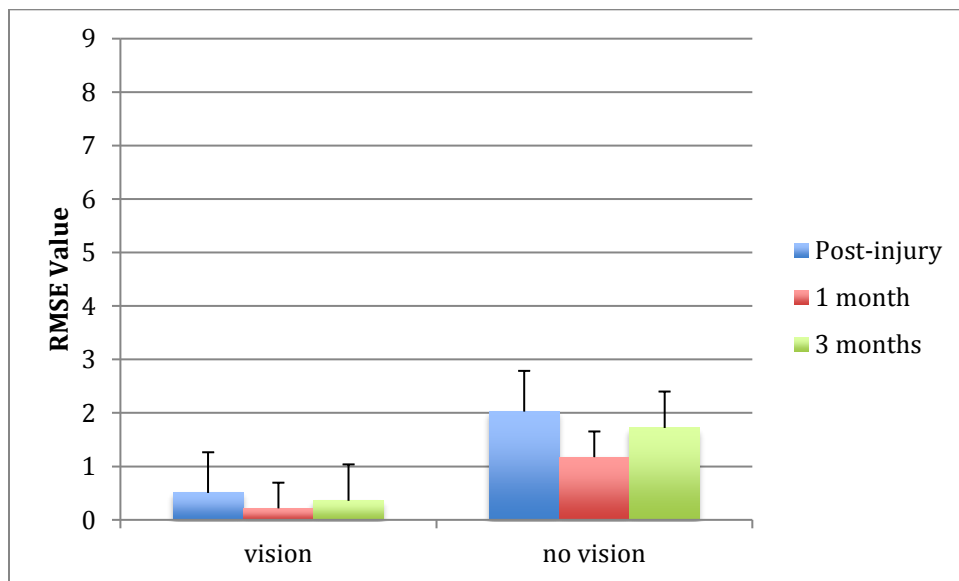

Figure 9. Subject 95 post-injury, 1 month, and 3 months post-injury RMSE values. Error bars represent one standard error.
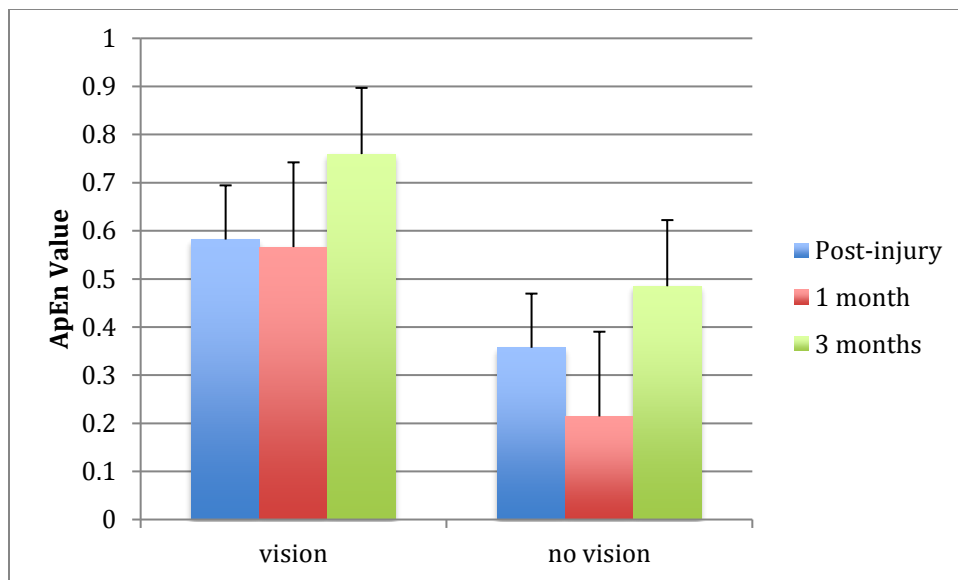
Figure 10. Subject 95 post-injury, 1 month, and 3 months post-injury ApEn values. Error bars represent one standard error.

We hypothesized that offensive and defensive linemen (1) and linebackers (2) would exhibit a higher pre-test RMSE value and lower pre-test ApEn value compared to wide receivers and defensive backs (3), tight ends and running backs (4), and quarterbacks and specialists (5). A one-way ANOVA was used to compare pre-test RMSE values with position group as a factor. Both the vision and no vision conditions showed no significant effect of position group on RMSE values (Figure 11). The analysis of ApEn vision condition showed a significant effect of position group, $F(4, 91) = 4.471$, $p = .002$. Post-hoc LSD contrasts of the ApEn scores revealed a significant difference between groups 1 and 3 ($p = .002$), 2 and 3 ($p = .001$), 2 and 5 ($p = .014$), 3 and 4 ($p = .046$) (see Figure 12). This means that offensive and defensive linemen and linebackers exhibited significantly lower ApEn scores (.49, .44) compared to the wide receivers and defensive backs (.59). Significant

differences were also seen between groups in the no vision condition (F = 4.185, p = .004).

A post-hoc LSD contrast showed significant differences between groups 1 and 2 (p = .036),

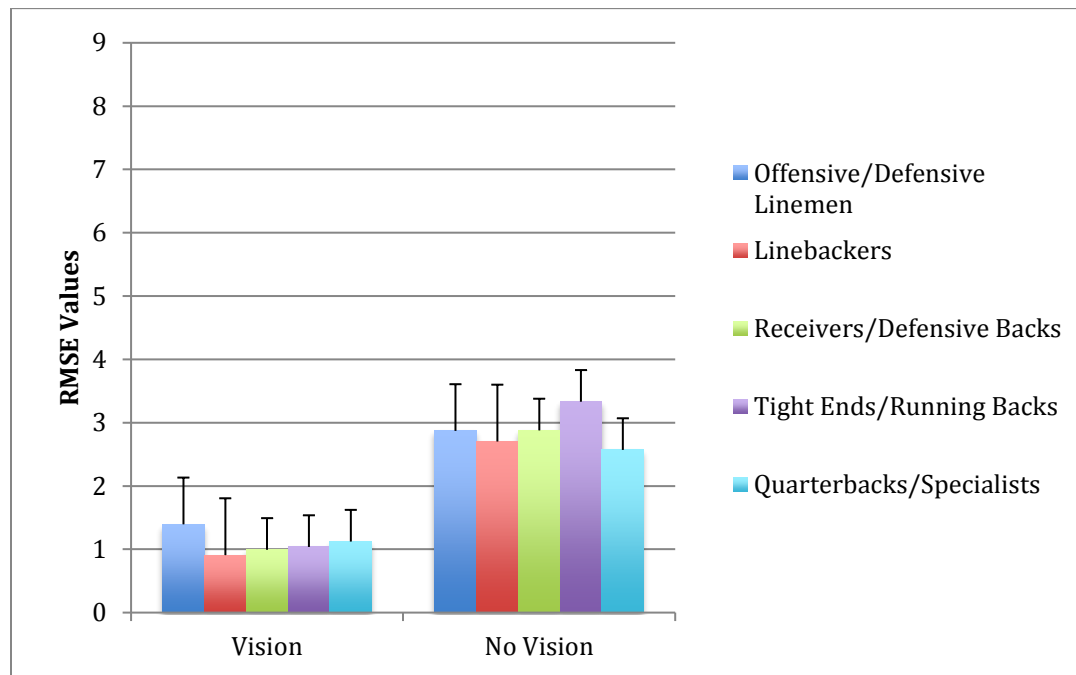1 and 3 (p = .022), 2 and 3 (p = .000), and 2 and 5 (p = .007).

Figure 11. Pre-test RMSE values of participants in different playing position groups. Error
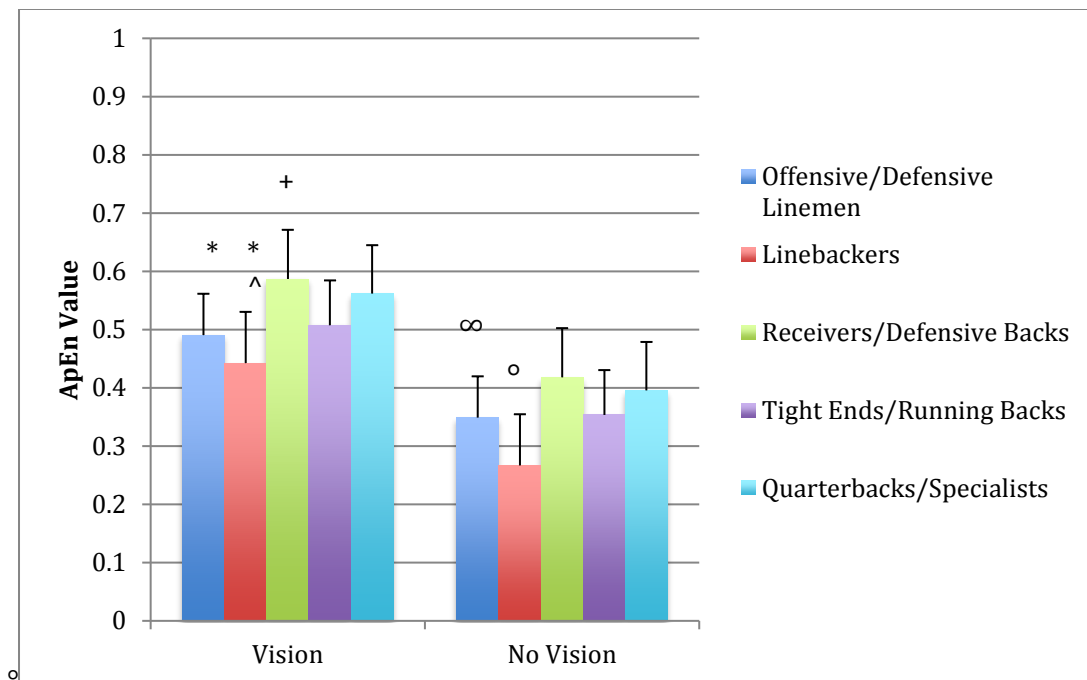
bars represent one standard error.

*Figure 12. Pre-test ApEn values of participants in different playing position groups. Error bars represent one standard error. * indicates a significantly lower ApEn score compared to WR/DB's. ^ indicates a significantly lower score than QB/specialists. + indicates a significantly higher score than TE/RB's. ∞ indicates a significantly lower score than LB's and WR/DB's. ° indicates a signficantly lower score than WR/DB's and QB/Specialists.*

Finally, we hypothesized that pre-test ApEn values would be lower in those individuals with a history of multiple concussions compared to those with no history or history of only one concussion. Pre-test baseline ApEn values in 96 individuals with a history of none, one, or 2+ concussions were compared using a one-way ANOVA with the number of previous concussions (0, 1, 2+) as a factor. There was no significant effect of number of concussions, $F_{(2, 93)} = 3.045$, $p = .052$. However, a post-hoc LSD test showed that there was a significant difference between those with a history of one concussion and

those with more than one concussion, *p* = .016. This indicates that ApEn values were lower in individuals with a history of 2 or more concussions (see Figure 13). There were no significant differences between groups within the no vision condition.
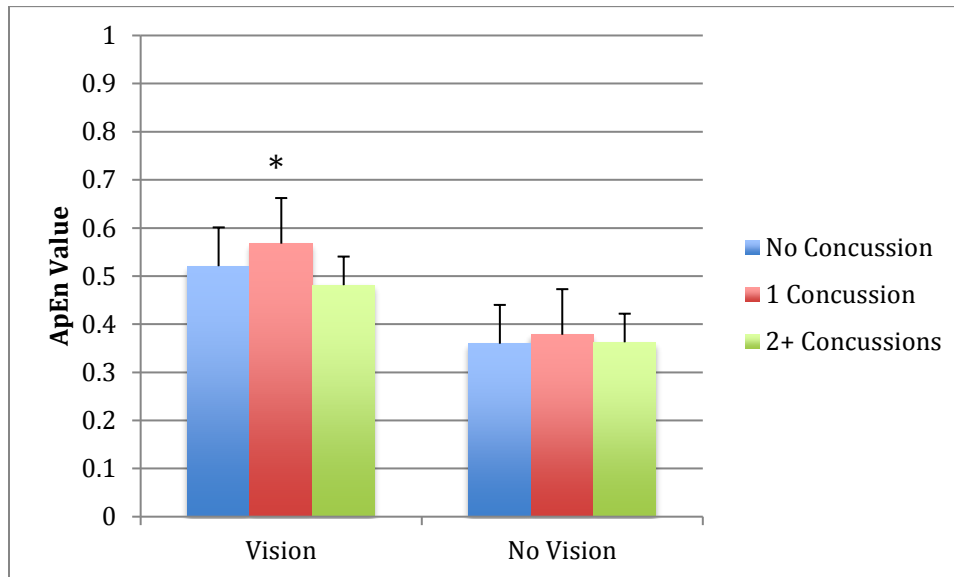

*Figure 13. Pre-test ApEn values of participants with none, one, and 2+ concussions. Error bars represent one standard error. * indicates a significant difference from 2+ concussion group.*

Discussion

This study was designed to assess the differences in motor control over time in subjects who suffered a sport-related concussion, as well as determine the effect of playing position on impairment due to concussion. This study built upon previous research and collected 41 of the total 99 testing values to contribute to the larger pool. Ninety-six of the participants had baseline values, while three began testing at the post-injury stage. Six

concussed and eleven non-concussed athletes were post-tested. One of the six concussed athletes was post-tested right after injury, at one month, three months, and six months. Two other concussed athletes and one non-concussed athlete were post-tested right after injury, at one month, and at three months.

Our first hypothesis that ApEn would decrease following concussion was not supported. No difference was seen between pre and post-test ApEn values in either the concussed or control group. One reason for this might be the conservative diagnosis of concussion, meaning that some individuals exhibit concussive symptoms that resolve in a short amount of time, but are still entered into the concussion protocol. There was a main effect difference between the concussed versus control group for baseline ApEn values. Although all participants were football players, this difference may be contributed to previous history of sub-concussive impacts, or previous history of concussion. The concussed group had a slightly higher mean number of previous concussion (.67) than the control group (.55). Additionally, we found that RMSE scores were not significantly different from pre to post-test for concussed and control participants in both the vision and no vision conditions, which was similar to the findings of Cavanaugh et. al (2007).

Although we were not able to attain a large enough data set with serial tested participants, it was valuable to see how different each subject performed on the motor-tracking task. Subject 51's results did not follow the pattern that we predicted. His post-test ApEn value was the highest out of all, and decreased each test going forward, ending with the lowest ApEn value at the six-month test. His RMSE values did not reflect the pattern we expected either. For the vision condition, his post-injury RMSE value was the lowest out of all of them, followed by one month, six months, three months, and pre-test

values. Subject 94 had increasingly lower ApEn scores as time went on, while Subject 95's one-month score was lower than post-injury, but the three-month score was much higher than post-injury. Because there was no baseline value for subjects 94 and 95, it is inconclusive whether the three-month value is close to the pre-test value, which is what we expected to happen. This indicates the need for a large sample size and a study conducted over a long period of time so that there is sufficient time to collect meaningful data.

Previous studies have suggested that, following concussion, individuals may adopt a more conservative pattern of movement to maintain balance, to compensate for reaction time impairment or a lack of visual-motor coordination (Sosnoff, Broglio, & Ferrara, 2011; Cavanaugh, Mercer, & Stergiou, 2007). Another study found that at six years post-concussion, the previously concussed group demonstrated a far more conservative and safer gait pattern to protect them from falls (Martini, Sabin, & DePasa et. al, 2011). Both our study and that of Cavanaugh et. al (2005) found decreased ApEn values following concussion. Because a lower ApEn value indicates a more regular structure, a lower value after concussion could indicate that the individual needs to devote more attention to the task, making it a less automatic pattern of movement (Rhea & Kiefer, 2014). All of these results support the belief that there are lasting effects of mTBI that persist after acute injury resolution, and present a concern for susceptibility to falls and other postural control related injuries later on in life (Broglio & Martini, 2016).

The second main aim of this study was to analyze the baseline ApEn values of individuals in various playing position groups to determine significant differences. We hypothesized that baseline ApEn values would be lower in groups 1 and 2, which include offensive and defensive linemen, and linebackers, respectively. We reached this hypothesis

based upon previous literature stating that offensive and defensive linemen and linebackers sustain a higher amount of sub concussive impacts on a daily basis (Baugh et. al, 2015), and that linebackers and offensive linemen have the highest rate of concussion per 1000 AE (Guskiewicz et. al, 2003). "Subconcussion" is defined as a low-magnitude impact that does not result in clinical signs and symptoms of a concussion, but may have long lasting influences on neurological function (Kawata et. al, 2016). A study of ocular near point of convergence (NPC) showed that individuals sustaining multiple sub concussive impacts did not report any differences in symptoms regardless of number of hits. The study also found, in support of previous literature, that NPC function was compromised in the higher impact group, and resolved in three weeks, which highlights the sensitivity of the ocular-motor system following impacts (Kawata et. al, 2016). There were varying results in other studies, which suggested that skills groups, including wide receivers, defensive backs, quarterbacks, and tight ends were at the highest risk for brain injury (Harmon et. al, 2012). We chose to separate the groups as we did because of the aforementioned studies. In support of Baugh et. al (2015) and Guskiewicz et. al (2003), our study found that groups one and two had significantly lower ApEn values compared to group three (wide receivers and defensive backs). It also showed that linebackers had significantly lower ApEn values compared to quarterbacks and specialists (group 5), and that wide receivers and defensive backs had significantly lower ApEn values compared to running backs and tight ends (group 4). These results indicate that although the skills positions may be at a higher risk for injury inducing impacts, the sub-concussive impacts that linemen and linebackers sustain on a regular basis may have a lasting effect on neurocognitive behavior. Previous studies on high school football players have used

ImPACT testing a functional MRI's to investigate the effect of head impacts on brain function over time. Breedlove et. al (2012) found that athletes that did not show signs and symptoms, but had functionally observed impairment (based on fMRI and neuropsychological testing) sustained more head impacts over the course of the season compared to athletes without impairment. Talavage et. al (2014) found similar results in that athletes with no clinical signs, but functional impairment sustained significantly greater impacts to the top frontal portion of their heads. These studies are important because they draw attention to the fact that athletes may not display any signs or symptoms of head impacts over time, but the damage is still occurring unnoticed.

Finally, this study aimed to compare baseline ApEn values between groups who had a history of none, one, or two or more concussions. We hypothesized that ApEn values would be lower in those subjects who had sustained a greater number of concussions, indicating lasting impairment. Our study found a significant difference between those with a history of one concussion and those with two or more concussions. Baseline ApEn values were significantly lower in individuals with a history of two or more concussions. There was no significant difference between the zero and one-concussion groups or zero and two-concussion groups. The group with a history of one concussion had the highest ApEn value. This could be due to underreporting of concussions in the zero group. Additionally, we only asked about the history of diagnosed concussions, not suspected concussions or frequency of sub-concussive impacts in their history of sport, which may have a long-term influence on behavior in the group that reported zero concussions. These findings support the hypothesis that multiple concussions would lead to long-lasting impairment that was exhibited through non-linear aspects of behavior. Previous literature supports the notion

that lasting impairment exists in individuals with a history of concussion. One study found that athletes who sustained a second concussion had a significantly slower recovery rate of neurological functions (Slobounov et. al, 2007). Another study found that the relative risk of sustaining a concussion was 5.8 times greater for high school and college players that had a history of concussion (Zemper, 2003).

Additionally, at this time this particular visual-motor tracking task would not be useful in the acute or sideline assessment of concussions, but would be most valuable in assessing the long-term behavioral changes in persons sustaining concussions. The ability of the non-linear assessment to detect subtle changes makes it best suited for follow-up tests rather than an immediate diagnosis, which is typically made based upon obvious signs and symptoms.

Limitations and Future Research

There were several limitations to the success of this study. One of the main limitations was the severity of concussion that the athlete sustained. Athletes with severe concussions were not able to complete the visual tracking task because, as per USU's concussion protocol, student-athletes are advised to avoid activities that increase their symptoms, which may include concentrating, screen use, attending class and meetings, and physical exertion. For this reason, there were three athletes that were concussed throughout the season, but did not participate in the study. For these individuals, it might still be feasible to collect data at one, three, and six months in order to analyze the longitudinal changes in behavior. Additionally, the particular visual-motor task used required individuals to come to the athletic training room, as it was not portable or

accessible from the sideline. More portable equipment would allow for better access to athletes both pre and post-concussion.

Secondly, I would recommend that if this line of research continues, the clinician should have at least one assistant that is not directly involved in the sports medicine program to help with the scheduling and administration of testing. This research would benefit from the support of the entire sports medicine staff rather than one individual. For example, many Division I football programs countrywide have multiple athletic trainers assigned to their team, along with undergraduate athletic training students. It would be easiest if all individuals were aware of the research study being conducted, trained in the administration of the test, and were able to work together in order to collect as much data on injured and control subjects as possible. Specifically, it would be most helpful if the motor-tracking task were a mandatory concussion baseline test, along with the other neurocognitive and balance tests that particular institution uses. That way, the researcher can ensure that everyone has a baseline test available in the event that they sustain a concussion during the season.

Lastly, the time limit of the data collection posed a limitation of the study. Two years was not enough time to collect a sufficient amount of follow up data to perform statistical analyses. This type of longitudinal research could be incredibly valuable to our understanding of how the human body recovers from a brain injury over time, and would require several years of data collection to obtain meaningful results. I would recommend that the data collection continue in order to eventually perform statistical analyses.

Conclusion

In conclusion, albeit a small difference, the difference between ApEn values in concussed and non-concussed subjects and the significant main effect of group on ApEn values suggests that the visual-motor tracking task could be a viable concussion evaluation tool. Future studies should focus on a larger subject pool in order to collect more data. The inconsistent results of the serial testing suggest that future studies should also collect more data from concussed and control participants to be able to run statistical analyses. The significant effect of position group on ApEn scores may indicate that certain playing positions are at a greater risk for sustaining a concussion. That, paired with the increased risk due to previous history of concussion, could provide the athlete with information in order to protect them in the best way possible. Lastly, lower ApEn scores in subjects with a history of two or more concussions could indicate long-term impairment due to concussion that may be undetected with typical concussion assessments. This task has the potential to detect long-term impairment in those with multiple concussions, which is important due to the increased risk of injury in athletes with a previous history of concussion.

References

Baugh, C.M., Kiernan, P.T., Kroshus, E., Daneshvar, D.H., Montenigro, P.H., McKee, A.C., Stern, R.A. (2015). Frequency of head-impact-related outcomes by position in NCAA division I collegiate football players. *Journal of Neurotrauma. 32*(5), pp. 314-326.

Bell, D.R., Guskiewicz, K.M., Clark, M.A., Padua, D.A. (2011). Systematic review of the balance error scoring system. *Sports Health. 3*(3), pp. 287-295. doi: 10.1177/1941738111403122.

Bey, T., Ostick, B. (2009). Second impact syndrome. *Western Journal of Emergency Medicine. 10*(1)*, pp. 6-10.*

Breedlove, E.L., Robinson, M., Talavage, T.M., Morigaki, K.E., O'Keefe, K., King, J., Leverenz, L.J., Gilger, J.W., Nauman, E.A. (2012). Biomechanical correlates of symptomatic and asymptomatic neurophysiological impairment in high school football. *Journal of Biomechanics. 45*(7), pp. 1265-1272.

Broglio, S.P., Cantu, R.C., Gioia, G.A., Guskiewicz, K.M., Kutcher, J., Palm, M., Valovich McLeod, T.C. (2014). National athletic trainers' association position statement: management of sport concussion. *Journal of Athletic Training. 49*(2), 245-265. doi: 10.4085/1062-6050-49.1.07.

Broglio, S.P., Martini, M.S. (2016). What are the long-term concerns with concussion? *Athletic Training & Sports Health Care. 8*(5), pp. 191-192.

Cantu, R. (1998). Second-impact syndrome. *Clinical Sports Medicine. 17*(1), pp. 37-44.

Cavanaugh, J.T., Guskiewicz, K.M., Stergiou, N. (2005). A nonlinear dynamic approach for evaluating postural control: considerations for the management of sport-related concussion. *Journal of Sports Medicine. 35*(11), pp. 935-950.

Cavanaugh, J.T., Mercer, V.S., & Stergiou, N., (2007). Approximate entropy detects the effect

     of a secondary cognitive task on postural control in healthy young adults: a

     methodological report. *Journal of NeuroEngineering and Rehabilitation. 4*(42).

Cifu, D., Steinmetz, B., Drake, D. (2008). Repetitive head injury syndrome. *eMedicine.*

Corso, P., Finkelstein, Miller, T., Fiebelkorn, I., & Zaloshnja, E. (2006). The incidence and

     lifetime costs of injuries in the United States. *Injury Prevention. 12*(4), pp 212-218.

Delaney, J.S., Lacroix, V.J., Leclerc, S., & Johnston, K.M. (2002). Concussions among

     university football and soccer players. *Clinical Journal of Sport Medicine. 12,* pp.

     331-338.

Guskiewicz, K.M., Ross, S.E., Marshall, S.W. (2001). Postural stability and

     neuropsychological deficits after concussion in collegiate athletes. *Journal of Athletic*

     Training. 36(3), pp. 263-273.

Guskiewicz, K.M., McCrea, M., Marshall, S.W., Cantu, R.C., Randolph, C., Barr, W., Onate, J.A., &

     Keely, J.P. (2003). Cumulative effects associated with recurrent concussion in

     collegiate football payers: the NCAA concussion study. *Journal of the American*

     Medical Association. 290, pp. 2549-2555.

Hamill, J., Heiderscheit, B.C., Haddad, J.M. & Van Emmerik, R.E. (2006). Clinical relevance of

     variability in coordination. In Davids, K., Bennett, S., & Newell, K. (Eds.). *Movement*

     system variability. pp. 153-165. Champaign, IL: Human Kinetics.

Harmon, K.G., Drezner, J.A., Gammons, M., Guskiewicz, K.M., Halstead, M., Herrin, S.A.,

     Kutcher, J.S., Pana, A., Putukian, M., & Roberts, W.O. (2012). American medical

     society for sports medicine position statement: concussion in sport. *Journal of*

     Sports Medicine. 47, pp. 15-26.

Kawata, K., Rubin, L., Lee, J., Sim, T., Takahagi, M., Szwanki, V., Bellamy, A., Darvish, K., Assari, S., Henderer, J., Tierney, R., Langford, D. (2016). Association of football subconcussive head impacts with ocular near point of convergence. *Journal of the American Medical Association Ophthamology. 134*(7), pp. 763-769.

Koscs, M., Kaminski, T.W., Swanik, B., & Edwards, D.G. (2008). Effects of exertional exercise on the standardized assessment of concussion (SAC) score. *Athletic Training and Sports Health Care, 1*(1), pp. 24-30.

Martini, D., Sabin, M., Depasa, S., Leal, E., Negrete, T., Sosnoff, J., Broglio, S. (2011). Chronic effects of concussion on gait. *Archives of Physical Medicine and Rehabilitation. 92*(4), pp. 585-589.

Rhea, C.K. & Kiefer, A.W. (2014). Patterned variability in gait behavior: How can it be measured and what does it mean? In Li, L. & Holmes, M. (Eds.). *Gait Biometrics (17-43).*

Saunders, R., Harbaugh, R. (1984). The second impact in catastrophic contact-sports head trauma. *Journal of the American Medical Association. 252* (4), pp. 538-539.

Shehata, N., Wiley, S.P., Richards, S., Benson, B.W., Duits, L., & Meeuwisse. W.H., (2009). Sport concussion assessment tool: baseline values for varsity collision sport athletes. *British Journal of Sports Medicine, 43*(10), pp. 730-734.

Talavage, T.M., Nauman, E.A., Breedlove, E.L., Yoruk, U., Dye, A.E., Morigaki, K.E., Leverenz, L.J. (2014). Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion. *Journal of Neurotrauma. 31*(4), pp. 327-338.

Valovich, T.C., Perrin, D.H., & Gansneder, B.M., (2003). Repeat administration elicits a

practice effect with the Balance Error Scoring System but not with the Standardized Assessment of Concussion in high school athletes. *Journal of Athletic Training,* 38(1), pp. 51-56.

Wilkins, J.C., Vavlovich, T.C., Perrin, D.H., & Gansneder, B.M. (2004). Performance of the balance error scoring system decreases after fatigue. *Journal of Athletic Training. 39*(2), pp. 156-161.

Yardley, L., Gardner, M., Bronstein, A., Davies, R., Buckwell, D., Luxon, L. (2001). Interference between postural control and mental task performance in patients with vestibular disorder and healthy controls. *Journal of Neurology, Neurosurgery, and Psychiatry. 71*(1), pp. 48-52.

Yentes, J. M., Hunt, N., Schmid, K. K., Kaipust, J. P., McGrath, D., & Stergiou, N. (2013). The appropriate use of approximate entropy and sample entropy with short data sets. *Annals of biomedical engineering. 41*(2), 349-365.

Zemper, E.D., (2003). Two-year prospective study of relative risk of a second cerebral concussion. *American Journal of Physical Medicine & Rehabilitation.* 82:9, 653-659.

Zuckerman , S.L., Kerr, Y.Z., Yengo-Kahn, A., Wasserman, E., Covassin, T., Solomon, G.S. (2015). Epidemiology of sports-related concussion in NCAA athletes from 2009=2010 to 2013-2014: Incidence, recurrence, and mechanisms. *American Journal of Sports Medicine. 43*(11), pp. 2654-2662.