OCULOMOTOR FUNCTION IN COLLEGIATE STUDENT-ATHLETES WITH A PREVIOUS HISTORY OF SPORT-RELATED CONCUSSION

by

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ABSTRACT

Context: Current clinical tools that diagnose and assess concussed athletes do not include a component for measuring oculomotor function. Researchers in optometry and neurology have shown that eye movement deficits in subjects with a history of acquired brain injury exist, but these measurements have not been implemented utilizing an athletic population, or a population with a history of mild brain trauma such as sport-related concussion. **Objective:** The purpose of this study is to determine if sport-related concussion creates lasting deficits in oculomotor function and learning, as measured by the King-Devick (KD) Test. **Design:** Quasi-experimental, ex post facto **Setting:** Laboratory **Patients or Other Participants:** A total of 170 collegiate athletes were evaluated for oculomotor function. Seventy-three of these subjects had a previous history of sport-related concussion. The remaining participants had no previous history of head injury. **Intervention(s):** Objective measurements were obtained through the use of the KD Test which assesses the speed of rapid number naming to capture impairments in eye movement. **Main Outcome Measure(s):** The time to complete (seconds) the KD Test was compared between a control group and a group with a previous history of concussion. The learning effect was also evaluated between the first and second trials across groups. **Results:** No significant differences existed between groups for oculomotor function (p=0.352) or learning effect (p=0.615). The control group revealed a mean

completion time of 38.21s as compared to the experimental group's mean time of 39.12s. Results from learning effect scores were very similar as well. The group with no previous history of concussion posted a mean improvement time of 2.48s, while the previously concussed group had a mean improvement of 2.68s. **Conclusions:** With respect to the KD test, no long-term deficits in oculomotor function or learning exist in the collegiate student athlete population after sustaining a concussion.

Chapter 1

INTRODUCTION

Over the past few years, clinicians and researchers have developed an increasing interest in the field of concussion assessment and management. This attention has drastically improved the knowledge regarding the physiological effects as well as the proper evaluation and recovery protocol associated with brain injury. Results from recent research have changed medical practices in all areas of athletics. The National Football League altered previous guidelines for concussion management by expanding the list of symptoms that could prohibit an athlete from returning to play. Similar adjustments, such as improving and mandating certain protective equipment, have been made in field hockey and lacrosse to ensure player safety. Even with these heightened precautions, incidence rates have increased considerably, classifying concussions as an epidemic.[1] Approximately 1.6 to 3.8 million sport-related concussions occur annually in the United States, with an estimated $60 billion associated with the direct and indirect costs of emergency room visits.[2] The highest risk of concussion exists in contact team sports such as ice hockey, rugby and American football and individual sports such as boxing, taekwondo and karate.[3] Furthermore, many athletes suffer concussions which go undiagnosed or medical providers fail to properly assess these injuries, categorizing

concussive blows as “dings.” This misinterpretation could result in further injury, irreversible damage and even death.

Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces, which result in transient neurologic signs or symptoms, and is largely the result of functional deficits.[4] The most common mechanism for sports related concussion is head to head contact with another individual.[5] This causes linear, rotational or angular movement of the brain inside the cerebral cavity forcing the brain to strike the cranial wall. This impact leads to tissue damage of the brain and brain stem, therefore creating a variety of neurologic symptoms. These symptoms are often indicators as to the extent of the injury and the recommended management process.

Controversy currently exists among medical providers as to the most reliable, practical and effective tool for clinically diagnosing and assessing sport-related concussion (SRC). In 2004, the National Athletic Trainers’ Association (NATA) released a position statement regarding the management of SRCs in an attempt to increase the consistency of care given to athletes suffering from these injuries. One of the recommendations suggested the use of a variety of instruments and apparatuses to comprehensively evaluate the concussed athlete including: symptoms checklists, the Standardized Assessment of Concussion, Balance Error Scoring System and computerized neuropsychological testing.[6] Despite their clinical utility; none of these tools are able to objectively assess precise oculomotor function, which is often affected by brain trauma.[7] Mechanisms such as linear, rotational and angular forces associated

with concussion, not only cause trauma to the brain, but also to the cranial nerves, which control eye movement. In addition, many clinicians are reluctant to test for oculomotor function because until recently there was no way to practically evaluate this skill. Without proper assessment of eye movement, concussed athletes may be misdiagnosed or returned to play prior to being asymptomatic. This in turn may predispose athletes to further injury, and reflect negatively on the competency of the medical provider.

To improve current protocol, clinicians must first recognize that these deficits exist in such a population. Sparse literature exists on the objective measurement of oculomotor function; however recent research has shown promising results. Researchers in optometry have recorded eye movement deficits in subjects with a history of acquired brain injury due to stroke.[8] However, these results do not necessarily extrapolate to the collegiate athletic population, nor do they include mild traumatic brain injuries such as sport-related concussion. The most revealing data on oculomotor function in concussed athletes may be seen in recent studies which utilize a new concussion screening tool known as the King-Devick (KD) Test.[9,10] This test challenges subjects to read a series of numbers as quickly as possible without making errors. Proper execution requires the subject to perform very quick, controlled movements of the eye, known as saccades. Examining saccadic eye movement reveals motor control and conduction velocity of several cranial nerves, including II, III, IV and VI. These nerves originate in the diencephalon and midbrain which has been shown to be the most affected portion of the central nervous system during rotational forces associated with concussion.[11] Currently, two studies exist which implement the KD test on concussed athletes.[9,10]

Results reveal concussion causes acute deficits in oculomotor function when comparing pre- to post-injury scores within subjects.[9] However, these deficits have not been examined at various times post injury, to rule out possible long term oculomotor deficits related to concussion.

The methods of this scientific study require the student athletes to complete the KD test twice; examining each participant's ability to improve performance between trials. This protocol allows researchers to observe a learning effect, which will provide insight into the possible long-term effects that concussion has on learning. Generally, the ability of an individual to learn a task is the result of chemical and anatomical modifications to the neurons and neural synapses in the brain.[12] These changes create a more efficient and effective neural pathway, allowing the same individual to complete the same demand more quickly.

Therefore, the purpose of this study was to determine if sport-related concussion creates lasting deficits in oculomotor function and learning. We hypothesized that a previous history of concussion will hinder oculomotor function resulting in higher overall test times and suppress learning effect revealing lower improvement times from trial one to trial two.

Chapter 2

METHODS

2.1 Participants

Oculomotor function was evaluated on 170 collegiate student-athletes. All participants were selected from a single Delaware-based university and ranged in age from 18 to 24. Seventy-three participants had a previous history of sport-related concussion (SRC). No other inclusion criteria were necessary. The control group contained ninety-seven individuals with no prior history of head injury and both groups were closely related in mean age, gender, height, and mass (Table 1). Researchers excluded potential participants from the study if prior diagnosis of oculomotor dysfunction or reading disability was reported. All participants signed institutionally approved documents of informed consent (UD IRB # 232543-3).

2.2 Instrumentation

The King-Devick Test was used to assess oculomotor function (Figure 1). This test required the participant to rapidly name numbers out loud from an index card. There are three test cards, each test card was timed using a stop watch and the total completion time for all three cards was the measured variable.

2.3 Procedures

The study protocol involved a quasi-experimental, ex post facto design. Testing took place in a lab environment, providing a quiet area that was free from distractions. All participants were first asked to complete a questionnaire with questions pertaining to general medical information and specific details regarding prior concussive incident(s). If the participant was part of the control group (no previous history of concussion) then this portion of the questionnaire was left blank. This allowed researchers to collect a variety of data pertaining to factors that may affect oculomotor function including number of concussions, as well as severity and time since injury. After the questionnaire was completed participants were then briefed on the KD test using a set of standardized instructions.

The KD Test was introduced to the participant and turned to the demonstration card. The researcher (PB) ensured that the test card was held at a comfortable reading distance. Subjects were able to use reading glasses or contacts if necessary. The researcher (PB) explained the directions of the KD test, making certain to iterate to the participant that they could not use their hands or fingers to assist themselves in reading. The demonstration card was used as a visual aid while explaining the directions. The test required the participant to read aloud a series of numbers from an index card from left to right, as quickly as possible but without making any errors. The participant read the numbers on each of the three "test" cards while being timed. The time it took to complete each card and the number of errors made was recorded and the entire test was repeated. After the third and final test card of the second trial was completed, the

participant was free to leave the testing area. Total testing time was approximately 10 minutes.

A pilot sub-group analysis was undertaken in this study. Five participants completed the KD test five times with minimal rest between trials. The purpose of this experiment was to examine the learning effect across multiple trials in order to determine when the greatest improvements in test time were seen. From this pilot study it was determined that two test trials would be sufficient to document maximal learning effect if present (Figure 2). This supports current research involving the KD test, which recommends two trials to establish an appropriate baseline score for each athlete.[9,10]

2.4 Data Analysis

The independent variable evaluated in this study was the participant's history of concussion. This separated the participants into two groups, the control group which has no history of concussion and the experimental group which has a previous history of concussion. Two dependent variables were examined. The main variable was the total time in seconds to complete the KD test and the secondary dependent variable is the improvement time in seconds from trial one to trial two which was used to examine the learning effect if any was present. Improvement time was recorded in positive and negative values. If the participant completed the KD test more quickly on the second trial then the improvement time was positive; conversely, if the participant's second trial took longer then the improvement time was negative. All data were analyzed with an alpha level set *a priori* at $P \leq 0.05$. Separate ANOVA's were used to compare means between the two groups for both total time and improvement time. Scores were removed from

analysis if they were deemed outliers. This was determined by first, standardizing all outcome measurements in to z-scores; then, removing any scores greater than 3.26. Only two improvement time scores in the control group were labeled outliers and removed from analysis. All other z-scores were lower than 3.26.

Chapter 3

RESULTS

All participant demographics (n = 170) are located in Table 1. Individuals in the experimental group displayed means of 1.5 concussions sustained during their lifespan with over two years of time since their most recent concussion. Mean recovery time from concussion was approximately 9 days.

The times to complete the King-Devick test ranged from 25.69 to 55.68 seconds in the control group and 25.77 to 55.01 seconds in the experimental group (Table 2). Median test times of the control and experimental groups were 37.73 and 38.29 seconds, respectively (Figure 3). The mean total test time of the control group was 38.21 ± 6.17 seconds, which was slightly lower than the experimental group at 39.12 ± 6.48 seconds. The ANOVA analysis of total test time resulted in no significant difference ($F_{1, 168}$ = 0.870, P = 0.352) between groups. Results of improvement time ranged from -4.93 to 12.04 seconds in the control group as compared to -1.24 to 9.12 seconds in the experimental group (Figure 4). Mean improvement time in the control group (2.48 ± 2.87s) revealed no significant difference ($F_{1, 166}$ = 0.253, P = 0.615) from the experimental group (2.68 ± 2.12s).

Chapter 4

CONCLUSION

Results indicate that there are no significant deficits in oculomotor function in the collegiate athlete population with a previous history of concussion as examined by the KD test. Certain commonly used tools such as the ImPACT test or SAC test have been utilized to measure cognitive function at a variety of time points post injury. Much of this research states that brain function is typically restored within a few days after the initial event and the athlete may begin return to play protocol once full function is achieved.[13,14,15] These tools contain aspects that analyze numerous functional properties of the brain; however there is very little emphasis on movement of the eye. The assumption that motor function of the eye improves in relation with other skills such as balance, memory, coordination or concentration has been commonplace in clinical practice. Results derived from this study support the premise that oculomotor deficits do not persist longer than other measureable cognitive functions.

Another assessment of neurologic ability that often goes untested with relation to concussion is learning effect. During head injury, neurons in the brain undergo physical, chemical and metabolic changes.[12] These changes affect the functional integrity of the involved neurons and manifest as symptoms.[16] Brain plasticity, or the ability to learn, is very difficult to recognize without proper testing. By examining learning effect,

researchers can gain a glimpse into the brain's ability to recognize the demand and employ an efficient and effective means to accomplish the task. Learning has been a topic that is often investigated with variables such as sleep, mental disorders, teaching styles, and other scientific fields, but has rarely been associated with concussion.[17,18,19] Although conclusions can not yet be made, initial results signify college-aged student athletes retain normal neuroplasticity after recovery from concussion.

Results from this study strengthen current management practices for concussion. The basis for returning an athlete to play is largely dependent upon the individual's symptoms. The two variables examined in this study, oculomotor function as measured by total time to complete the KD test and learning effect as represented by improvement time expand the possible objective components that may be employed to monitor concussion recovery. Medical providers and researchers both agree that a multi-faceted approach to assessment and management of concussion is essential to optimize proper care for the athlete.[4] Data collected from this study also enhance the foundation of knowledge concerning the operational definition of concussion. A central component to defining concussion entails that symptoms are transient and mainly the result of functional deficits in the brain.[6,4] By incorporating the idea that oculomotor function and learning return to acceptable standards after injury, we can suggest that any symptoms or deficits that did exist are no longer recognizable by the KD test.

Limitations existed in the design of the study. A retrospective methodology does not allow for standardization of the diagnostic criteria for concussion. Different examiners, assessment tools, and knowledge on the topic introduce incredible uncertainty

regarding the accuracy of the diagnosis. Future studies need to implement a prospective design to eliminate controllable factors that could affect group placement. Secondly, the nature of the test implemented in this study created large variances within the results. If a difference did exist between groups, a substantial amount of participants would need to be recruited in order to create a significant and powerful study with a large effect size. The gender distribution differences between groups could also contribute to inaccurate data. Males and females exhibit differing anatomical and functional characteristics of the brain.[20] Males exhibit cortical networks that are less economical than women[21]; inferring that females display a larger over all connectivity of neurons in the brain. Females have also been shown to have a larger corpus callosum, which functions as the bridge between the left and right hemisphere of the brain.[20] Conclusions can not yet be made as to if these differences affect KD test times, however a distinction between cognitive function of males and females must be noted.

The number of errors during testing was another variable recorded by researchers in this experiment. Post-study analysis revealed trending data which indicated that student athletes with a previous history of multiple concussions (2 or more) generated more errors during testing than those student-athletes with one or less past concussions (Figure 5). These results produce an interesting topic for future research which could impact current knowledge and practice concerning multiple concussion management and return to play guidelines.

The KD test is a screening tool for concussion that is quick, easy, and accurate. Further research involving this test should include variables such as gender, age, and as

discussed previously, errors committed during testing. Clinicians should recognize the usefulness of the KD test and consider incorporating it into concussion assessment protocols. Even without the application of this tool, more focus should be placed on areas of cognitive function such as oculomotor function and learning so that head injury examinations can be more comprehensive and athletes can receive the highest quality of care.

Chapter 5

LEGEND

Figure 1: The King-Devick Test. The upper left portion of figure displays the demonstration card. This card does not serve as practice but to help the participant visualize the task. The upper right, lower left and lower right cards are used for testing. Each card has a different format but the objective remains the same.

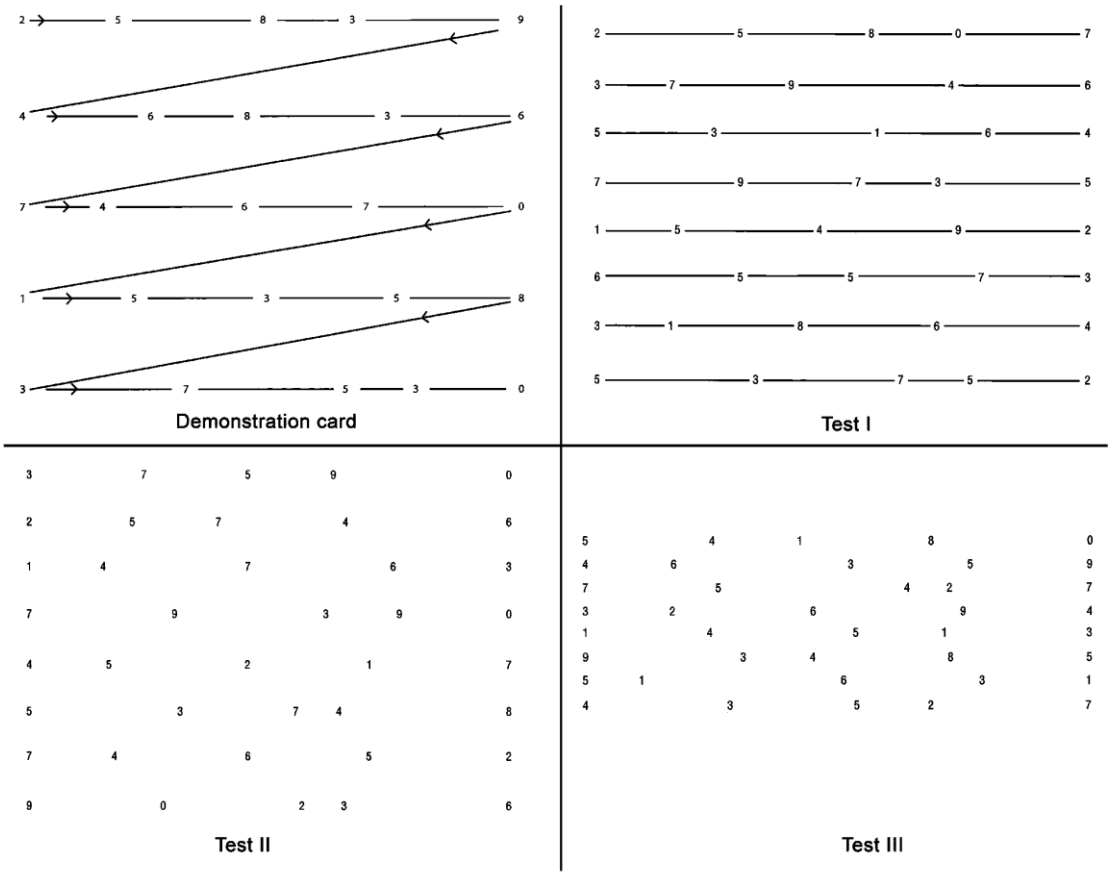


Table 1: Participant demographics (Mean ± SD)

	Control	Previous History of Concussion
Number of Participants	*97*	*73*
Mean Age (yrs)	*19.7 ± 1.3*	*19.7 ± 1.3*
Gender	*Male (45) Female (52)*	*Male (40) Female (33)*
Mean Height (cm)	*175.6 ± 10.2*	*177.4 ± 10.6*
Mean Mass (kg)	*77.1 ± 16.3*	*79.0 ± 17.2*
Mean Number of Concussions	*N/A*	*1.5 ± 1.3*
Mean Time Since most Recent Concussion (months)	*N/A*	*28.7 ± 28.0*
Mean Recovery Time (days)	*N/A*	*8.6 ± 12.9*

Figure 2: Pilot test data of sub-group learning effect. Trial 1 represents the change in mean KD test completion time from trial 1 to trial 2. Trial 2 represents the change from trial 2 to trial 3 and so on. The greatest improvement time existed between trials 1 and 2.

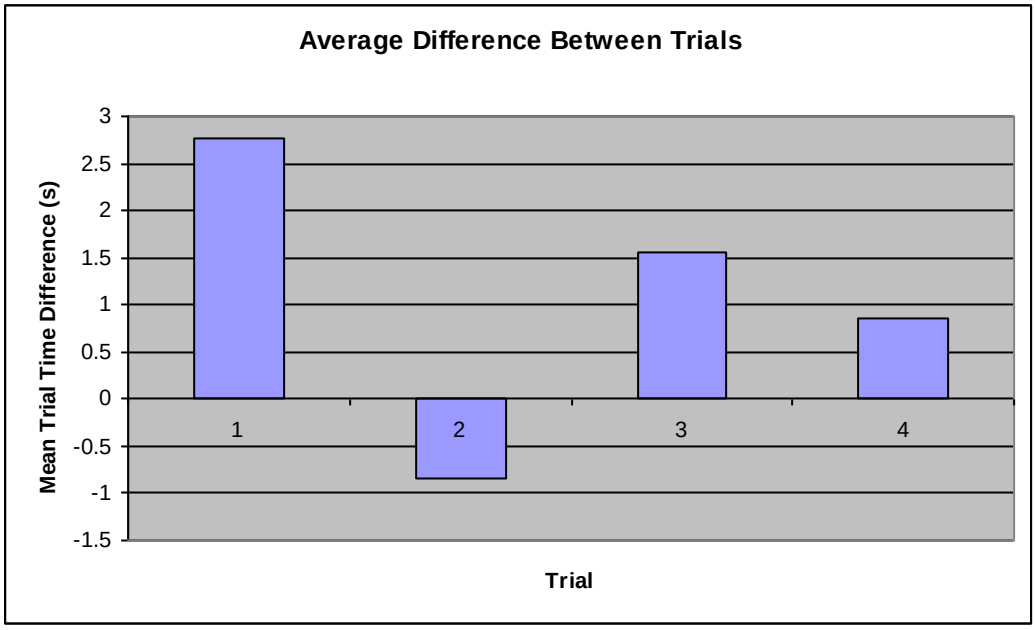


Table 2: Descriptive statistics of "Total Test Time" and "Improvement Time" between groups.

	Control		Previous History of Concussion	
	Total Test Time (s)	**Improvement Time (s)**	**Total Test Time (s)**	**Improvement Time (s)**
Range	*25.69 - 55.68*	*-4.93 - 12.04*	*25.77 - 55.01*	*-1.24 - 9.12*
Mean ± SD	*38.21 ± 6.17*	*2.48 ± 2.87*	*39.12 ± 6.48*	*2.68 ± 2.12*
Median	*37.73*	2.43	*38.29*	*2.53*
95% CI for Mean	*36.97 - 39.45*	*1.90 - 3.07*	*37.61 - 40.63*	*2.19 - 3.18*

Figure 3: Box plot of results for total completion time compared between groups. Group 0 has had no history of head trauma. Group 1 represents the experimental group with a previous history of concussion. The whiskers represent the data range, the box indicates the 95% confidence interval and the horizontal black line is the median number. The circular markers display the outlying values that were removed from the box plot.

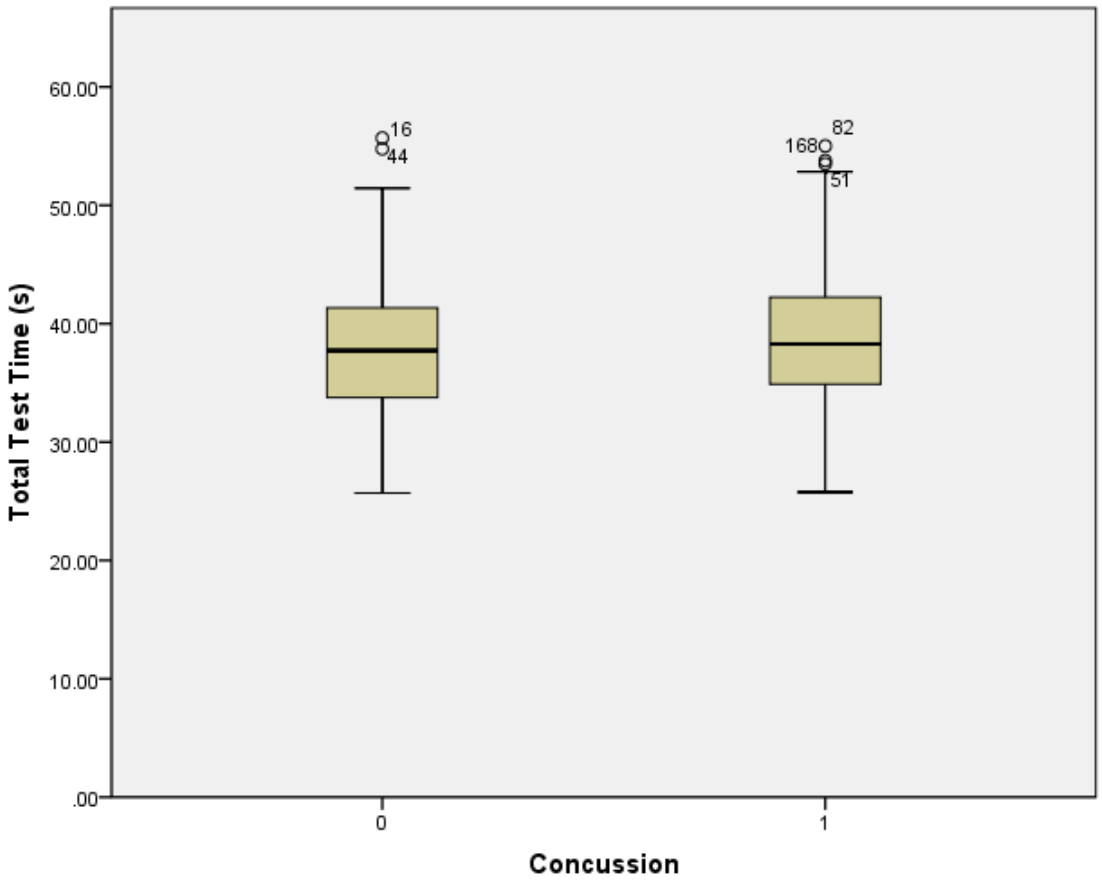


Figure 4: Box plot of results for learning effect between trials compared across groups. Group 0 has had no history of head trauma. Group 1 represents the experimental group with a previous history of concussion. The whiskers represent the data range, the box indicates the 95% confidence interval and the horizontal black line is the median number. The circular markers display the outlying values that were removed from the box plot.

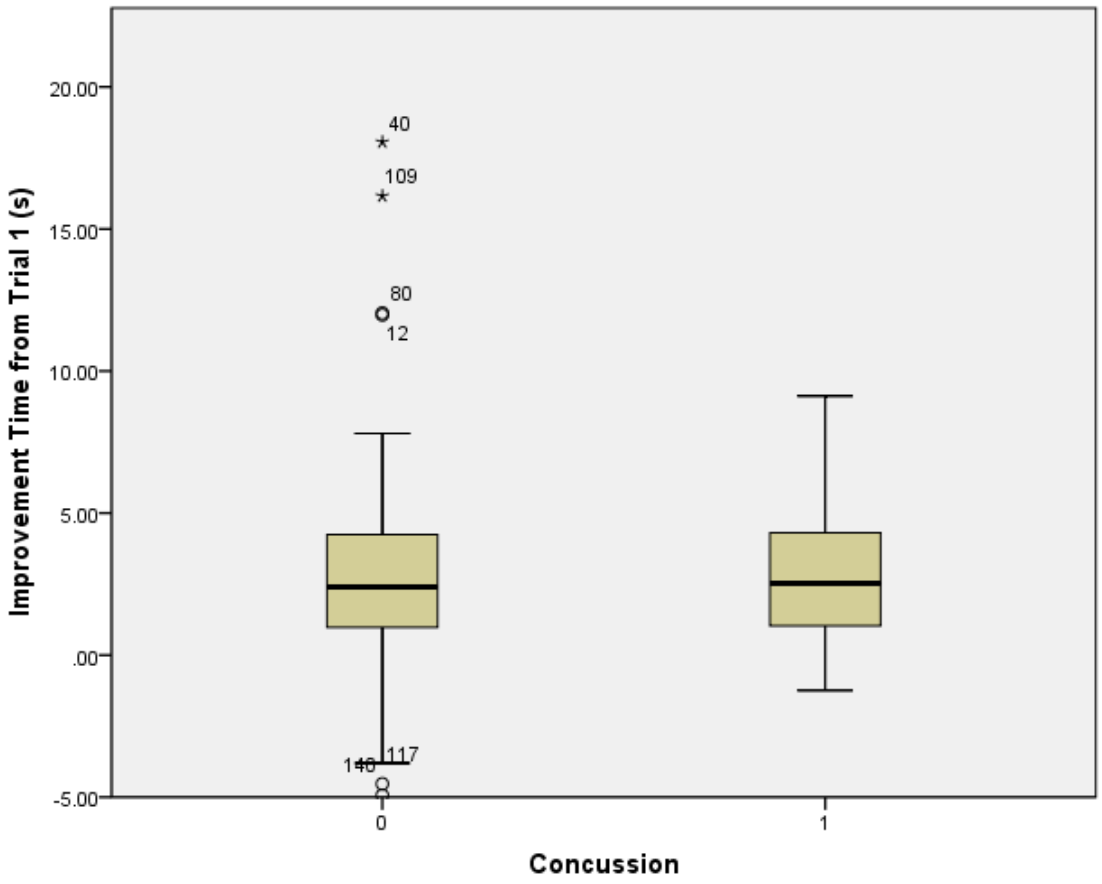
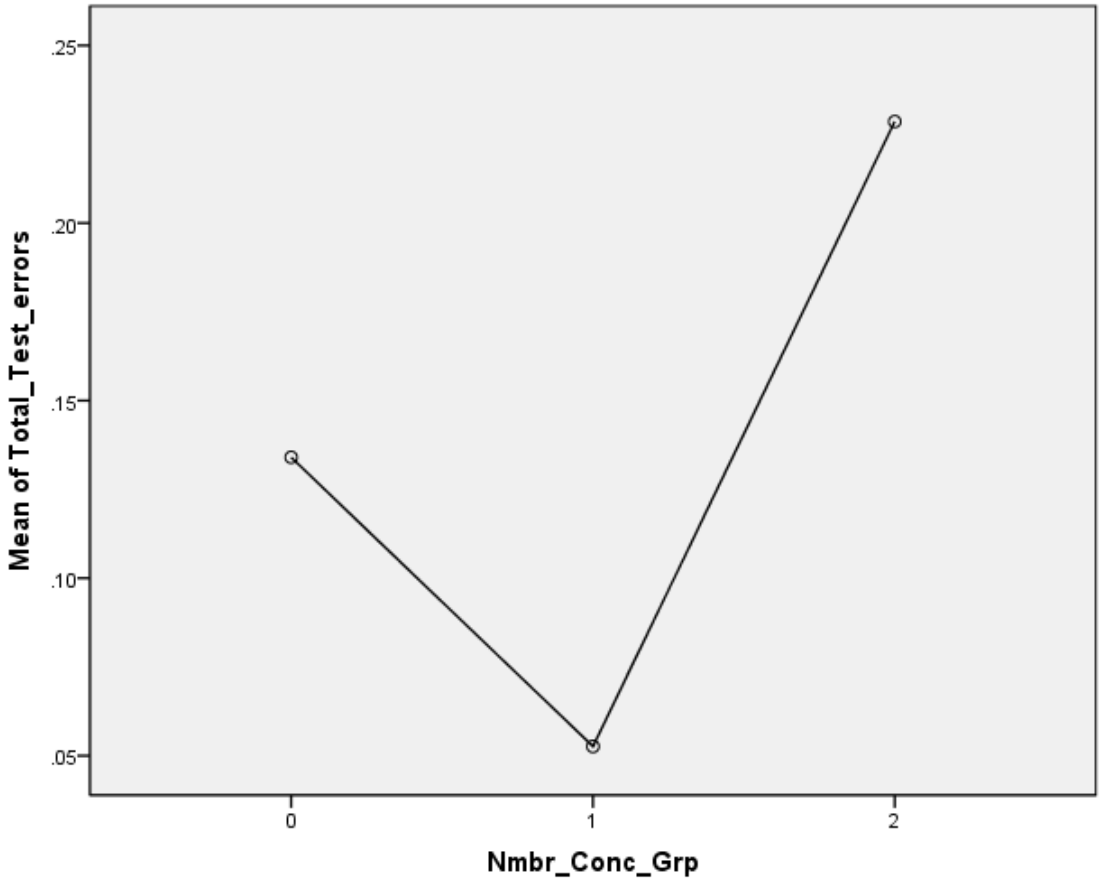


Figure 5: Mean number of errors committed during KD test across concussion group. Group 0 includes individuals with no previous history of concussion. Group 1 contains individuals who have sustained only one concussion. Group 3 has individuals with a previous history of multiple concussions.



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Appendix A

University of Delaware Human Subjects Informed Consent Form

RESEARCH STUDY: Oculomotor function in collegiate student-athletes with a previous history of sport-related concussion.

INVESTIGATORS: Peter Braun (Principal Investigator) and Thomas W. Kaminski, PhD (Advisor) from the Department of Kinesiology and Applied Physiology

INTRODUCTION

You are invited to take part in a research study which serves to gain knowledge about head injuries and the effects that these injuries may have on eye movement.

PURPOSE

The purpose of this study is to measure the effects of sport-related concussion with respect to performance on a test that measures eye movements.

PROCEDURES

You are one of 200 student-athletes (male and female) from the University of Delaware being asked to participate in this study. Your participation will involve one test session lasting 15 minutes. You will report to the Athletic Training Research Lab for testing. You will be asked to complete a medical questionnaire to obtain both general information and more specific information regarding concussion history (for those who have a previous history). Upon completion you will be given instructions on how to perform the eye movement test (this is called the King Devick Test). This test requires you to read aloud a series of numbers off of an index card from left to right, as quickly as possible but without making any errors. The lab environment provides a quiet area that is free from distractions. A practice card will be given to you so that the directions are thoroughly understood. The three remaining "test" cards will then be given one at a time. The time it takes for you to complete each card will be recorded. Speed and accuracy are important! After the 3rd and final test card has been completed you are free to leave the testing area.

CONDITIONS OF SUBJECT PARTICIPATION

The information obtained by this study will be publicly reported, however all personal information that links you to your results will remain confidential and will only be seen by investigators. These tasks require minimal exertion and do not place you or others in harm or at any risk of injury. Your participation could be terminated by investigators if you are not cooperating with the instructions that are given to you. You, as a participant, also have the right, at any point, to cease participation. In either instance, all information obtained through the study will be properly disposed of, so that confidentiality is maintained. However, your consent form and contact information must be kept for the required length of time, in case referral is necessary.

RISKS AND BENEFITS

Your participation will not place you at any risk of physical injury, however investigators must obtain certain medical information from each participant, therefore this study places you at risk for breach of confidentiality. To prevent such a breach, investigators will follow strict procedures so that these risks are minimized. Data from this project are intended to provide insight into the proper assessment and treatment of concussion.

FINANCIAL CONSIDERATIONS

There will be no compensation for participating in this study. There will be no cost to you for participating in the study.

CONTACTS

Any questions that you may have that are associated with this research study may be directed toward the following individuals:

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Your questions concerning your rights in relation to this research study may be directed towards:

Human Subjects Review Board
University of Delaware
Newark, Delaware 19716
Phone: (302) 831-2137

ASSURANCE

By signing this consent form you indicate that you have read and agreed to all procedures and understand the conditions of your participation, the risks and benefits associated with participation as well as the financial considerations. You were also informed that your participation in this research study is considered voluntary and that you may exercise your right to refuse or cease participation at any point. Your discontinuation in this study does not result in penalty or the loss of the previously discussed benefits. All of your personal information will remain confidential. You also understand that a copy of this consent form will be given to you.

CONSENT SIGNATURES

Participant's Name: _____

Participant's Signature: _____Date: _____

I, the investigator, certify that I have explained the procedures, conditions of participation, risks and benefits associated with participation as well as the financial considerations. I also informed the participant that their involvement in this research study is considered voluntary and that he/she may exercise their right to refuse or cease participation at any point. I have answered all questions that the participant asked and have witnessed the above signature.

Investigator's Name: _____

Investigator's Signature: _____Date: _____

Signed consent forms will be retained by the researcher for three years after completion of the research.

Appendix B

MEDICAL HISTORY QUESTIONNAIRE

Research Study: Oculomotor function in collegiate student-athletes with a previous history of sport-related concussion.
Investigator: Peter Braun, ATC
Advisor: Thomas Kaminski, PhD, ATC, FNATA, FACSM

PART 1: *(All participants must fill out)*

Name:_____
Age:_____yrs.

Gender*(Please circle one)***:** M F **Height**:_____in.
Weight:_____lbs.

Have you ever been diagnosed with any type of eye movement or reading disorder?

YES NO

PART 2: *(For previously concussed student-athletes only)*

1. Have you ever been diagnosed by a health care professional (i.e. physician, nurse, athletic trainer) of sustaining a concussion? *(Please circle one)*

YES NO

If, yes, how many?_____

2. In the space below, can you please list the date(s) *(to the best of your ability)* on which your concussion(s) was/were sustained, followed by the approximate amount of time until all of your symptoms were resolved? *(Ex: Jan. 2011- 4 days)*

PART 3: *(All participants must fill out)*

I, the participant, have filled out this questionnaire to the best of my ability and sign that all the above information is correct to my knowledge:

Participant's Signature:_____ Date:_____

Appendix C

SPECIFIC AIMS

C.1 Specific Aim 1: To identify if differences in oculomotor function exist between individuals with a previous history of concussion and individuals with no prior history of concussion, as measured by the King-Devick Test.

C.2 Hypothesis 1: When compared to those with no prior history of concussion, individuals with a previous history of concussion will take longer to complete the King-Devick Test. This difference is expected because evidence indicates that oculomotor function is highly affected by concussion due to the location of the cranial nerves which transmit ocular movement.[11] In addition, other types of acquired brain injury have lasting effects on eye function and no research has been done which proves the timeframe of recovery regarding oculomotor symptoms in a concussed population.[7]

C.3 Specific Aim 2: To identify differences of within subject learning effects on the King-Devick Test between individuals with a previous history of concussion and individuals with no prior history of concussion.

C.4 Hypothesis 2: Individuals with a previous history of concussion will exhibit less of a learning effect between trials than similar individuals with no prior history of concussion. Previous King-Devick data suggest that smaller improvements are made between pre and post season testing scores in athletes who had sustained a concussion during the season.[10]

Appendix D

BACKGROUND AND SIGNIFICANCE

D.1 Concussion Epidemiology

Approximately 300,000 sports related traumatic brain injuries occur annually in the United States, and nearly 75% of these injuries are considered mild.[22] Mild traumatic brain injury (MTBI), may be defined as traumatically induced physiological disruption of brain function. This injury manifests as at least one of the following symptoms: any change in mental state at the time of injury, any form of amnesia, any loss of consciousness, or any neurological deficits. These symptoms however, must not exceed 24 hours of post traumatic amnesia, more than 30 minutes of consciousness loss, and must be under a score of 15 (30 minutes post injury) on the Glasgow Coma Scale.[23] Concussion may be classified as a type of MTBI and the prevalence of this injury has become increasingly alarming due to the improvements made in record keeping and data collection. Now, clinicians can stratify concussion incidences across age, gender, sport etc as to develop possible risk factors. Injury prevalence can also be seen by calculating economic burden, however the most disturbing statistics are those derived from studies which research the under reporting of mild traumatic brain injury. These data confirm the prevalence of this injury and reveal that improvements still need to be made in the areas of prevention and diagnosis.

Common mechanisms and sport specific incidences are typically the main categories examined while identifying possible risk factors. In 2005 to 2006 researchers collected data from two injury surveillance systems to compare injury rates across a variety of categories.[2] The terms *athletic exposure* and *injury* were precisely defined as to standardize the results. An athletic exposure (AE) may be defined as one athlete's participation in a practice or competition.[2] In order for an athlete to be considered to have sustained an injury, 1) the injury must have occurred during an organized practice or competition, 2) require medical attention, 3) and resulting in the restriction of participation in practice or competition for one or more days.[2] Contact sports present the highest incidence rate of concussion per athletic exposure, the highest rate occurring in collegiate football (0.61 per 1000 AE).[2] The activity in football that is most highly associated with concussion was running plays, accounting for approximately 55%.[2] Researchers attributed the high injury rate during running plays to the increased rate of player to player contact, which was the leading mechanism of concussion in football, soccer, basketball and wrestling.[2] Despite the remarkably high reported incidence of concussion, more concerning statistics involve the pediatric population.

In August of 2010, the *Journal of the American Academy of Pediatrics* released an article which reported emergency department visits for concussion in young child athletes (8-19 years old). The most discerning results arose while tracking concussion incidences versus sport participation over a ten year period. From 1997 to 2007 emergency department visits for concussion doubled in the 8- to 13-year-old age group and increased by 200% in the 14- to 19-year-old population.[24] Contradictory to popular

belief, these increases were not due to an increase in population, child participation in organized team sport actually declined by 13% over the same time frame.[24] Although, concussion incidences in the pediatric population are not as high as in the adult population; these results are noteworthy and require additional research. Clinicians, medical providers, parents and coaches must all be aware of this data and stress the importance of proper management and education strategies in the younger population. In conjunction with increasing incidence rates, a recent study has quantified the immense under reporting of concussion. In 2006, an article published in the *British Journal of Sports Medicine* sought to compare concussion rates in youth ice hockey that were estimated from a variety of reporting strategies.[25] Official reports were retrieved from the injury database of the British Columbia Amateur Hockey Association (BCAHA). These reports were compared to retrospective surveys taken by the same sample of youth hockey players. In considering the retrospective survey results, between 2001 and 2004, 178 (of 497) male and 112 (of 326) female elite players reported sustaining at least one hockey induced concussion.[25] These rates proved significantly higher than the official reports recorded by the BCAHA.[25] Although these results can not be extrapolated to the general population, these severe differences in incidence rates across reporting strategies are cause for great concern and must be addressed in order for society to fully grasp the enormity of concussion.

D.2 Understanding Concussion

The main mechanism for sport-related concussion is player-to-player contact.[5] This contact causes acceleration, deceleration or rotational movement of the brain inside

the cranial cavity. If this movement forces the brain to impact the inside of the skull on the same side as the impulse, the mechanism is defined as a coup injury.[26] If the concussion is a result of the brain contacting the opposite side of the skull, with relation to the impulse force, then the mechanism may be deemed a countrecoup injury.[26] A combination of the torsion forces originating from rapid acceleration/deceleration or rotation of the brain and the compression forces associated with coup or countercoup injury cause diffuse shearing of the axonal connections in the white matter of the brain. This shearing catalyzes a cascade of chemical and metabolic changes within the brain that leads to a development of symptoms.[11] The initial neural insult causes an excess release of glutamate. Glutamate is a chemical which increases neural excitability. An increase in excitability corresponds to hypersensitivity and rapid, unnecessary transmission of neural impulses.[16] As the neural cells in the brain continue to fire, intracellular metabolic activity becomes unstable. Ions such as potassium and calcium accumulate inside of the cell creating an excessively positive intracellular charge. The increase in neural activity also forces cells to begin anaerobic glycolysis, which results in the production of the harmful byproduct lactate. This process may alter the brain's physiology for hours to weeks after injury.[16]

Concussion often affects motor function of the eye, and these functional deficits may be due to two different physiological changes which occur during injury. All aspects of vision are controlled by the occipital lobe. Afferent information is retrieved by retinal sensors in the eye and sent to the brain. These stimuli are interpreted by the occipital lobe and efferent information is sent out of the brain via cranial nerves II, III, IV and VI.

These efferent pathways originate just below the base of the brain in the diencephalon and midbrain, which creates a short track for relaying information, however the location of these motor neurons places them at risk for injury, especially during rotational acceleration and deceleration forces of the head.[11] Therefore, damage to the neurons in the occipital lobe or the cranial nerves which control eye movement at the base of the brain will produce visual deficits. This damage results in the same cascade of events described above which begins with the excessive accumulation of glutamate. Recovery from concussion can only begin after glutamate concentration is reduced. There has been little evidence which indicates an effective strategy at quickening the metabolic and chemical process to improve recovery rate.

After the acute phase of injury, the body begins to reverse the cascade of physiological changes sustained as a result of head trauma, in order to heal and recover. As time since the initial injury passes, the neurons begin to heal and regenerate. As neurons heal, the concentration of glutamate decreases and the cells slowly decrease unnecessary activity. Lactate is removed through the blood stream and aerobic glycolysis becomes the primary means of energy production.[16] Ionic imbalances return to homeostasis and the neurons return to proper function. This progression is very crucial in understanding the proper management process associated with a concussed athlete.

Current recommended protocol for concussion treatment and management are described in the 2004 manuscript, *National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion*. This manuscript creates guidelines for athletic trainers and other health care providers to follow, based on the most current

scientific and clinical-based literature. The position statement advises all athletic trainers to develop a consistent management plan that focuses attention on the athlete's recovery via symptoms, neurocognitive testing, and postural stability testing.[6] Researchers state that a 7-day symptom free period after injury may be the most effective procedure at reducing the risk of recurrent injury.[6] However, this symptom free period may also be utilized as a means of slowly integrating an athlete back into activity. Current research revealed in the *Consensus Statement on Concussion in Sport: the 3rd International Conference,* establishes a widely excepted program recommended for use by clinicians and health care professionals in returning concussed athletes to play. This process involves a stepwise and systematic routine that allows for individualized progression through increasing levels of physical exertion. The first step is complete rest until neurological symptoms have resided. Second, the athlete is instructed to perform light aerobic exercise in order to increase heart rate (less than 70% max heart rate). The third stage aims to add sport-specific movement into exercise without any risk of head impact. The forth stage begins non-contact training drills and progressive resistive training. This stage serves to integrate coordination and cognitive load. The final stage before returning to play is a full-contact practice, meant to restore confidence and assess functional skill.[4] The most important aspect of this progression is that the next stage can not be completed until the athletes demonstrate that they can remain symptom-free for 24 hours after the completion of the current stage. This allows the protocol to be tailored to each specific athlete and follows the conservative guidelines established by the NATA and has

shown great success in athletes recovering from concussion, especially in the acute stages.[4]

D.3 Current Practice

One improvement that has increased the diagnosis of concussion in recent years is the Standardized Assessment of Concussion or SAC test. A study performed by McCrea in 2001 analyzed the sensitivity and specificity of the SAC in the diagnosis of concussions. McCrea collected test results of 63 subjects before, immediately after and forty eight hours after sustaining a concussion. These data were compared with those from a control group of 55 uninjured participants. The SAC includes four sections which are scored numerically depending on correctness. A higher score corresponds to a better performance on the task. The sections are as follows: orientation, immediate memory, concentration and delayed recall. The researcher averaged the results of the experimental and control groups and compared these results across each section of the SAC. Paired t-tests determined if statistical differences existed between group scores. Results indicated a high sensitivity and specificity of the SAC. Significant deficits existed in every category of the SAC immediately after concussion. These deficits remained significant 48 hours after injury in the immediate memory category. Results also revealed the SAC to be 95% sensitive and 67% specific.[27] These values support the use of this standardized test in the immediate diagnosis and post injury evaluation of a concussed athlete.

Computerized neurocognitive testing has become another popular diagnostic and assessment tool among medical providers. As opposed to the more subjective on-field assessment tools, programs such as the ImPACT test allow for a more detailed,

standardized and objective measurement of neurologic symptoms. However, discrepancy exists among providers about the clinical use of the results. In a study done by Covassin et al., researchers observed the protocol of sports medicine professionals who utilized baseline neurocognitive testing.[28] Nearly four hundred athletic trainers participated in the survey. Each participant answered questions regarding the methods by which they assess concussion, and the time in which they administer these assessments. Results indicated nearly ten percent of athletic trainers would return an asymptomatic athlete to activity regardless of a decreased score compared to baseline. By doing so, this percentage of medical providers places more emphasis on subjective information from the athlete rather than objective information. This phenomenon creates an inconsistency in the standard of care and may also lead to a misdiagnosis or improper return to play decision. These occurrences, therefore, decrease the percentage of proper diagnosis of concussion and any associated neurologic deficit.

Covassin et al. also found that medical providers utilized symptoms checklists in 77% of athletes to help evaluate and diagnose concussion.[28] Conversely, Broglio et al. discourage medical providers from implementing subjective checklists as the standard criteria for return to play. Broglio et al. compared results of the ImPACT exam and a commonly used symptoms checklist on 21 concussed athletes. Findings indicated 38% of participants measured to be asymptomatic, however these athletes still exhibited deficits in at least one category of the ImPACT test.[29] Categories included verbal memory, visual memory, visual motor speed, reaction time and concussion related symptoms. Researchers concluded that symptoms checklists should not be emphasized as an

evaluation tool in concussed athletes, Neurocognitive deficits may be present even after an athlete no longer reports concussion-related symptoms.[29]

With these conclusions in mind, improvements have been made in recent years to enhance the reliability and precision of symptoms checklists, as well as to create an accepted "gold standard" checklist that is consistently used by all medical providers. Before 2009, a variety of checklists existed that used different means of achieving a similar result: to question concussed athletes about the symptoms they are experiencing. In May of 2009, Randolph et al. released a compilation of data that supported the reliability of a new, appended graded-checklist that addressed all relevant concussion symptoms.[30] The study compared popularly accepted symptoms checklists to an experimental checklist created by the researchers. A large sample size of 641 concussed athletes participated in the study. Findings showed the purposed checklist, titled Concussion Symptom Inventory (CSI), to be more precise and reliable than previously accepted checklists in determining symptoms in concussed athletes.[30] The application of a standard, evidence based tool such as the CSI, when used in conjunction with other evaluation tools, will enhance the standard of care given to athletes suffering from mild traumatic brain injury and reduce the occurrence of misdiagnoses.

Researchers also documented that less than 18% of medical providers implement a balance assessment scale to aid in the evaluation of concussed athletes.[28] A study performed by Guskiewicz et al. revealed the importance of such a tool in the clinical setting. The study collected data from 72 collegiate athletes, half of whom sustained a sports related concussion.[31] Data included postural stability measurements taken before

injury (baseline) and at one, three and five days post injury utilizing the Balance Error Scoring System (BESS). This assessment tool requires the subject to perform balance exercises in a variety of different ways. These exercises are monitored for a period of time and the administrator records the number of compensatory balance movements made by the subject. Indicators of poor balance include: 1) lifting hands off iliac crests, 2) opening eyes, 3) stepping, stumbling, or falling, 4) moving hips into more than thirty degrees of flexion or abduction, 5) lifting forefoot or heel and 6) remaining out of testing position for more than five seconds. At the end of the testing period the sum of these errors represents the subject's balance score. A higher score results from more compensatory motion during the exercise, which in turn, correlates to poorer balance.

Guskiewicz et al. found a significant decrease ($p < 0.05$) in postural stability of concussed athletes immediately after injury.[31] Researchers concluded that these findings are best explained by, neurologic decrements that prevent the proper exchange of sensory information from the visual, vestibular, and somatosensory systems.[31] Without the use of assessment tools such as the BESS test, certain symptoms related to concussion may be undetected, possibly leading to poor management and improper return to play of the injured athlete.

In conclusion, each concussion screening tool exhibits some degree of limitation and a multitude of tools should be used to evaluate an injury.[27] For example the SAC does not include a visual component, and an athlete suffering from visual deficits, possibly due to concussion, may not necessarily exhibit a decreased SAC score from baseline. This should be a major concern of clinicians working with populations at risk

for head injury. In addition, return-to-play decisions should be made utilizing the same approach. Solitary tools such as symptom reports do not provide enough information to create an appropriate decision. A proper evaluation of concussion should include a variety of testing tools so that all possible deficits may be assessed.[29]

D.4 King-Devick Test

Concussion produces a large variety of neurologic deficits in the body. The previously mentioned diagnostic tools address a wide range of symptoms; however some symptoms can not be detected utilizing these tools. Vision is often a difficult component to objectively assess and therefore may lead to improper management of an injury. Some tools, used in the fields of optometry and neurology such as the Trail Making A and B test, the Developmental Eye Movement Test and infrared imaging are helpful and effective at recognizing oculomotor deficits, however these tools are not typically utilized to diagnose of assess concussions. It is important that medical providers become aware of the possible visual deficits that may occur in concussed athletes, so that better and more complete care may be provided.

Researchers have recently developed a concussion screening tool that objectively assesses eye movement in a practical manner.[9] This tool is known as the King-Devick (KD) Test (Figure 1). The KD Test is based on the speed of rapid number naming and can capture impairments of eye movement, attention, language and other areas that correlate with sub optimal brain function.[9] Although in its infancy, the KD test shows a high test-retest and inter-rater reliability and is quickly becoming a widely accepted tool for rapid sideline concussion screening.[9] A recent study revealed an Interclass

correlation coefficient of 0.97 for two prefight measurements and 0.95 between pre and post exercise measurements in a group of 39 boxers and mixed martial arts fighters.[9] Similar research involving the KD test has also shown that fatigue does not have a negative effect on test performance.[10] A group of 18 men's basketball players were tested before and after a mid season basketball scrimmage and there was no increase in mean KD test time.[10] This indicates that fatigue does not seem to have an effect on oculomotor function. In addition, due to the nature of the test, results generate a more objective evaluation of a subject's mental status than most other cognitive function testing. This is achieved because the task of rapid reading required by the KD test is a very innate skill that is primarily controlled by subcortical pathways. These subcortical pathways are not impacted by factors such as intellectual ability and depression which inhibits performance on other cognitive tests.[10] In conclusion, the KD test is a reliable, practical and objective examination of oculomotor function, which is often affected by concussion.

D.5 Learning Effect

Throughout an individual's lifetime the brain is constantly changing, reorganizing and growing. Learning is a result of persistent functional changes in the brain based on the environment or experiences incurred by an individual.[32] Task learning is a complex and intricate process involving multiple aspects of the nervous system. Many types of brain cells such as neurons, glial and vascular cells contribute to the brains ability to modify neural pathways based on new experiences. There are a few different events associated with learning new skills. The first is commonly referred to as long-term

potentiation. This is a phenomenon which results when two neurons are repeatedly stimulated at the same time. By completing the same task over and over, these neurons grow stronger synapses with one another.[33] Once a strong connection has been made between neurons, stimulating the first neuron will more likely excite the second, creating a more efficient flow of information across cells.[33] Neural imaging reveals that an increase in efficiency has actually been shown to decrease the activation of neurons associated with the task.[34] Therefore suggesting that less neurons within a network are activated, but the signal is stronger and more precise.[35] Additionally, cells will not only increase the strength between synapses, but the number of connections as well. In animal studies, optical imaging has shown that within minutes of learning novel skills, new protrusions known as dendritic spines grow on the cells which are excited during that skill.[36] This leads to a greater number of synapses between cells and therefore more information can be relayed from one to the other. The brain will often recruit addition units as well, which expands the size of the functioning network.[34] This can be seen as an increase in spatial activation in topographically oriented neural imaging.[37] A third change can be noticed in the physical structure of each connection. Neurons that our more commonly stimulated have a greater synaptic cross sectional area than neurons which are less activated.[38] This means that the terminal buton and dendrite actually grow in size to compensate for the greater demand.

Functional reorganization is the final adaptation which may be integrated by the brain during learning. This event combines different aspects of the above anatomical and physiological responses and can be categorized into reorganization or redistribution.[37]

Reorganization is characterized by a coordinated increase in neural activity of one are of the brain in conjunction with a decrease in activity in a separate brain area.[39,40] A change in the location of activation or differences in task strategy have been theorized to contribute to neural reorganization.[34] In this phenomenon, a completely different area of the brain has acquired control of the task after practice. Redistribution, also known as pseudo-reorganization, involves an increase and decrease in activation of certain pathways within the same area of the brain.[37] Researchers have titled the initial pathways 'scaffolding' because this neural framework is typically utilized while performing novel, effortful tasks for the first time.[41] After practice, the 'scaffolding' is no longer used and the brain adjusts the flow of information to increase signal efficiency and strength.[41]

The protocols of this study require the participant to complete the KD Test once and then again with minimal rest between trials. Typically, findings indicate that the second trial improves from the first.[9,10] These improvements may be attributed to the redistribution of neural activity in the brain. As described previously, a novel, effortful task requires a scaffolding-like framework of neural pathways during the early stages of practice.[41] Research associates structures such as the prefrontal cortex (PFC), anterior cingulate cortex (ACC) and posterior parietal cortex (PPC) as the main areas which perform this role.[37] These three structures are also identified as components of the working memory. During the KD test, an active working memory is necessary to control attention, recognize numbers and verbalize print.[42] After the skill is practiced, neural activation decrease in the PFC, ACC, and PPC and greater activity is seen in task specific

areas such as the representational cortex, primary and secondary sensory or motor cortex, or in the parietal or temporal cortex.[37] A redistribution of neural activity occurs very quickly and often has the greatest effect on task efficiency, which is the reason most improvements are classically recorded between the first two trials.[9,10,43,44]

D.6 Summary

The transient neurologic signs and symptoms associated with concussion may be the result of a variety of mechanisms, most commonly, head to head contact with another player.[5] This impulse force to the brain produces a cascade of chemical and metabolic changes which affect a large array of cognitive functions, one of which is oculomotor function.[11] A plethora of tools exist which clinicians may use to recognize functional deficits in the brain, however none of these tools practically and objectively examine precise movement of the eye. Recently, researchers have developed a new test which addresses these areas of cognition, known as the KD test.[9,10] The KD test is a rapid number naming exercise which has been proven to have high test re-test and inter-rater reliability.[9]

Appendix E

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