VISUAL INFORMATION PROCESSING AND EYE TRACKING DEFICITS FROM SPORTS-RELATED CONCUSSIONS

by

Emily Carlson
and
Shannon Crane

This paper is submitted in partial fulfillment of the
requirements for the degree of

Doctor of Optometry

Ferris State University
Michigan College of Optometry

May 2016

VISUAL INFORMATION PROCESSING AND EYE TRACKING DEFICITS FROM SPORTS-RELATED CONCUSSIONS

by

Emily Carlson
and
Shannon Crane

Has been approved

13 March, 2016

APPROVED:

Faculty Advisor: _____

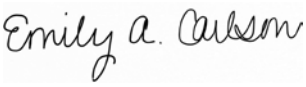
ACCEPTED: 

_____
Faculty Course Supervisor

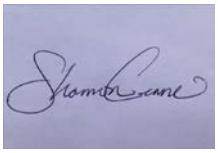
Ferris State University
Doctor of Optometry Senior Paper
Library Approval and Release

VISUAL INFORMATION PROCESSING AND EYE TRACKING DEFICITS FROM SPORTS-RELATED CONCUSSIONS

We, Emily Carlson and Shannon Crane, hereby release this Paper as described above to Ferris State University with the understanding that it will be accessible to the general public. This release is required under the provisions of the Federal Privacy Act.



Doctoral Candidate(s)



Doctoral Candidate(s)

03-13-16

Date

ABSTRACT

Background: Sports-related concussions (SRC) lead to deficits in cognitive and neurobehavioral function, short-term memory, academic performance, and visual tracking. Limited research exists regarding SRC effects on visual information processing. This study explores visual information processing skills before and after a SRC in collegiate student-athletes. In addition, it investigates whether student-athletes with a history of SRC will perform worse than those without a history of SRC.

Methods: Visual memory, reading and language, figure ground, spatial relationships, and tracking eye movements were tested at pre-season baseline, post-concussion, and at the end of in-season competition in student-athletes participating in men's ice hockey and women's soccer at Ferris State University (N = 52; 27 males, 25 females). An analysis of variance was conducted to examine the differences in visual information processing scores in student-athletes with and without a SRC.

Results: 26 players (50%) reported a history of 1 or more concussions prior to this study (15 hockey, 11 soccer). During the season in which research was conducted, a total of 5 concussions (9.6%) were diagnosed (3 hockey, 2 soccer), however 1 concussed player left the team before testing could be completed. Through the use of pre and postseason testing methods and t-tests, change in standard scores from pre to postseason show no statistically significant difference between student-athletes with and without SRC during the season with the exception of phonetic decoding which was significant ($p = 0.014$).

Student athletes with a lifetime history of concussion did not show a significant difference in pre to postseason standard score gains compared to those without a history of concussion.

Conclusion: Visual information processing skills following a collegiate SRC are statistically insignificant from collegiate student-athletes without SRC, using data obtained from a small sample participating in two sports with the exception of phonemic decoding. Previous research indicates neurological function and the visual system are highly susceptible to concussive events. It is recommended that all athletes should be evaluated prior to and following SRC and participate in rehabilitative therapies as necessary. Further study is needed on visual information processing and eye tracking resulting from SRC within different sports and age groups with larger sample sizes.

ACKNOWLEDGMENTS

We would like to acknowledge the contributions of Dr. Sarah Hinkley and Dr. Vandana Rajaram who supported our research and data analysis throughout this project. We would also like to thank the Ferris State University Athletic Department and student athletes, specifically men's ice hockey and women's soccer, and the Ferris State University athletic trainers for their participation in our research.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION OF SPORTS-RELATED CONCUSSIONS AND THE EFFECTS ON THE VISUAL SYSTEM

Between 1.6 and 3.8 million athletes suffer sports-related concussions (SRC) in the United States each year.[1] Estimates of SRC prevalence vary depending on age, gender, sport, and level of competition.[2] Recent studies have suggested that estimates of diagnosed SRC may underestimate the actual number of injuries due to the nondisclosure of concussive symptoms at the time of injury. [2, 3] Meehan, et al., concluded that nearly one third of athletes have sustained previously undiagnosed SRC.[4] Failure to diagnose a concussion at the time of injury may lead to further insults to the brain prior to full recovery and expose these athletes to cumulative damage.[4]

According to a 2004 study published by McCrea et al., a concussion may be defined as "a blow to the head followed by a variety of symptoms that may include any of the following: headache, dizziness, loss of balance, blurred vision, 'seeing stars,' feeling in a fog or slowed down, memory problems, poor concentration, nausea or throwing up." [5] The most common causes of SRC include head-to-head or helmet-to-helmet contact, head contact with other body parts, and head-to-ground contact.[2]

Recent studies have indicated that female athletes may be at a greater risk for concussion due to difference in head-neck dynamic stabilization.[2, 6] Female athletes may also experience greater and more severe symptoms and poorer cognitive performance during preseason testing than their male counterparts.[2, 6]

Previous research has suggested that athletes with a history of concussion have been shown to have cumulative cognitive effects, in addition to an increased number of symptoms, more severe presentation of symptoms at the time of diagnosis, and longer recovery time.[1, 7] Some athletes may experience chronic setbacks in cognitive and neurobehavioral functioning, short-term memory, problem solving, academic performance, and visual tracking.[8] Thought leaders in the area of SRC suspect concussions cause deficits in visual information processing.

The purpose of this study was to explore the extent of visual information processing deficits following a SRC in collegiate student-athletes. In addition, we examined the difference in performance in student-athletes with and without a history of concussion. We chose to use student-athletes participating in ice hockey and soccer due to an equivalent number of participants and a similar incidence of concussions between sports in previous seasons. We hypothesized that (1) visual information processing skills would be negatively impacted following a SRC and (2) student-athletes with a lifetime history of concussion would perform worse than those without a previous concussion.

Conducting research on visual perception and eye tracking is important to determine the impact of SRC, the expected recovery time, and effects on academic performance. Collegiate student-athletes often have an increased visual demand and

work load in higher education. Therefore, it is important to identify visual insufficiencies after concussions in order to properly manage classwork and to communicate post-injury deficits with professors and instructors.[9] It is logical to assume that visual processing tasks would be negatively impacted by SRC since concussion is known to impact neurological processing and other visual functions such as tracking, accommodation and convergence.[10, 11, 12] This study utilized two collegiate-level sports teams, one male and one female, to look at the lifetime rate of SRC, the incidence of SRC in one season, the effects of time and academic studies on visual processing skills in all student athletes and the short-term effects of SRC on eye tracking and visual processing skills immediately after concussion and at the end of the season.

CHAPTER 2

METHODS

2.1 PARTICIPANTS

Data was obtained from the 2014-2015 academic and athletic years. A total of 52 student-athletes were selected from National Collegiate Athletic Association (NCAA) Division I men's ice hockey (N=27) and NCAA Division II women's soccer (N=25) teams. Coaches and trainers were invited to a meeting to discuss the research and approvals were granted. Players were invited to participate, educated on the research and provided a consent form to sign if willing. All players agreed to participate. A certified athletic trainer reported SRCs as soon as possible after they occurred and coordinated testing throughout the study. This study was approved by the Institutional Review Board at Ferris State University.

2.2 PROCEDURES

All SRC injuries were diagnosed and reported by a certified athletic trainer who was present at the time of the injury. Student-athletes were diagnosed with a SRC if they reported symptoms such as a new headache, dizziness, nausea, or difficulty with balance following a blow to the head. Ferris State University Athletics utilizes the ImPACT (Immediate Post-concussion Assessment and Cognitive Assessment) concussion-history

questionnaire and test battery for baseline testing, diagnosis, and recovery monitoring. All student-athletes complete a series of questions regarding previous blows to the head that involved an alteration or loss of consciousness or loss of playing time prior to athletic competition. The ImPACT test battery evaluates multiple aspects of cognitive functioning, including attention, visual scanning, and information processing.[2, 7] The test battery is scored automatically and produces a report with age-referenced percentile scores. ImPACT testing is widely used throughout athletics at all levels.[2, 13]

The standard visual information processing assessment (VIPA) testing battery for this study included: Test of Visual Perception Skills, 3rd Edition (TVPS-3), Test of Word Reading Efficiency, 2nd Edition (TOWRE-2), Detroit Tests of Learning Aptitude, 4th Edition (DTLA-4), and the Visagraph. Key areas of analysis were spatial relationships and figure ground in TVPS-3, eidetic and phonetic reading ability and efficiency in TOWRE-2, short-term visual memory using the letter sequences subtest in DTLA-4, and reading rate and grade level equivalence with Visagraph. Baseline data was documented for each subject and tests were subsequently repeated within a week of a diagnosed concussion. Concussed athletes were asked to complete a survey detailing their concussion, and any symptoms both visual and non-visual that were experienced. All student-athletes were retested at the completion of their respective seasons.

2.3 STATISTICAL ANALYSIS

A multivariate analysis of variance (ANOVA) was conducted to examine differences in visual information processing performance in student-athletes with and without diagnosed SRC at the end of the athletic season. Analysis of overall performance

was also completed to assess the differences between athletes with a history of concussion and those who had never suffered a diagnosed SRC. Differences were examined through one-tailed *t* tests. $P < 0.5$ was considered statistically significant.

CHAPTER 3

RESULTS

A total of 52 (27 males, 25 females) collegiate student-athletes were included in our initial analysis with 7 athletes leaving the team before all data was gathered. The average age of our sample was 20.7 years. Prior to both men's ice hockey and women's soccer seasons, 26 players (50%) reported a history of 1 or more concussions in the past (15 hockey, 11 soccer). During the season in which research was conducted, a total of 5 concussions (9.6%) were diagnosed (3 hockey, 2 soccer), however 1 concussed player left the team before testing could be completed. Table 1 depicts the characteristics of the sample group.

Table 1. Characteristics of participants prior to season.

	Participants with history of previous SRC	Participants without history of previous SRC
Mean Age	21.163	20.246
Mean number of previous concussions	2.0	0
Number playing a given sport at time of injury		
Ice Hockey	15 (57.7%)	12 (46.2%)
Soccer	11 (42.3%)	14 (53.8%)

The first relationship analyzed was between the individuals that had experienced a concussion during the 2015 season of athletic competition and those that had not suffered a concussion using a one-tailed t-test assuming equal variance in all but TOWRE-2

Phonetic Word Decoding where the F-test showed a high probability of unequal variances. It was noted that there was improvement in standard scores for most players from preseason to postseason testing whether or not they had a SRC. In order to compare whether SRC had impacted scores, the gain in scores from pre to postseason were analyzed for the concussed group versus the non-concussed group. There was no statistically significant difference found in the change of any of the standard scores from the visual information processing testing battery or the Visagraph eye tracking assessment (Table 2) except for the change in the TOWRE-2 Phonetic Word Decoding where it was significant. It is important to note that the TVPS Spatial Relations test standard score change was also extremely close to being statistically significant. (Table 2)

Table 2. P-values analyzing the relationship between individuals concussed vs non-concussed during the 2015 season.

Test Performed	**P-Value**
TOWRE-2 Sight word decoding	0.253693
TOWRE-2 Phonetic word decoding	***0.013649***
TOWRE-2 Total word reading efficiency	0.152431
TVPS-3 Spatial Relations	***0.07021***
TVPS-3 Figure Ground	0.272187
DTLA-4 Letter Sequences	0.25497
Visagraph Reading Rate with rereads	0.422187
Visagraph Reading Rate without rereads	0.425134
Visagraph Grade Level Efficiency	0.481372

The next relationship analyzed was the gain in standard scores from preseason to postseason in student-athletes that had never experienced a concussion and the players that reported having at least 1 concussive event in their lifetime. Again, a one-tailed t-test assuming equal variance was utilized except for Visagraph reading rates that used

unequal variance assumptions based on the F-test of variance. The p-values indicate that there was no statistically significant difference found in any of the visual information processing tests or the Visagraph eye tracking assessment gains from preseason to postseason in student athletes with a history of concussion and those without. (Table 3)

Table 3. P-values analyzing the relationship between individuals with a history of concussion vs individuals who have never suffered a concussion.

Test Performed	**P-Value**
TOWRE-2 Sight word decoding	0.439966
TOWRE-2 Phonetic word decoding	0.17297
TOWRE-2 Total word reading efficiency	0.164162
TVPS-3 Spatial Relations	0.318632
TVPS-3 Figure Ground	0.401772
DTLA-4 Letter Sequences	0.369744
Visagraph Reading Rate with rereads	0.205862
Visagraph Reading Rate without rereads	0.162713
Visagraph Grade Level Efficiency	0.256666

The surveys completed by concussed athletes were analyzed showing that one concussion occurred during practice, while four occurred during a game. There were two caused by head-to-board contact while being checked, one by head-to-head contact, one by head-to-ball contact, and one caused by an elbow to the head. All subjects stated that they experienced headaches post-concussion, while two athletes stated feeling "out of it." There was only one individual that denied experiencing any visual symptoms following concussion. Three athletes noticed photophobia immediately following the incident, and two experienced transient vision loss. One individual stated, "half of coach's face was gone, peripheral vision was gone in my left eye, and I had blurred vision in my right eye. Vision returned in 10 minutes." The player also stated that he finished playing the game

after the incident had occurred. Interestingly, only one athlete experienced remaining symptoms at re-test with slight blurred vision after reading.

Figure 1 depicts the mean change in standard scores for each visual information processing test administered preseason and post-season, specifically differentiating concussed and non-concussed athletes. Minimal change was noted among the visual information processing tests. The largest difference in scores was found with the Visagraph reading rate; non-concussed athletes gained, on average, a greater improvement in reading rate than athletes that had suffered a concussion during the season.

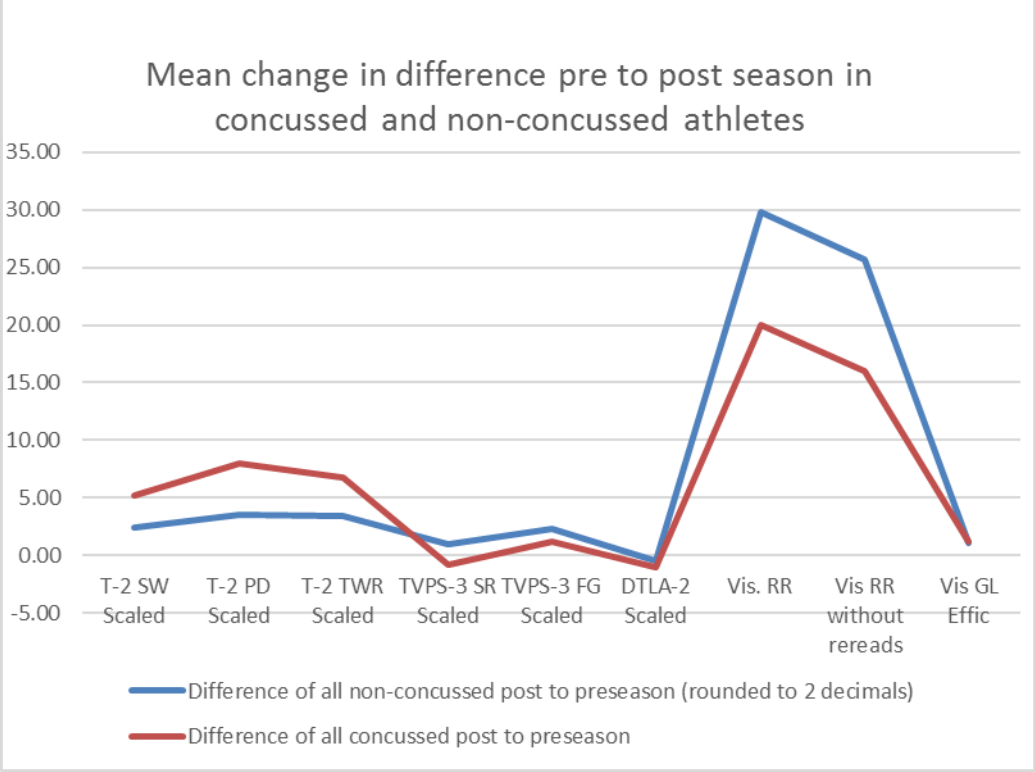


Figure 1. Difference in mean standard scores for each visual information processing test administered pre to postseason, in both concussed and non-concussed student-athletes.

CHAPTER 4

DISCUSSION

Despite a rapid rise in research and overall public awareness of the long-term impacts of sports-related concussion in the past few years, significant uncertainty and controversy remains regarding the extent and recovery of cognitive impairment. The purpose of this study was to determine if visual information processing or tracking are impacted following a SRC.

Due to the fact that such a large portion of the brain is involved in vision, it is not surprising that the visual system is highly susceptible to the effects of traumatic brain injury. Following head trauma, individuals often complain of various visual disturbances including photophobia, blurred vision, diplopia, and visual perception problems.[14] Concussions have also been found to cause deficits in binocular vision including convergence, accommodation, and saccadic eye movements with a prevalence of up to 30-45%.[9, 15] Convergence insufficiency (CI) has been found in up to 42% of student athletes after a SRC.[15] CI often leads to visual discomfort and functional difficulties such as slowed reading and compromised attention, leading to impaired academic, work, and athletic performance.[15] Reading is a complex brain function requiring proper binocular vision in order to maintain efficiency and comfort. Loss of place while reading and visual attention difficulty are common complaints following an SRC.[9] However, the

results of our study suggest that concussions do not cause visual information processing deficits in visual memory, figure ground, spatial relationships, and sight word decoding immediately following an SRC and at the end of the athletic season. An interesting relationship was uncovered between phonemic decoding gains pre to post-season and SRC. This leads to questions as to the effect and lasting impact of SRC on reading and language. Terry et al. recently examined neural activation associated with verbal encoding and memory retrieval in former high school football athletes and suggests that multiple early-life concussions may be associated with subtle changes in the verbal encoding system, which may lead to verbal learning and late-life memory deficits.[16] Although the results from our study did not find a statistically significant difference in Visagraph standard scores from preseason to postseason and in concussed and non-concussed subjects, previous research has shown that eye tracking movements are impacted by SRC [9, 10, 15] This must be taken into account when collegiate student-athletes suffer an SRC, because they typically have significant visual demands academically, in addition to athletic participation.

It is important to note that our data is limited to small sample of collegiate student-athletes participating in two sports at a single university. Thus, generalizability may be limited. We did not compare data of male and female athletes participating in the same sport and recommend further studies using gender comparisons. We suspect our data may have been affected due to the nature of each sport and the fact that all ice hockey participants are required to wear helmets while soccer participants are not. Additional limitations of our study were the fact that our student-athletes were not retested on the exact same day after the injury due to injuries occurring at an away

contest or scheduling conflicts, although all were retested within one week of the concussion. In addition, we did not have documented evidence of past concussions for our subjects. Our determination of previous concussive events was based solely on the reporting and recollection of the student athletes. We are unable to ascertain the accuracy of the information recalled or nondisclosure of previous concussions. Research suggests about 33% of athletes have sustained an SRC in the past and did not report, although the prevalence of nondisclosure is higher among men than women and varies among different sports.[3] An additional difficulty was defining what constituted a SRC. We were relying on report of SRC by the team's athletic trainer. However, multiple student athletes in post-season testing reported instances where they took a blow to the head and had minor symptoms but did not report them because the symptoms were not severe enough to be a concussion. In discussion, student athletes acknowledged the requirement to report but also expressed fear of being removed from play that could impact the team or their personal careers as a barrier to reporting.

Further investigation involving a larger sample of student-athletes involved in a variety of sports is required to come to a definitive conclusion regarding the impact of SRC on visual information processing. We suggest studying and analyzing data from larger sample sizes, male and female athletes participating in the same collegiate sport, and athletes participating in collision sports, such as football. Additional visual processing skills should be evaluated beyond the few chosen for this study. With the discovery of a potential impact of SRC on phonemic decoding efficiency and possibly spatial relationships, further study is needed focusing on the impact of SRC on these

skills. Expanding research to a larger number of participants will also allow for more visual information processing data from those affected by SRC.

REFERENCES

1. Wasserman E, Kerr Z, Zuckerman S, Covassin T. Epidemiology of sports-related concussions in National Collegiate Athletic Association athletes from 2009-2010 to 2013-2014: symptom prevalence, symptom resolution time, and return-to-play time. Am J Sports Med. Nov 2015. [PubMed]

2. Colvin A, Mullen J, Lovell M, et al. The role of concussion history and gender in recovery from soccer-related concussion. Am J Sports Med. May 2009 37:1699. [PubMed]

3. Kerr Z, Register-Mihalik J, Kroshus E, Baugh C, Marshall S. Motivations associated with nondisclosure of self-reported concussions in former collegiate athletes. Am J Sports Med. Nov 2015. [PubMed]

4. Meehan W, Mannix R, O'Brien M, Collins M. The prevalence of undiagnosed concussions in athletes. Clin J Sport Med. Sept. 2014 23:339-342. [PubMed]

5. McCrea M, Hammeke T, Olsen G, et al. Unreported concussion in high school football players: implications for prevention. Clin J Sport Med. Jan.2004 14:13-17. [PubMed: 14712161]

6. Brooks M. Sports concussion symptoms worse in female athletes? Medscape. Jul 2015.

7. Schatz P, Pardini J, Lovell M, Collins M, Podell K. Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. Arch Clin Neuropsych. 2006. 91-99. [PubMed]

8. Brown J, Dalecki M, Hughes C, Macpherson A, Sergio L. Cognitive-motor integration deficits in young adult athletes following concussion. BMC Sports Sci Med Rehab. 2015. 7:25. [PubMed]

9. Master C, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. Clinical Peditrics. 2015. [PebMed]

10. Samadani U, Eng R, Reyes M, et al. Eye tracking detects disconjugate eye movements associated with structural traumatic brain injury and concussion. J Neurotrauma. April 2015. 32(8): 548-56. [PubMed]

11. Ciuffreda K, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. Optometry. 2007. 78: 155-61. [PubMed]

12. DiCesare CA, Kiefer AW, Nalepka P, Myer GD. Quantification and analysis of saccadic and smooth pursuit eye movements and fixations to detect oculomotor deficits. Behav Res Methods. Dec.2015. [PubMed]

13. Resch J, Brown C, Macciocchi S, et al. A preliminary formula to predict timing of symptom resolution for collegiate athletes diagnosed with sport concussion. J Athl Train. 2015. 50(12). [PubMed]

14. Ventura R, Balcer L, Galetta S. The neuro-ophthalmology of head trauma. Lancet Neurol. 2014 13:1006-16. [PubMed]

15. Pearce KL, Sufrinko A, Lau BC, Hnery L, Collins W. Kontos AP. Near point of convergence after a sport-related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. Am J Sports Med. Dec 2015. 43(12): 3055-61. [PubMed]

16. Terry DP, Adams TE, Ferrara MS, Miller LS. FMRI hypoactivation during verbal learning and memory in former high school football players with multiple concussions. Arch Clin Neuropsychol. Jun 2015. 30(4): 341-55.

APPENDIX A

IRB APPROVAL FORM

Ferris State University

Institutional Review Board (FSU - IRB)
Office of Academic Research
Ferris State University
1201 S. State Street-CSS 310 H
Big Rapids, MI 49307
(231) 591-2553
IRB@ferris.edu

To: Dr. Sarah Hinkley, Emily Carlson and Shannon Crane
From: Dr. Stephanie Thomson, IRB Chair
Re: IRB Application #140702 (Title: *Visual Information Processing and Eye Tracking Deficits from Sports-Related Concussions*)
Date: July 21, 2014

The Ferris State University Institutional Review Board (IRB) has reviewed your application for using human subjects in the study, "*Visual Information Processing and Eye Tracking Deficits from Sports-Related Concussions*" (#140702) and has determined that it meets Federal Regulation category, *Expedited –2D*. This approval has an expiration date of one year from the date of this letter. **As such, you may collect data according to procedures in your application until July 21, 2015**. It is your obligation to inform the IRB of any changes in your research protocol that would substantially alter the methods and procedures reviewed and approved by the IRB in this application. Your application has been assigned a project number (#140702), which you should refer to in future correspondence involving the same research procedure.

We also wish to inform researchers that the IRB requires follow-up reports for all research protocols as mandated by Title 45 Code of Federal Regulations, Part 46 (45 CFR 46) for using human subjects in research. We will send a reminder to complete either the Final Report Form or the Extension Request Form to apply for a study continuation. Both forms are available on the IRB homepage. Thank you for your compliance with these guidelines and best wishes for a successful research endeavor. Please let us know if the IRB can be of any future assistance.

Regards,

[redacted]

Ferris State University Institutional Review Board
Office of Academic Research, Academic Affairs

APPENDIX B

IRB EXTENSION APPROVAL FORM

FERRIS STATE UNIVERSITY

Institutional Review Board for Human Subjects in Research

Office of Academic Research, 220 Ferris Drive, PHR 308 · Big Rapids, MI 49307

Date: July 1, 2015

To: Dr. Sarah Hinkley, Emily Carlson and Shannon Crane
From: Dr. Joshua Lotoczky, Interim IRB Chair
Re: IRB Application #140702 *(Visual Information Processing and Eye Tracking Deficits from Sports-Related Concussions)*

The Ferris State University Institutional Review Board (IRB) has reviewed and approved your request for an extension to continue using human subjects in the study, *"Visual Information Processing and Eye Tracking Deficits from Sports-Related Concussions"* (#140702). This approval has an expiration date of one year from the date of this letter. **As such, you may collect data according to the procedures outlined until July 1, 2016.**

Your project will continue to be subject to the research protocols as mandated by Title 45 Code of Federal Regulations, Part 46 (45 CFR 46) for using human subjects in research. It is your obligation to inform the IRB of any changes in your research protocol that would substantially alter the methods and procedures reviewed and approved by the IRB in your application. Thank you for your compliance with these guidelines and best wishes for a successful research endeavor. Please let us know if the IRB can be of any future assistance.

Regards,

[redacted]

Ferris State University Institutional Review Board