EVALUATION OF NEUROPSYCHOLOGICAL AND ATTENTIONAL DISTURBANCES IN CONCUSSED HIGH SCHOOL ATHLETES

by

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THESIS ABSTRACT

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Title: Evaluation of Neuropsychological and Attentional Disturbances in Concussed High School Athletes

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Approximately 1.5 million concussions occur annually in the United States, many affecting individuals between the ages of 15 and 18. Little is known about this age group's response to a concussion as they have been thought to respond differently than adults due to immature brain development. Additionally, relying on symptoms alone to determine level of brain function may lead to early return back to sport participation. Through the use of 3 computerized tests, neuropsychological and attentional deficit recovery post concussion was assessed between 12 subjects with concussions and 12 controls up to 2 months after injury. Memory tasks and symptoms resolved within a week after injury. Executive function tests showed small group differences up to two months post injury, suggesting these types of tests may be a useful tool in the evaluation of concussion recovery and provide an objective measure in evaluation.

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CHAPTER I

INTRODUCTION

Each year in the United States, approximately 1.54 million mild traumatic brain injuries (mTBI) or concussions occur, many to those participating in sport activities between the ages of 15 and 24 (Solomon, Johnston, & Lovell, 2006). The Centers for Disease Control and Prevention (CDC) have described brain injury as a silent epidemic and current evidence suggests that mTBI has become a public health problem. The extent to which this problem has impacted the nation is still unknown. However, there is a great need to determine the magnitude of the mTBI problem, to identify risk factors which can easily be assessed, and to develop and test strategies to reduce mTBI and improve clinical outcomes.

Concussion is defined by the 3rd International Conference on Concussion in Sport (Zurich, 2008) as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical factors (McCrory, Meeuwisse, Johnston, et al., 2009e). Symptoms of a concussion are classified into 5 categories: clinical signs, physical signs, behavioral changes, cognitive impairment, and sleep disturbances. Symptoms vary highly across individuals and the nature of the injury. Within these 5 categories, specific symptoms have been documented to assess recovery and return to a healthy state. This is commonly assessed using a self reported scale on 23 symptoms via a 6 point Likert scale.

Previously, it has been stated that almost 80% of high school and collegiate athletes would return to play prematurely if the clinical decision was based solely on a concussion grading guideline (McClincy, Lovell, Pardini, Collins, & Spore, 2006c). Many of these guidelines are based solely on symptoms and could miss other disturbances to brain function not represented by what the patient reports. Only relying on symptoms may be inconclusive because other deficits may be present which the clinician cannot effectively see. If decisions regarding return to play are made based solely on this scale, an athlete may be put at further risk for injury when returning to competition prior to full recovery.

Through a variety of testing batteries, certain deficits have been observed, which affect concussed subjects in many different ways. Attention, memory, and executive function disturbances are three cognitive components which have been observed to affect mTBI patients. Those suffering from mTBI often display deficits in maintaining, distributing, and focusing attention within tasks (Chan, 2002; Felmingham, Baguley, & Green, 2004; Ponsford & Kinsella, 1992; Spikman, van Zomeren, & Deelman, 1996; Stuss et al., 1989). Additionally, the capacity to utilize working short term memory effectively and accurately has been observed to be negatively affected by concussion (Collins, Grindel, Mark R. Lovell, et al., 1999). This loss or decrease of brain function affects not only sport participation, but scholastic or job related activities as well. The ability to perform tasks using short term memory is a necessary cognitive component to successfully complete a job task or school assignment.

Studies at on college students at the University of Oregon have shown that those suffering a mTBI have systematic deficits of cognition (Catena, van Donkelaar, & Chou, 2007; Parker, Osternig, van Donkelaar, & Chou, 2007). Executive function, a primary cognitive system function affected by concussion, is defined as a combination of cognitive processes which utilize all of the cortical information available from sensory systems to produce behavior based on this information (Yogev, Hausdorff, & Giladi, 2008). By performing tasks that are driven by conflicting cues, a relatively automatic form of regulation is probed which has been observed to be deficient in concussed subjects (van Donkelaar et al., 2005; Halterman, Langan, Drew, Rodriguez, et al., 2006). Risk of further injury, secondary injury, or long term neuronal damage may occur if an athlete returns to play at a time prior to full recovery following mTBI.

Healthcare providers, such as Certified Athletic Trainers and physicians rely on many different clinical findings in order to determine severity and ensuing recovery from a concussion. However, orienting and executive function variables are believed to be particularly affected by a concussion in adult populations because they have been shown to require a greater time to recover than certain commonly used neuropsychological test variables (Halterman, Langan, Drew, Rodriguez, et al., 2006; Parker, Osternig, van Donkelaar, et al., 2007). However, these variables have not been examined in the high school population.

There are approximately 1 million high school football players in the United States, 13 times more than the number of collegiate football players (Solomon et al., 2006). The adolescent brain has not reached full maturation (Daniel et al., 1999) leaving high school athletes at risk for devastating long term consequences if multiple injuries to the brain are sustained during this time of life. Furthermore, the brain of high school athletes may be at a higher risk than their college-age counterparts because the mechanical, musculoskeletal and tissue properties of the head differ between the two age groups (Bauer & Fritz, 2004). The musculoskeletal strength of the adolescent population also plays a role in force absorption. Anatomically, the neck muscles play a predominant role in absorbing the forces imparted to the head and neck during a high impact collision.

The smaller size of immature brains, skull geometry, and suture elasticity potentially affect the absorption of force to the head, but to what extent is still largely unknown (Kirkwood, Yeates, & Wilson, 2006). With less relative strength, this age group cannot effectively distribute the forces as efficiently as mature adults, possibly predisposing them to concussions.

According to a recent investigation by Broglio et al (2010), high school football players sustain similar levels of impact forces as their collegiate and professional counterparts (Broglio, Schnebel, Sosnoff, Feng, & Zimmerman, 2010). This is an alarming thought because football players competing in college are far more skilled and are trained to become stronger. As a product of playing football, or any sport that involves collisions, technical and training adaptations are made in order to effectively absorb forces and minimize injury. Immature and less experienced athletes, however, may not have yet learned or achieved these adaptations, which may place them at greater risk for head impacts.

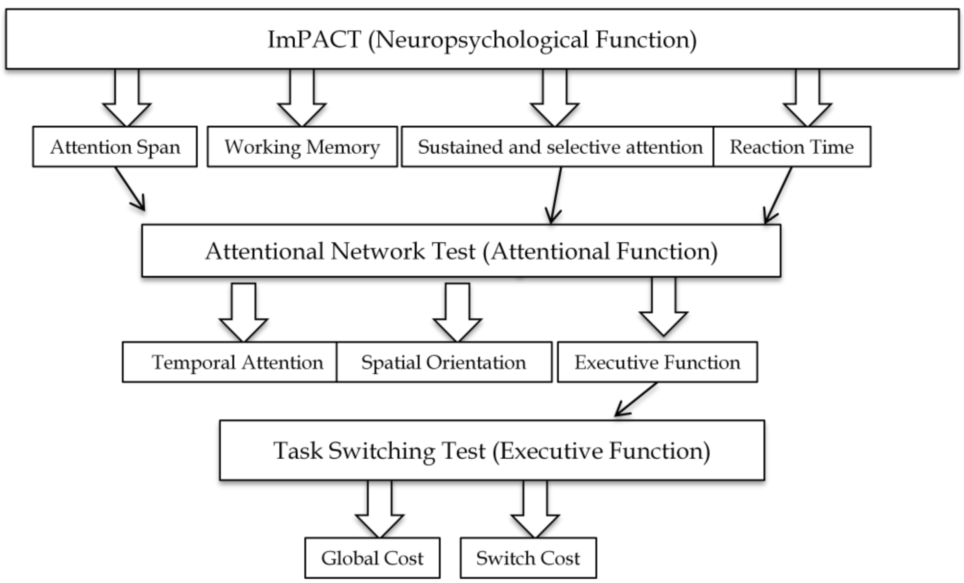
Many studies have focused on the long term consequences of mTBI on college and professional athletes, yet few have investigated the consequences to their younger, high school counterparts. Hence, the need exists to study this population and determine effective ways to assess brain function following concussion and during recovery in order to improve return-to-play decisions.

Purpose and Rationale

This study used three different computerized neuropsychological and attentional tests to analyze how high school athletes recover from a concussion due to a sport activity. By examining high school athletes through tests shown to be sensitive to mTBI recovery in college-age subjects, but not typically administered in high schools, new tools may be made available to clinicians who manage concussions. Therefore, the purposes of this experiment were: a) to study the recovery of high school athletes who suffer a sport related concussion and their matched controls; and b) to examine three tests designed to detect brain deficiencies following a concussion and their potential clinical application. Within this study, the use of a neuropsychological test (ImPACT) as well as attentional deficit tests (Attentional Network and Task Switching Test) were implemented to track of the effects of concussion on different cognitive systems.

This study examined three computerized tests because they represent different levels of probing of neurocognitive function and attentional deficiencies. These include: the Immediate Post Concussion Assessment and Cognitive Tool (ImPACT, ImPACT Applications, Pittsburgh, PA), the Attentional Network Test (ANT), and Task Switching Test (TS).

The rationale for using each of these tests is based on the components of cognitive function each measures and the sensitivity of each test (see Scheme 1). The ImPACT test probes attention span, working memory, sustained and selective attention time, response variability, non-verbal problem solving, and reaction time—all components of cognition. These aspects of cognitive function allow for an examiner to have an objective tool which tracks recovery from concussion. This test is designed specifically for sport concussion, thus it is a useful tools for sports medicine clinicians. The ANT then examines only the attentional components of cognition, through the assessment of how a subject reacts to differing stimuli. It is a narrower examination of brain function, but attentional components of cognition have been shown to affect those suffering from mTBI, thus making it a potentially viable test to examine in high school aged individuals (Halterman, Langan, Drew, Rodriguez, et al., 2006). Finally, the Task Switching test was the third test chosen within this study. Task switching models have been shown to examine executive control (Arrington & Logan, 2004) and because of its focus on active response to stimulus presentation, this test evaluates this function at a highly sensitive level. Thus, the task switching test was chosen to evaluate the executive function component of attention specifically.



Scheme 1: A flow chart of how the three tests relate to each other and examine different components of cognition

Aims and Hypotheses

The aim of this study was to investigate the way which each of the three computerized tests can detect subtle differences in brain function for two months following a mild traumatic brain injury. Based on previous work at the University of Oregon, it was hypothesized that: 1) on average, subjects would return to similar levels as matched controls within two weeks of the injury in the variables measured by the

ImPACT; 2) executive function variables measured by the ANT and TS would show significant group differences between concussed and control subjects within 72 hours of the injury and up to two months post injury; and 3) that the biggest group differences between the concussion and control groups would be found on the task switching test.

CHAPTER II

METHODS

Subjects

During subject recruitment, specific inclusion/exclusion criteria were used by the investigator as well as the collaborating athletic trainers to identify potential concussion subjects. Inclusion criteria included the following:

1. Diagnosis of a concussion by a team physician or Certified Athletic Trainer (ATC)
2. Participant on an interscholastic high school sports team in selected high schools in the Eugene area.

Exclusion criteria included:

1. A concussion within a year prior to the initial testing day.
2. A lower extremity deficiency or injury which may have affected normal gait patterns.
3. A history of cognitive deficiencies, such as permanent memory loss or concentration abnormalities.
4. A history of three or more previous concussions
5. Loss of consciousness from the concussion lasting more than one minute
6. A history of attentional-deficit hyperactivity disorder

Each concussed subject in the study was paired with a non-injured control subject (n=12), matched by gender, height, mass, sport and age; no significant differences between the groups were found indicating that similar demographic groups were used (see Table 1). These control subjects were also identified by the high school ATC and after permission was obtained, contacted by the investigator or assistants.

Group Characteristics	**Concussed Subjects**		**Control Subjects**	
	Mean	**SD**	**Mean**	**SD**
Age (year)	14.67	0.98	15.17	1.03
Height (cm)	170.96	8.73	171.26	9.66
Mass (kg)	74.41	19.93	69.00	12.33
Sex (M/F)	10/2		10/2	
* p<.05				

Table 1: A comparison of group characteristics between the concussed and control groups

Once subjects were identified and granted permission, the investigator contacted them directly to inform them of their possible inclusion in the study. Once enrolled in the study, each subject returned for each subsequent testing session according to the established timeline. All subjects and parent/guardian (if under the age of 18) signed informed consent in compliance with the University of Oregon's Human Subjects Committee. Permission was also granted by the Bethel School District, Marist High School, and 4J Eugene School District to conduct testing with participants from each respective school within the district.

Twenty-four high school athletes participating in school sports at two local high schools (20 males/4 females: see Table 1) were identified and recruited for testing. Thirteen of the participants were identified by the attending Certified Athletic Trainer (ATC) at two high schools in Eugene, OR as suffering a concussion (see Table 2 for demographic information). One subject was lost to attrition.

Sex	Sport	Age (yr)	Mass (kg)	Height (cm)	Previous Conc?	Injury Venue	Days Missed from sport
M	FB	14	84.5	173.5	No	Practice	7
M	FB	15	74	175	No	Game	13
M	FB	17	68.5	173	No	Game	35
M	FB	15	99	175	No	Practice	Season
M	FB	14	66	165	Yes	Practice	36
M	FB	15	123	183	No	Practice	Season
M	FB	14	71	173	No	Game	Season
M	SOC	14	58	175	No	Game	30
M	FB	14	68	173	No	Game	24
M	FB	16	65.7	177	No	Practice	Season
F	SOC	14	46.8	157	No	Game	13
F	VB	14	68.4	152	No	Game	7

Table 2: Demographic information from each concussion subject who participated in the study

Concussion was diagnosed and treated by a sport concussion specialist (Dr. Michael Koester, Slocum Center for Orthopedics and Sports Medicine) or by the attending ATC at each subject's respective high school. Athletic trainers are unique health care providers who specialize in the prevention, assessment, treatment, and rehabilitation of injuries and illnesses. They undergo concussion-specific training as a part of their education. Each athletic trainer involved with the study communicated with the investigator throughout the study period and communicated to him that a concussion had occurred and that the potential subject was interested in participating in the study.

Each subject missed greater than one week of participation in sport as a direct result of the injury. Four subjects missed the entire season.

Testing Protocol

This study employed a prospective, repeated measures design where each subject reported to the Motion Analysis Laboratory within 72 hours of the injury as well as on four subsequent testing days at the following time increments: 1 week, 2 weeks, 1 month, and 2 months post injury. Each session included a medical history, gait analysis, assessment of neuropsychological function (ImPACT), and assessment of components of attention (ANT and TS). This protocol was similar in time increments as previous studies on college students performed in this laboratory (Catena, van Donkelaar, et al., 2007; Catena, van Donkelaar, & Chou, 2007; Parker, Osternig, van Donkelaar, et al., 2007; Parker, Osternig, van Donkelaar, & Chou, 2008), with the addition of a testing day at 2 months after injury.

The ImPACT, ANT, and TS were each administered on a laboratory computer, located in a visually enclosed space free from distracting noise and away from other people present in the laboratory at the time (e.g. parents or siblings present at the testing session).

Gait data were also collected and will be used in the analysis of future studies related to this subject population and data set. Each testing session (gait and computer tests) took approximately 2 hours to complete.

Test Descriptions

ImPACT Neuropsychological Test

The Immediate Post Concussion Assessment and Cognitive Testing Tool (ImPACT; ImPACT applications, Pittsburgh, PA, USA) is a widely used neuropsychological test in sports settings and has been shown to be a valid and reliable way of understanding underlying pathologies associated with concussion (Randolph, McCrea, & Barr, 2005). Additionally, it has been observed to be a sensitive and specific tool to use in the overall evaluation of a concussion (Schatz, Pardini, Lovell, Collins, &

Podell, 2006e). Specifically, it has been reported to successfully measure neurocognitive performance in high school adolescents (Collins, Lovell, Iverson, Ide, & Maroon, 2006; Collins, Lovell, Iverson, et al., 2002a; Iverson, Lovell, & Collins, 2003). However, others have cautioned that the results should never be used alone to perform a full assessment of brain health (Broglio, Ferrara, Macciocchi, Baumgartner, & Elliott, 2007).

The ImPACT contains six different modules that test for multiple components of neuropsychological function. Within these six modules, four composite scores including those in the domain of verbal memory, visual memory, visual motor processing speed, and reaction time. A graded symptom score from a checklist is also recorded during the test. The test administration typically takes between 20 and 30 minutes.

Module 1 includes an evaluation of the attentional processes and verbal recognition memory using a word discrimination paradigm. The subject is presented with 12 target words which appear on screen for 750 milliseconds. The list is presented twice, after the second viewing of the words they are subsequently asked to determine if a list of words was presented to them. This list of words includes all of the presented words as well as a matching word for each from the same semantic category. Additionally a delay condition is utilized after the administration of all other test modules for the purpose of again testing for recall of the same of words.

Module 2 is a design memory test which evaluates attentional processes and visual recognition memory using a design discrimination paradigm. Like the word discrimination, twelve targets appear on screen for 750 milliseconds. These targets are designs which are presented twice. The subject then is presented with the designs again and asked if it was shown during the initial presentation. Each shape is matched with another shape, but rotated in space. They respond using a yes/no option on screen. A delay condition also exists for this testing module.

Module 3 measures visual working memory and visual processing speed and consists of a visual memory paradigm and a distractor task, through the use of an x's and o's test. The task is to click the left mouse button if a blue square appears or the right mouse button if a red circle appears on screen (distractor task). This is a choice reaction time task. After this task, a screen of randomly assorted x's and o's is presented for 1.5 seconds. Three are yellow while all others are black. The subject is asked to remember the location of these three yellow markers. After the presentation of this screen, the distractor task appears again, followed by the memory screen (X's and O's). Scores for accuracy in identifying X's and O's as well as a reaction time for the distractor task are recorded.

Module 4, a symbol matching module, evaluates visual processing speed, learning, and memory. The subject is presented with 9 symbols which correspond to a number from 1 to 9. The subject is asked to remember the symbol/number pairing and completes 27 trials with accuracy feedback. Following the completion of these, the numbers disappear and the subject is asked to recall the correct symbol/number pairing. A reaction time and memory condition score is calculated from this module.

Module 5 includes a color match module which represents a choice reaction time task and also measures impulse control and response inhibition. The subject simply clicks with a computer mouse a red, blue, or green button as they appear on screen. Following this they read words that are colors such as red, blue, etc. that are displayed in the same colored ink as the word or in a different colored ink. This visual stroop task allows the subject to click in the box only if there is a congruency between the ink and the word and provides a reaction time score and an error score.

Module 6, the final module, measures working memory and visual-motor response speed. A distractor task is first presented, a screen of a 5x5 grid which has one number from 1-25 in each box. The subject clicks as quickly as possible in backward order starting from 25. Three letters are then displayed. The grid then reappears and the subject clicks the numbers in backwards order again. Finally, the subject must recall the three letters and type them in. This module reports a memory score and an accuracy score form the distractor test.

An overall verbal memory composite score is then calculated using three different modules from total memory of words presented, a symbol match test, and a three letter delayed memory test. Visual memory is calculated from a combination of design memory and x's and o's memory tests. Visual processing speed comes from an x's and o's memory test and a three letter counting/memory test. Finally, the reaction time composite score comes from reaction times in the x's and o's, symbol match, and color match tests.

Additionally, a symptom score inventory is recorded by inquiring via a 7 point Likert scale, the self-reported current severity of their injury based on 23 different concussion symptoms. This scale is commonly used in the National Football League and National Hockey League and is also endorsed by the Vienna Concussion in Sports group (Aubry, Cantu, et al., 2002).

ImPACT Dependent Variables

Specific dependent variables related to the ImPACT are the verbal memory, visual memory, visual motor speed, and reaction time composite scores, as well as the graded symptom score. Table 3 illustrates the way in which each of the individual tests measure different neurocognitive domains as well as how each dependent variable becomes a composite score.

ImPACT Neurocognitive Test Battery	
Test Name	*Neurocognitive Domain Measured*
Word Memory	Verbal recognition memory (learning and retention)
Design Memory	Spatial recognition memory (learning and retention)
X’s and O’s	Visual working memory and cognitive speed
Symbol Match	Memory and visual motor speed
Color Match	Impulse inhibition and visual motor speed
Three Letters Memory	Verbal working memory and cognitive speed
Symptom Scale	Rating of individual self-reported symptoms

Composite Score	*Contributing Score*
Verbal memory	Averaged percentage correct scores for the Word Memory (learning and delayed), Symbol Match memory test, and Three Letters Memory test
Visual memory	Averaged percentage correct scores for the Design Memory (learning and delayed) and the X’s and O's test
Reaction time	Mean time in milliseconds for the X’s and O’s (mean counted correct reaction time), Symbol Match (mean weighted reaction time for correct responses), and Color Match correct response)(mean reaction time for correct response)
Visual motor processing speed	X’s and O’s (mean correct distracters), Symbol Match (mean correct responses), and Three Letters Memory (number of correct numbers correctly counted)

Table 3: Immediate Post Concussion Assessment and Cognitive Tool (ImPACT) composite score measures. From Van Kampen et al (2006)

Attentional Network Test (ANT)

The orienting and executive function components of attention were assessed through two testing batteries: the attentional network and task switch tests. The ANT has been reported to show differences in college students suffering from a concussion when compared to controls up to one month following the injury (Halterman, Langan, Drew, Rodriguez, et al., 2006). These computer-generated testing modules have been reported to successfully record components of attention in adults suffering from mTBI (Halterman, Langan, Drew, Rodriguez, et al., 2006) and in healthy children (Rueda et al., 2004). To the author's knowledge, no studies have examined the adolescent populations suffering from mTBI with this test.

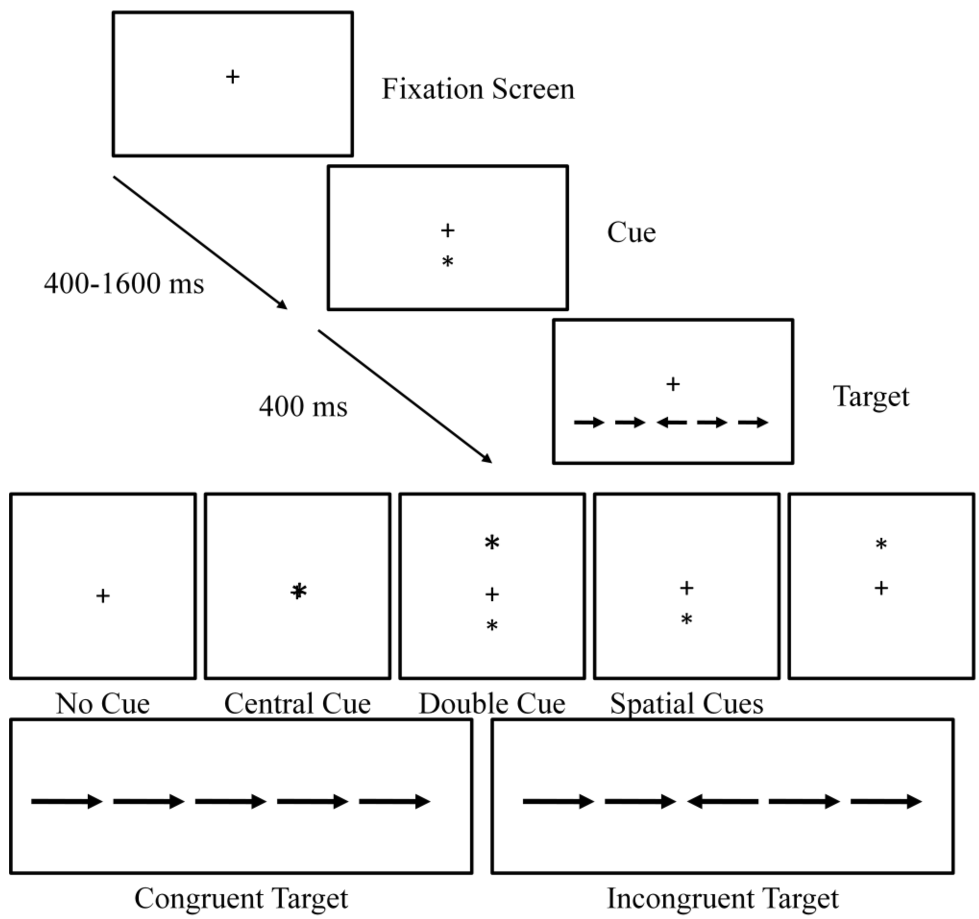


Figure 1: Attentional Network Test: a) an example of the procedure, in this example the left arrow button would be pressed; b) the four cue conditions; c) two of the flanker arrow target conditions. From Fan et al (2001).

During the ANT, the subject faces a computer in which visual targets appear starting with the appearance of a target cross (see Figure 1). Different conditions include the appearance of a precue (an asterisk) which appears briefly (100 ms) before the target arrow appears. The delay from the precue appearance to the target arrow appearance is variable and ranges from 400-1600ms. On other trials, no precue appears. The target arrow then appears either above or below the central fixation cross pointing to the left or to the right. The subject is instructed to respond quickly and accurately to the appearance of the arrow by pressing the left or right arrow on the computer keyboard with their respective right or left index finger. The arrow appears visible until the subject responds, or for 1700 ms, whichever comes first.

Variables exist within the precue conditions as well as with the target arrow conditions. A spatial precue is a condition in which the asterisk appears at the location where the consequent target arrow will appear. A double precue involves the asterisk appearing above or below the central fixation crosshair. A center precue condition trial includes the asterisk appearing at the same location as the central fixation cross. Finally the no precue condition exists in which no visible asterisk appears before the response arrow(s) appear. These spatial precues are always valid because they always appear at a location in which the target subsequently appears.

In conjunction with the preceding cue conditions, target arrow conditions are manipulated throughout the test as well. The target arrow can appear by itself (single arrow) pointing to the left or right, termed a “neutral” trial. It also can be surrounded by flanker arrows of the same size (2 on each side for a total of 5 arrows). They can be arranged in a congruent fashion (all pointing the same direction) or in an incongruent fashion (in the opposite direction of the target arrow). The three different target arrow conditions are equally distributed throughout the test containing each of the four different precue conditions.

The first part of the test includes a practice block of 24 trials so that the subjects have a chance to learn the procedure and they are given feedback of their accuracy. This is followed by 2 blocks of experimental trails each containing 96 trials (4 cue conditions x 2 target locations x 2 target directions x 3 flanker conditions x 2 trials). These trials are done in a pseudo-randomized order with no visual feedback regarding subject accuracy.

ANT Dependent Variables

The primary dependent variables of interest are the median reaction time differences between various cue conditions and target configurations. Reaction times are calculated as the time from the onset of the target arrow to the time when the arrow on the keyboard is pressed. Three dependent variables of interest are examined in this paper: the alerting effect, orienting effect, and conflict effect. These are calculated as relative differences between relevant precue and target arrow conditions. The extent to which concussion affects each component of attention is measured through these relative differences. Alerting effect is defined as the median reaction time on double cue trials subtracted from the no cue median reaction time. This subtraction represents the benefit the subject gets from knowing that the target will appear 400ms after the cue, thus examines temporal attention. Orienting effect is calculated by subtracting the spatial cue median reaction time from the center cue median reaction time. Although each precue communicates when the target arrow is going to appear, the exact location of where the target will appear is only known in the spatial precue condition, as the center cue only allows the subject to know when, but not where the target arrow(s) will appear. The subtraction of these reaction times represents the decrease in reaction time associated with awareness of the precise location at which the target is going to be displayed. Thus, the spatial orienting capacity of a subject is tested. The third effect, the conflict effect is calculated to probe the executive function component of attention. This effect is calculated by taking the difference between the median reaction time of the congruent target condition and the incongruent target condition. This difference represents the influence of distracting or irrelevant information and its effect on the subject's response time to this stimulus. Thus the subject must ignore the unnecessary information and focus attention on one aspect of space. This variable examines their ability to utilize the executive function component of attention.

Additionally, the other dependent variable examined is the grand median or median reaction time. This is calculated by finding the overall median reaction time on all accurate trials throughout the test. This variable examines how well and how fast the subject reacts to various stimuli throughout the test.

Task Switching Test

The task switch test is the third computerized test included in this study. It includes stimulus presentation in a rectangular frame on a computer screen (see Figure 2). Once again, the patient is instructed to use their left and right index finger to respond to the stimulus. Each trial contains a 1cm diameter circle on the left or right side of the rectangle.

Three different testing blocks exist within this test, termed "same," "opposite," and "switching." For the "same" testing block, subjects respond to the side of the rectangle the circle appears in by pressing the appropriate arrow key that matches with the direction of the circle. The "opposite" testing block requires the subject to hit the arrow on the keyboard in the direction opposite of where the circle appears. Finally, the final testing block instructs the patient to alternate between every two trials of choosing the same side and the opposite side. Cues are provided in the event that the subject misses a trial and cannot remember what the next correct response should be. During test administration, the circle does not move until the correct response has been entered and a reaction time between stimulus presentation and response is recorded.

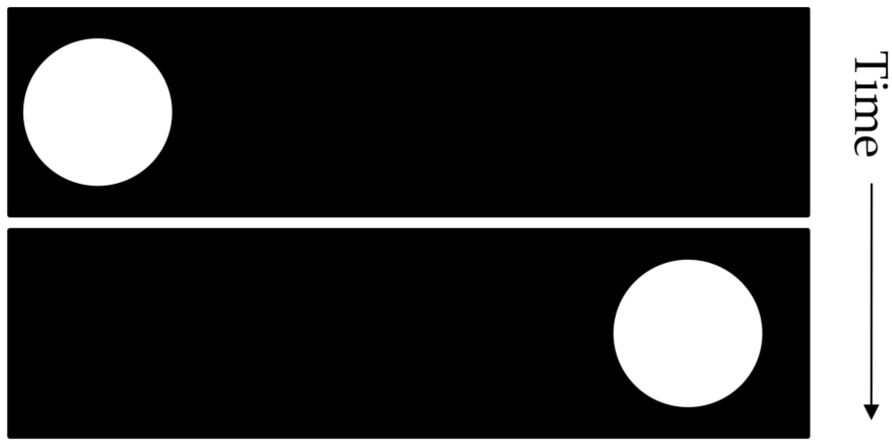


Figure 2: Stimulus presentation during the task switching test. During the "same" trials, the subject would press the left arrow, followed by the right arrow. During the "opposite" trials, the subject would press the right arrow, followed by the left arrow.

TS Dependent Variables

The primary dependent variables of interest are termed the global cost and switch cost (both defined below). The mean accurate reaction time of the same and opposite (first two) blocks of trials are calculated and represent the subject's baseline response time to a simple task. Within the final block of testing, accurate response times are taken from two different measures. The "stay" reaction times are calculated by taking the mean accurate response time within the trials in which the subject stayed on the same or opposite response cue. The "switch" reaction times are calculated by taking the mean accurate response time within the trials where the subject needed to switch from one condition to the other (either same to opposite, or opposite to same).

The global cost is then calculated by dividing the mean accurate reaction time "stay" trials by the mean accurate reaction time of the same and opposite blocks. This number is then multiplied by 100 to give a percentage response of the global cost. The switch cost is similarly calculated, but takes the mean accurate "switch" trials and divides them by the mean accurate reaction time of the same and opposite blocks, and then is multiplied by 100.

Gait Analysis

Preceding these computerized neuropsychological tests, a biomechanical motion assessment occurred in the motion laboratory at the University of Oregon. These data are not included in this particular analysis because of the focus on these three testing batteries. However, future studies will include gait parameters as another factor within concussion assessment.

Data and Statistical Analysis

Data were analyzed as a two-way, mixed-effects analysis of variance. The dependent variable was the subject's score on the different result scores on each of the three computerized neuropsychological/attentional deficit tests (ImPACT, ANT, TS). Group type was a between-subjects effect with two levels: (a) concussion subjects and (b) control subjects. The within-subject effect was testing time with five levels: (a) within 72 hours of injury, (b) 1 week after injury, (c) 2 weeks after injury, (d) 1 month after injury, and (e) 2 months after injury. Unadjusted p-values were used to evaluate within-subjects effects because the assumption of sphericity was evaluated with the Mauchly Sphericity Test and found to be tenable in most analyses. Tests which yielded a significant Mauchly Sphericity Test were evaluated using the Greenhouse-Geisser analysis. Follow up

Pairwise comparisons and main effect differences were then evaluated with a Bonferroni adjusted alpha level set to .002, consistent with the logic of this analysis. The original p-value (.05) was divided by 25 (the number of comparisons that were made within the analysis) allowing the new p-value to be adjusted to .002. The analysis of variance results are reported in Appendix B: tables 4-16, 21-27, and 31-33. All statistical analyses were done using SPSS Software (SPSS Inc., Chicago, IL, USA).

Additionally, due to the varied nature of each concussion, group mean analysis may not provide the full picture for some individuals. Therefore, each individual compared to the group mean was examined at each testing session and reported relevant findings. Specific variables were then examined on an individual basis based on our statistical findings and previous studies done in this laboratory. Specifically, the visual memory component of ImPACT, the self reported symptom score, the conflict effect of the ANT, and the switch cost score of the TS were examined as a part of this analysis.

CHAPTER III

RESULTS

Subject Testing

Each concussion subject reported to the motion analysis laboratory at the University of Oregon at a mean of 2.08 days (+/- 0.67) of the initial injury. After the initial testing took place, each participant returned to the lab in the following increments after the injury occurred: a mean of 8 (+/- 1.81) days, 16.8 (+/- 2.37) days, 30.5 (+/- 2.5) days, and 57.8 (+/- 2.3) days. This followed the proposed testing timing guidelines of within 72 hours of injury and 1 week, 2 weeks, 1 month, and 2 months post injury. Control subjects also followed the same timeline of testing sessions.

ImPACT Analysis

Verbal Memory

The verbal memory variable of the ImPACT hypothesis that concussion subjects would score significantly higher than matched controls during the initial injury assessment and at two weeks post injury was not upheld. Sphericity was assumed because Maulchy's Test of Sphericity $p>.05$.

There was a significant effect of testing day $F(4, 68) = 2.554$, $p = .046$. Using the Bonferroni procedure to control Family-Wise Type I Error, the only difference was detected between 72 hours of injury and 2 months post injury (M=-9.193) $p = .046$ suggesting a group learning effect throughout the length of the testing protocol because both groups improved at a similar rate, due to the fact that lower scores indicate better performance on this variable. No significant main effect was found for group, and no significant interaction for group by day was found. Further verbal memory results are shown in Appendix A (Figure 4) as well as in Appendix B (Tables 4, 5, 17).

Visual Memory

The hypothesis that the concussion group would record significantly lower scores on visual memory between the initial testing up to two weeks post injury was not upheld. No group or day effects for visual memory were detected using a two way repeated measure analysis of variance.

Because Maulchy's Test of Sphericity was found to not be significant, $p>.05$, sphericity was assumed. A day by group interaction was found to be significant $F(4, 64) = 4.335$, $p=.004$. Therefore, consistent with analysis of variance logic, main effects of group and day were examined. Using the Bonferroni procedure to control Family-Wise Type I Error among group marginal means, the one week testing session was found to be significantly different from the two month testing session, with concussion subjects performing worse (lower scores) (M=-15.625), $p=.001$. Additionally, a between group difference at the 72 hour assessment the initial injury were found to be significant (M=-17.841), $p=.002$. The concussion group had lower (worse) scores than the control group on this testing day. At one week post injury, there was still a difference between the groups (M=-14.568), $p=.021$, but not significant within the post hoc analysis. Further visual memory results are shown in Appendix A (Figure 5) as well as in Appendix B (Tables 6-8, 18).

Visual Processing Speed

The visual processing speed hypothesis that concussion subjects would be significantly higher than matched controls at the initial injury assessment and each subsequent testing session up to two weeks post injury was not upheld. Sphericity was assumed because Maulchy's Test of Sphericity $p>.05$.

There was a significant main effect of day $F(4, 68) = 13.709$, $p<.001$. Using the Bonferroni procedure to control Family-Wise Type I Error, a significant difference was detected within 72 hours of injury and 1 month post injury (M=-5.176) $p=.002$, between 72 hours of injury and 2 months post injury (M=-6.698) $p<.001$, and between one week post injury and 2 months post injury (M=-4.428) $p=.002$ suggesting that both groups improved their ability (by increasing their composite score) to visually process information over the testing time, but one group did not perform significantly better than the other.

No significant main effect was found for group, and no significant interaction for group by day was found. Further visual processing speed results are shown in Appendix A (Figure 6) as well as in Appendix B (Tables 9, 10, 19).

Reaction Time Composite

No main effects or interactions were observed for the analysis of the reaction time composite score aspect of the ImPACT test. Further reaction time composite results are shown in Appendix A (Figure 7) as well as in Appendix B (Table 11).

Symptom Score

The hypothesis that symptom score would decrease during each subsequent trial within the concussion group was supported because the a priori contrast comparing the between subject scores were significantly higher in the concussion subjects $F(1, 17) = 22.506$, $p<.001$.

There was a significant main effect of day $F(2, 68) = 3.043$, p=.023. Using the Bonferroni procedure to control Family-Wise Type I Error, no significant differences were detected between days.

The group by day interaction was also significant $F(4, 68) = 2.897$, p=.028. Thus the hypothesis that a symptom score could detect differences between the two groups was not upheld. Consequently, consistent with conventional analysis of variance logic, main effects of group and day were examined. Using the Bonferroni procedure to control Family-Wise Type I Error among group marginal means, the one week difference (M=11.375), p=.001 and one month difference (M=24.375) p<.001 in the concussion group were significantly lower (improved) from the initial testing session. The two week difference (M=15.125) p=.009, and two month difference (M=22.000) p=.013 follow ups were below alpha .05, but not statistically significant using the adjusted p value of .002.

No means differed significantly within the control group. Further symptom score results are shown in Appendix A (Figure 8) as well as in Appendix B (Tables 12-16, 20).

Attentional Network Test Analysis

Median Reaction Time

The overall accurate median reaction time variable of the ANT showed a significant main effect of day $F(4, 76) = 5.194$, p=.001. Using the Bonferroni procedure to control Family-Wise Type I Error, significant differences were detected between the within 72 hour testing session and one month post injury (M=51.611) p=.002 as both group reaction times continued to decrease across the testing sessions between 72 hours of injury and 1 month post injury.

The group by day interaction was also significant $F(4, 76) = 4.708$, $p=.002$. Thus, in line with conventional analysis of variance logic, main effects of group and day were examined. Using the Bonferroni procedure to control Family-Wise Type I Error among group marginal means, the two week difference (M=66.682), $p<.001$, one month difference (M=83.273) $p<.001$, and two month difference (M=83.812) $p=.001$ were significantly different from the initial testing session. The one week difference (M=39.773) $p=.016$ was below alpha .05, but not statistically significant using the adjusted p value of .002. Thus the concussion group continually improved significantly for two months after their injury while no significant differences were noted within the control group. So then the hypothesis that overall accurate reaction time results could detect differences between 72 hours post injury and all during subsequent testing trials up to two months after injury in the concussion subjects was upheld. Further median reaction time results are shown in Appendix B (Tables 21-23).

Alerting Effect

Because no previous literature supported any differences in the alerting effect component of attention, the hypothesis regarding this variable was that no differences would be detected. No day interaction was noted, but a group (between-subject) interaction was found $F(1, 19) = 4.676$, $p = .044$ as the concussion group had lower scores than the control group, indicating better performance on this measure. No differences within each day were found to be significant using the Bonferroni follow up comparison.

No group by day interaction was found to be significant within this analysis. Further alerting effect results are shown in Appendix A (Figure 8) as well as in Appendix B (Tables 24, 28).

Orienting Effect

No main effect or interactions were observed for this analysis of the spatial orientating component of attention. Further orienting effect results are shown in Appendix A (Figure 9) as well as in Appendix B (Tables 25, 29).

Conflict Effect

The conflict effect hypothesis that concussion subjects would be significantly higher than matched controls from the initial injury as well as two months post injury was not upheld. Sphericity was not assumed because Maulchy's Test of Sphericity $p<.001$, so the Greenhouse-Geisser test was used.

There was a significant main effect of day $F(1.265, 24.043) = 14.639$, $p<.001$. Using the Bonferroni procedure to control Family-Wise Type I Error, a significant difference was detected within 72 hours of injury and 1 week post injury (M=72.164) $p<.001$, with both groups performing with a better (lower) difference time on the test. This may suggest a learning effect during the first two testing days. The following testing day differences had an alpha value below .05, but were not statistically significant using the adjusted alpha level of .002: within 72 hours and 2 week difference (M=95.380) $p=.012$, within 72 hours and 1 month difference (M=95.448) $p=.005$, and within 72 hours and 2 month difference (M=12.293) $p=.003$.

No significant main effect was found for group, and no significant interaction for group by day was found. Further conflict effect results are shown in Appendix A (Figure 10) as well as in Appendix B (Tables 26, 27, 30).

Task Switching Test Analysis

Global Cost

No statistical differences or main effects were observed for this analysis of the global cost variable of the task switch test. Further global cost results are shown in Appendix A (Figure 12) as well as in Appendix B (Tables 31, 34).

Switch Cost

The hypothesis that the switch cost would identify differences between the two groups at two months post injury was not withheld as the group differences were not significant at any point during the two months after injury. Sphericity was not assumed because Maulchy's Test of Sphericity $p<.001$, so the Greenhouse-Geisser test was used.

There was a significant main effect of day $F(2.546, 51.282) = 10.586$, $p<.001$. Using the Bonferroni procedure to control Family-Wise Type I Error, significant differences were detected between the following testing sessions: 72 hours and 2 weeks post injury (M=26.363) $p<.001$, 72 hours and 1 month post injury (M=26.363) $p<.001$, and 72 hours and 2 months post injury (M=26.363) $p<.001$. Both groups continually scored better (lower) on this variable at the latter testing session.

There was also a significant main effect of group (between subject effect) $F(1, 20) = 5.944$, $p=.024$. Using the Bonferroni procedure to control Family-Wise Type I Error, no differences were found between the two groups on any single day.

No significant differences were noted within the control group. Further switch cost results are shown in Appendix A (Figure 13) as well as in Appendix B (Tables 32-33, 35).

Individual Subject Analysis

Within each of the three testing batteries, key variable differences were examined on a subject by subject basis, comparing each subject to the control group mean on each of the testing days. The rationale behind this analysis is that the result of the difference between a concussion subject and a normal healthy subject participating in the same time increments of each test (defined as the control mean at that testing day) may provide clinicians a more accurate view of recovery in each individual subject compared to relying on mean data.

Visual memory assessment, measured by the ImPACT, which was shown to have a significant group by day interaction when comparing group means, revealed that only 1 subject had more than a 20% lower (worse) score than the control mean at two months post injury. In contrast, at this same testing time, 1 subject scored 20% better than the control mean.

During the self reported symptom score, 4 of 12 concussed subjects had a symptom score 3.5-11.5 times that of the control mean. Of these 4 subjects, 3 had symptoms well above the control mean present at the one month testing and did not return to play for the entire season. However, one subject returned to play five weeks after the injury (between the one month and two month evaluations). He had an increase of symptoms from 3 to 26 despite not suffering a second documented concussion during this time. This difference could be due to the fact that he returned to physical activity and experienced some lingering effects from the initial concussion which may have been exacerbated by his return to physical activity, even though all clinical signs of his concussion revealed he had recovered from the injury. For this same subject, scores between the one month and two month sessions on conflict effect (77.5-93) and orienting effect (93-109) increased. This indicates that the subject may have had a more difficult time distinguishing between conflicting cues and orienting them in space and that his attentional capacities may have been affected by returning to physical activity. Meanwhile, measures taken by ImPACT between the one and two month testing times on verbal memory scores (99-97), visual memory (86-86), and visual processing speed (38.88-37.48) remained relatively constant for this subject during this month of return to activity.

The conflict effect variable of the ANT showed no statistical group by day interactions, but an analysis of each individual subject shows that at two months post injury, 8 of the 12 concussion subjects still demonstrated a greater difference between conflicting cues in their reaction time than the control mean. Seven of these 8 were greater than 25% higher than the control mean. This indicates that most of the concussion subjects still showed deficiencies responding accurately and quickly to conflicting cues when compared to the control mean. This type of analysis supports the hypothesis that at 2 months post injury, most concussion subjects still have lingering executive function deficits. This is in opposition to the group comparison which showed no significant effect or interaction at two months. Due to the relatively low number of participants in the study and high standard deviations within the data, many relevant findings may have been masked by the group analysis.

Using the switch cost variable of the Task Switching Test as a measure to evaluate concussion deficit, 10 subjects reacted slower on switching trials than the control mean at two months post injury. Only three subjects had more than a 20% slower reaction time score than the control mean; this indicates that most subjects performed somewhat worse on this measurement. However, a clear trend can be seen that concussion subjects are affected to a greater degree in the switch cost variable as only 5 subjects performed worse than the control mean in the global cost variable. These data suggest that the switch cost may be a more sensitive indication of impaired brain function at two months post injury than the global cost. However, because this test is a relatively new way to evaluate this population, no clear clinical significant conclusions can be made. However, it warrants further investigation as more differences may be seen with an increase in the subject population.

CHAPTER IV

DISCUSSION

This study examined the effects of neuropsychological and attentional disturbances experienced after a concussion when compared to a healthy control group from within 72 hours of the injury up to two months post injury. The data collected were used to examine whether executive function measures could provide a sensitive indication of the lingering effects caused by a concussion. In summary, working memory and a self reported symptom score revealed initial group effects, while executive function capacities were initially affected to a mild degree by those suffering a concussion.

As indicated by the mean comparison analysis, the number of statistically significant findings between the concussion and control group was different than had been hypothesized. Fewer statistical differences between groups were found at each testing increment than expected. However, many of the trends within concussion recovery observed through these means may still hold clinical significance. Clinicians no longer treat all concussions in a similar fashion. Instead, each individual is evaluated and treated according to the symptoms and deficiencies which the subject experiences. Therefore, many of the meaningful data collected in this study may be masked by group mean analyses. Thus, reporting of group mean significance will be followed by an individual analysis of subjects on key variables within the testing battery.

ImPACT

The results measured by the visual memory component of the ImPACT showed a recovery pattern of improvement following concussion while no control group differences were found to be significant. It has been shown previously that visual memory showed significant differences between concussed college and healthy up to one week after injury (Parker, Osternig, van Donkelaar, et al., 2007). Our study showed a similar trend as a group effect was noted within 72 hours of the injury, but not on any subsequent testing day. Although recovery of this brain function could not be determined on a specific day, previous literature supports the notion that visual memory capacities recover typically within a week of the injury (McCrea et al., 2003).

Verbal memory comparisons showed a learning effect throughout the two month testing period for both groups, as evidenced by the overall day difference between the first testing session and the final testing session two months later. The trends seen visually (see Appendix A: Figure 4) indicate a difference in recovery and learning between the groups, but the only statistical differences were seen for both groups between these two testing days two months apart.

Visual processing speed provides an objective score which detects how fast and accurately a subject can process and react to differing stimuli. An improvement in both groups was found between the initial testing session and the one and two month testing sessions. This suggests that test learning happened for both groups. However, an examination of the recovery curves for this variable suggests that the concussion group had poorer scores than the control group across testing days. Possibly due to the relatively small subject group (n=12), statistically significant differences were not found, but the trends suggest that with increased group size, statistical differences may be found. Thus, visual processing speed may provide a good indication of recovery in this age group.

The concussed subjects showed continued recovery at one week as well as at one month after the injury as measured by their symptom score. Based on the latest consensus statement on sport concussion, (McCrory et al., 2009) it was anticipated that symptoms would resolve typically within two weeks of the injury. The group effects were seen in the present study at the 72 hour testing session as well as one week evaluation agreed with this sentiment. However, the concussion group mean was still more than double that of the control mean two months after the injury, indicating that concussed subjects were still suffering symptoms well after the injury occurred. Four subjects missed the entire season due to the injury and may have been experiencing significant symptoms at this point in their recovery, thus increasing the overall group mean of the concussed group. This variability within the group supports an individualized method to evaluate sport concussion as much of the meaningful data is masked by a group comparison analysis.

Attentional Network Test

The purpose of utilizing the ANT as an assessment tool in high school athletes suffering from concussion is that it allows for examination of the attentional disturbances they experience in their recovery. While this type of measure may provide a clear look at a subject's deficits after injury, it is far less utilized clinically in high school athletes than neuropsychological tests such as the ImPACT. The value of neuropsychological tests in the diagnosis and treatment of concussion has been well documented and utilized clinically throughout the literature in the past several years (McClincy, Lovell, Pardini, et al., 2006c; Randolph et al., 2005; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006f).

Some recovery patterns in ANT measures were found to exist similarly to what was found in college athletes (see Figure 3). Especially in the conflict effect variable of the ANT, a very similar pattern has been established in between the two populations (14-17 year old and 18-23 year old) of concussed athletes and matched controls. The present study suggests that recovery may not yet be complete at two months after injury.

This comparison demonstrates similar trends in recovery patterns in both high school and college age groups. While meaningful statistical significance was not found to be apparent in any of these variables within the ANT, it can be hypothesized that as the number increases in the subject population, comparisons between groups will reveal statistically significant differences.

The conflict effect, or executive component of attention, as measured by the ANT assesses how well subjects can ignore extraneous information while using the relevant information effectively. Even in healthy populations, the reaction to an incongruent stimulus takes longer than a congruent one (Fan, McCandliss, Sommer, Raz, & Posner, 2002). However, the concussion group could have had more difficulties than controls in ignoring the unnecessary information and reacting appropriately, resulting in a longer reaction time in each of the testing sessions. Because the two groups still differed at the two month testing time, it is possible executive function capacities may be still impaired at this time post injury. Although not significantly different, the similarities in the recovery curve to the previous study by Halterman et al (n=20) suggest that as the subject pool increases, a clearer contrast between groups may become evident.

Comparison between college (left) and high school (right) athletes

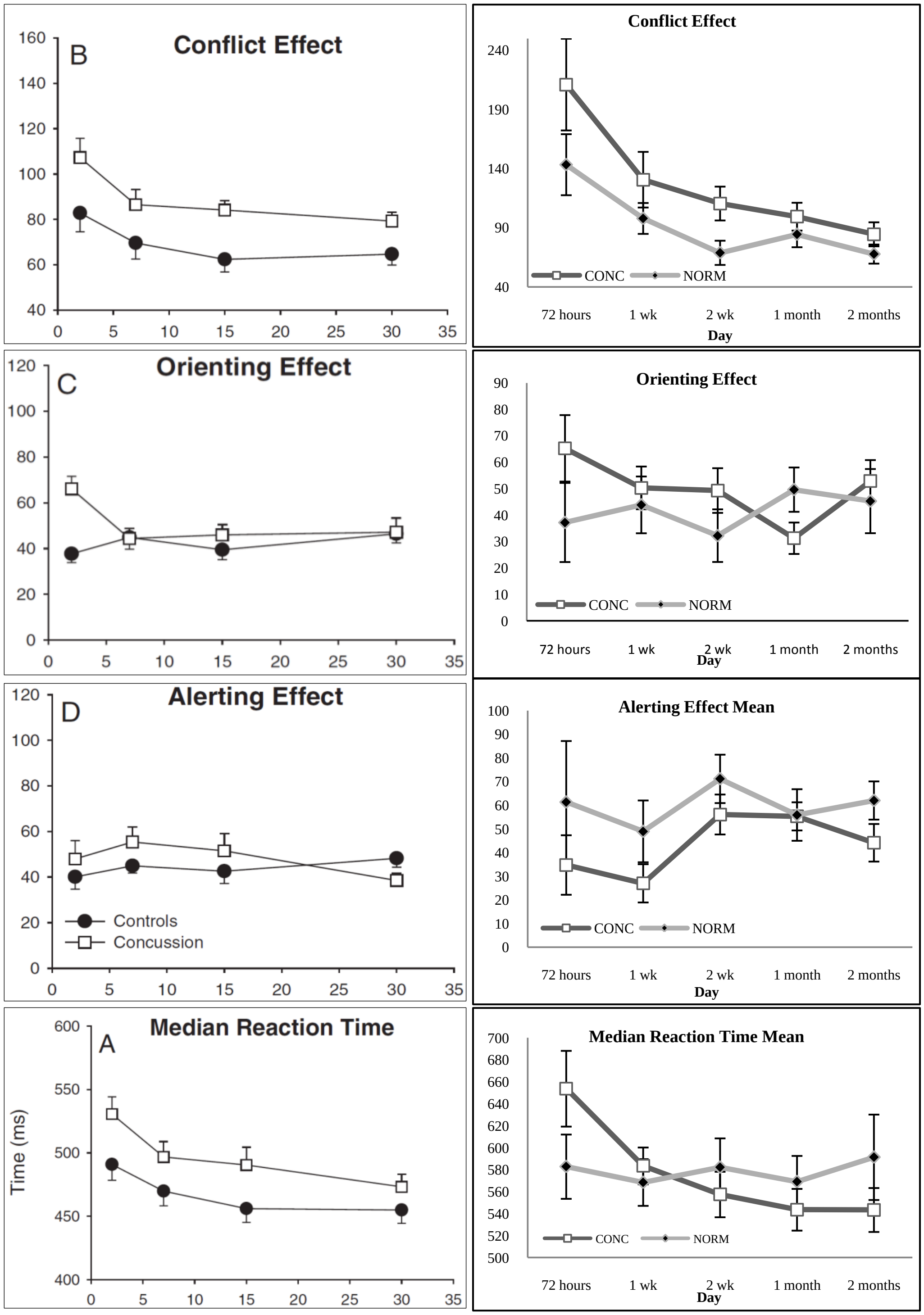


Figure 3: A comparison of the findings reported in college aged athletes by Halterman et al (2008) on the left and current study data on high school athletes on the right. Y axis values for each effect are the differences in condition reaction times (described on pages 14-16).

The orienting component of attention assesses the ability of the subject to make shifts of attentional resources to a location preceded by a cue, which leads to quicker processing of the target location. Based on the data collected, subjects with a concussion and controls showed no significant difference throughout the two month testing period. This is in contrast to previous studies on college populations which reported a difference within the first two days of a concussion (Halterman, Langan, Drew, Rodriguez, et al., 2006).

The alerting component of attention has previously shown a very weak differentiation between concussed and control groups in the past. This effect assesses the subject's ability to use temporal and not spatial precues to accurately identify and respond to the presented stimulus. Both groups benefitted equally from the spatial and temporal information provided by the precues. Thus the patient's ability to uphold vigilance throughout the testing period seems to affect all subjects tested in a somewhat equal manner. The results from this study echoes previous studies which have found no significance between concussion and control groups in the alerting effect of attention (Halterman, Langan, Drew, Rodriguez, et al., 2006; Ponsford & Kinsella, 1992; Spikman et al., 1996).

Task Switching Test

The task switching test measures the level of executive function a subject has by using a voluntary paradigm which involves them voluntarily switching within a given set of stimuli. A task cue, such as the one used in this test, informs subjects to follow a standard rule, such as switching between the same and opposite direction of the stimulus.

This scenario is a commonly used tool to examine executive function (Mayr & Bell, 2006).

The difference in this measure of executive function and what was utilized in the attentional network test is the voluntary control aspect. This element may expose aspects of executive control that would not be found in a standard, more reactive paradigm. Thus we hypothesized that those afflicted with a concussion would be affected in this measurement at a much higher rate and that the differences seen between the groups would be significant. A group effect was found to be significant, indicating that concussion subjects had a more difficult time performing a switch task when compared to controls. Additionally, the day effect found between the initial testing session and the two week, one month, and two month testing sessions indicates a possible learning effect of practicing and repeating the same experiment five times over a two month period of time. While both groups appeared to learn at a similar rate, concussion subjects repeatedly had a slower switch reaction time, resulting in a greater switch cost, than controls in their reaction time at two months.

The ability to voluntarily switch tasks effectively and accurately may be directly related to other measures of executive control and thus a sensitive indicator of recovery. Previous studies which have reported that cognitive tasks performed while undergoing a simultaneous balance or walking task indicate that executive function is probed when doing this (Broglio, Tomporowski, & Ferrara, 2005; Parker, Osternig, Lee, van Donkelaar, & Chou, 2005). Future studies should focus on relating the findings on these sensitive dynamic measures and ability to effectively complete this task switching test to give clinicians another useful tool in the evaluation and treatment of concussion.

Individual Subject Performance

Clinicians evaluate and treat a concussion based on the individual signs and symptoms exhibited by the patient they are treating. When comparing groups, much of this individuality is masked by a mean analysis. Thus we investigated how individuals performed throughout the two month testing period as assessed by each of the neuropsychological and attentional tests.

Visual memory deficit has been shown to be a variable which suffers following a concussion (Field, Collins, Lovell, & Maroon, 2003b). In the current study, it was found that only two subjects were outside of 20% lower than the control mean at two months after injury. While the level of clinical relevance this information is limited, it is worth noting that the differences seen in this variable at two months after the injury between groups are very small. This indicates that subjects have either recovered fully or that this variable which was tested is not a good indication of the subtle deficits which may still exist at this time during recovery. However, all subjects except one were greater than 15% below the control mean during the first testing session within 72 hours of injury. These data may suggest that initially, this variable can be a viable option to diagnose a concussion, but may not be able to detect any subtle deficits which exist two months after the injury.

Within the task switching test, no significant group differences were found. However, by inspecting the individual differences, it is revealed that 10 out of the 12 concussed subjects were slower at the switch cost at two months post injury. In contrast, only 6 out of the 12 concussed subjects were slower at the global cost at two months post injury. This suggests that, although not statistically significant, the switch cost variable may have clinical implications to detect subtle changes brought forth by a mild traumatic brain injury that would otherwise be undetectable by standard neuropsychological tests.

Three subjects stood out as examples of changes detected by all three tests, but in different ways. A female soccer player had symptoms resolve to similar levels as control subjects within two weeks of the injury. She was then cleared to play at that time. However, orienting and executive function components of attention were still more than double the control mean. This suggests that her attentional capacities continued to be affected well after she returned to play. Even at two months post injury her conflict effect score was 25% worse than the control mean, despite ImPACT measures returning to normal ranges within two weeks of her concussion. This indicates that her executive function ability may have been deficient while other neuropsychological functions of her brain such as memory and sustained attention had returned to near control level function. She returned to play two weeks after her injury and her ability to react to relevant and irrelevant information (measured by the conflict variable) decreased by 10% and visual memory capacity also decreased by 17%. While some of these results may be due to other factors, it may suggest that slight deficiencies may have still been present in her memory and executive function components of attention. Whether these changes have any clinical usefulness is still unknown, but the changes seen further demonstrate the need for continued vigilance of an athlete once they return to their respective sport activity.

The second individual subject whose executive function was slow to recover was a 14 year old female volleyball player. She performed worse than the control mean from the time of injury through two months post injury in both the conflict effect and switch cost measures. She performed at least 20% slower the control mean on the conflict effect and switch cost throughout the testing period, indicating worse executive functioning than the matched controls. However, she was returned to play based on clinical signs such as symptom resolution and ImPACT scores returning to normal at one week after the injury. As time went on and she continued to play, her ImPACT scores remained near control levels, but her conflict effect score and switch cost increased to more than double the control mean, with an increase in symptoms from 4 at one week to 77 at two months post injury. Additionally, she reported a higher symptom score at each subsequent testing session once she returned to play. While this subject may or may not be the typical example of concussion recovery, it suggests a necessity to examine each patient on an individual basis and treat them accordingly.

Finally, a 14 year old male football player was concussed and initially had a symptom score of 18. At one week, his symptoms had resolved to a score of 2 and he returned to play approximately 2 ½ weeks after the injury took place. All ImPACT variables consistently stayed within 20% of the control mean from one week through the rest of the testing sessions. However, he continued to remain 50% over the control mean in the orienting and conflict effects at two months post injury. These data suggest that he had lingering effects remaining from his concussion that did not resolve, and may have been due to the fact that he returned to the same activity before his attentional capacities (measured by the ANT) had resolved to control levels.

The areas affected by a concussion are highly variable across each individual due to the way different subjects may have responded to the injury (Broglio, Schnebel, Sosnoff, et al., 2010; Zhang, Yang, & King, 2004). However, by individually comparing each subject to the mean of the control group, specific aspects of a single subject in recovery can be seen that may have been otherwise masked in the group analysis.

Effect of Three Different Testing Assessments

Within this analysis, differentiating between a learning effect on the tests and true concussion recovery is difficult to do. The tests are unfamiliar to most subjects but simple in nature and relatively easy to learn. However with each subsequent practice a normal amount of improvement was expected. This was accounted for by comparing subjects to a mean of healthy control scores. Within this testing battery, the concussion subject's executive function measures (conflict effect- ANT, switch cost-TS) were on average worse than the controls. As the population of this study increases, variance within the mean may decrease and group differences may be revealed, leading to significant findings. If this is found to be true, the usefulness of this tool for diagnostic and treatment purposes may be indicated.

The ImPACT is already a clinically useful tool utilized by physicians and athletic trainers across the country. However, the data shown in this study suggest that utilizing more specific executive function tools can also be useful and may improve the diagnosis and treatment of a sport concussion in the high school age group. This is relevant because often, clinical decisions are based partially on ImPACT information. If executive functioning is not accounted for, subtle deficits may be present and returning these individuals to play may be putting them at risk for further injury.

Based on previous reports that state those who suffer a concussion and return to play within the same season are nine times more likely to suffer a subsequent concussion within the same season, (Guskiewicz, Weaver, Padua, & Garrett, 2000) a further investigation into multiple measures of recovery is warranted. Although neuropsychological testing has been implemented and documented throughout the literature, the data found in this study suggest that executive function may be a valid measure of concussion recovery in the high school athlete population.

CHAPTER V

CONCLUSION, LIMITATIONS, FUTURE DIRECTIONS

Conclusion

Concussed individuals within the high school age group showed similar trends as college aged athletes, suggesting both groups recover from concussion at a similar rate within the first month after injury. However, the data presented suggest that recovery may even go beyond one month in high school athletes. Additionally, executive function may prove to be a good measure of recovery as concussion subjects consistently took longer to recovery from a mild traumatic brain injury using this as an assessment tool.

Of the three tests examined within this study, the ANT and TS clearly show the biggest difference between concussion subjects and control subjects at two months post injury. Although no statistically significant findings were present at two months after injury, the prospect of this finding warrants further investigation. Finally, the data presented in this study also suggest that clinical tools which focus on attentional capacities of cognition may be a useful way to evaluate a high school athlete who has suffered a concussion.

Limitations

The author acknowledges that many different limitations existed within this study. The relatively small number of subjects in each group (n=12) was due in part to a one year period of data collection in which considerable time was needed to organize multiple high schools in the region to participate in the study. This resulted in fewer referrals than otherwise might have been possible if more time was available. Although it is estimated that many more athletes in the regional high schools suffered concussion than were tested in this study, it is impossible to accurately predict how many concussions will occur, identify when they happen, and bring them to the laboratory within 72 hours of their injury. While communication with the athletic trainers involved in the study was constant, many subjects were lost due to the short window of time possible for the initial testing.

Due to the fact that subjects had transient, rapidly resolving deficits from their injury as well as slow recovering, long term injuries, no uniform range of severity of injury was established. While the inclusion/exclusion criteria attempted to control for some of these factors, there is no way to know how a subject will respond after the injury. The range of concussion severity appeared to be quite large in this study.

No randomization occurred within the order of tests given. Each testing session included the subject first participating in walking gait trials, followed by the ImPACT, ANT, and finally the TS test. A fatigue effect may have played a part in the results of the study as the patient became mentally or physically tired by the end of the two hour testing.

Comparisons were made between a group of concussed subjects and a group of healthy, matched controls. In order to compare the current high school group findings and previous college group studies, a comparison between concussed and control subjects had to be made as only limited baseline data existed in these prior studies.

Many other studies have compare a subject to a baseline test so that each subject serves as their own control (Broglio, Ferrara, Piland, & Anderson, 2006; Iverson et al., 2003; Lovell et al., 2003; Schatz, Pardini, Lovell, et al., 2006e). However, the baseline testing environment for the subjects often occurred in a room with 15-20 other athletes, was very different than the follow up assessments, on a laboratory computer isolated from noise and other distractions. Because the conditions in the baseline tests were not controlled, it was decided that a comparison between a concussion and control group would serve as a more accurate view of recovery because each person was subjected to the same conditions in the same time increments. Preliminary results of an examination of existing baseline data for subjects in this study revealed that on average, those who suffered a concussion had improved on most variables within 72 hours of their injury. This is opposite of what would be expected, and possibly indicates a lack of effort or numerous distractions from attention during the baseline test.

Future Directions

While this preliminary data shows promise for utilizing each of the three different tests in a clinical setting, more subjects are required in order to see the effect across a given population. Differences between younger aged (14-15) and older aged (16-18) high school athletes may be present due to differences in brain maturation, so there is a need for more older aged high school athletes.

Additionally, the gait analyses which were also conducted on the subject population in this study will help to further understand how postural control is affected when recovering from concussion as well as the effects gait has on cognitive processes.

Finally, differences between sex, sport, position, classification of symptoms, and age differences in their recovery from concussion will be looked at as subject pool increases.

Findings from future research will help to assist clinicians make clinical return to play decisions based on safe, objective, and scientifically sound results and help to ensure the safety of high school athletes in their return from sport related concussion.

APPENDIX A

GROUP MEAN GRAPHS

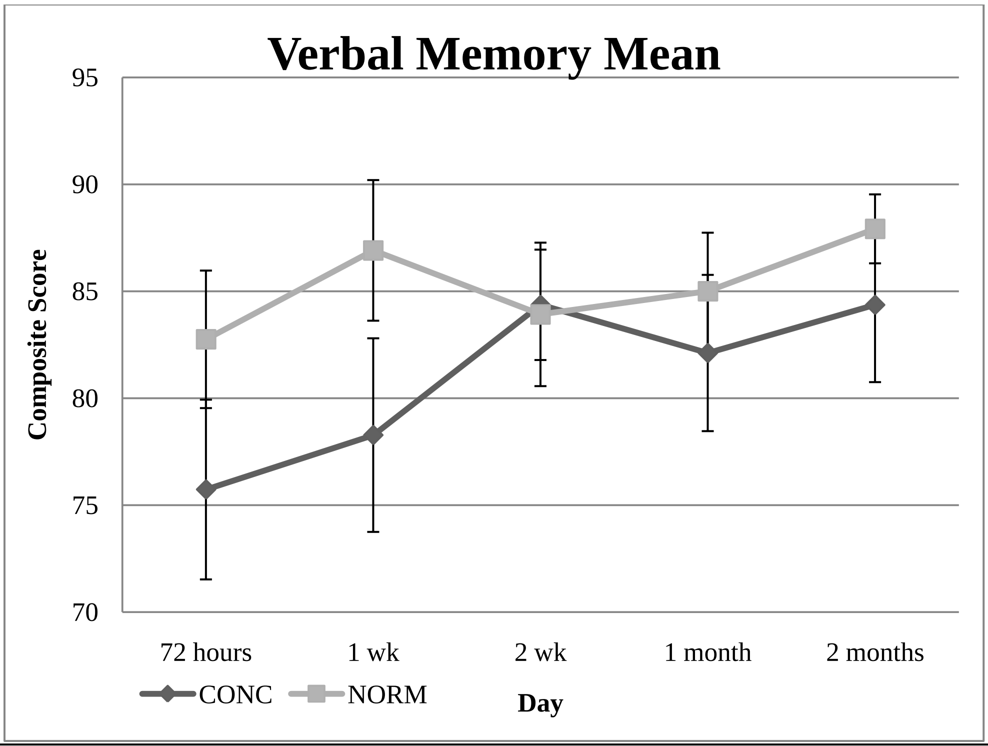


Figure 4: Concussion and control group means throughout each of the five testing days measured by the verbal memory variable of the ImPACT.

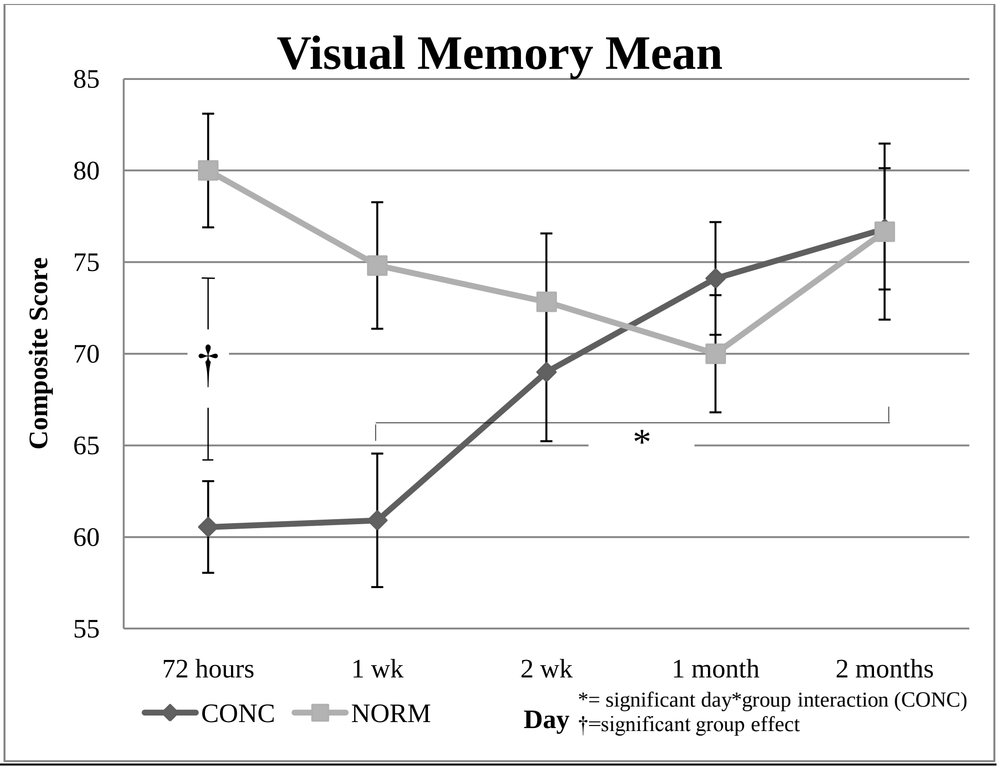


Figure 5: Concussion and control group means throughout each of the five testing days measured by the visual memory variable of the ImPACT.

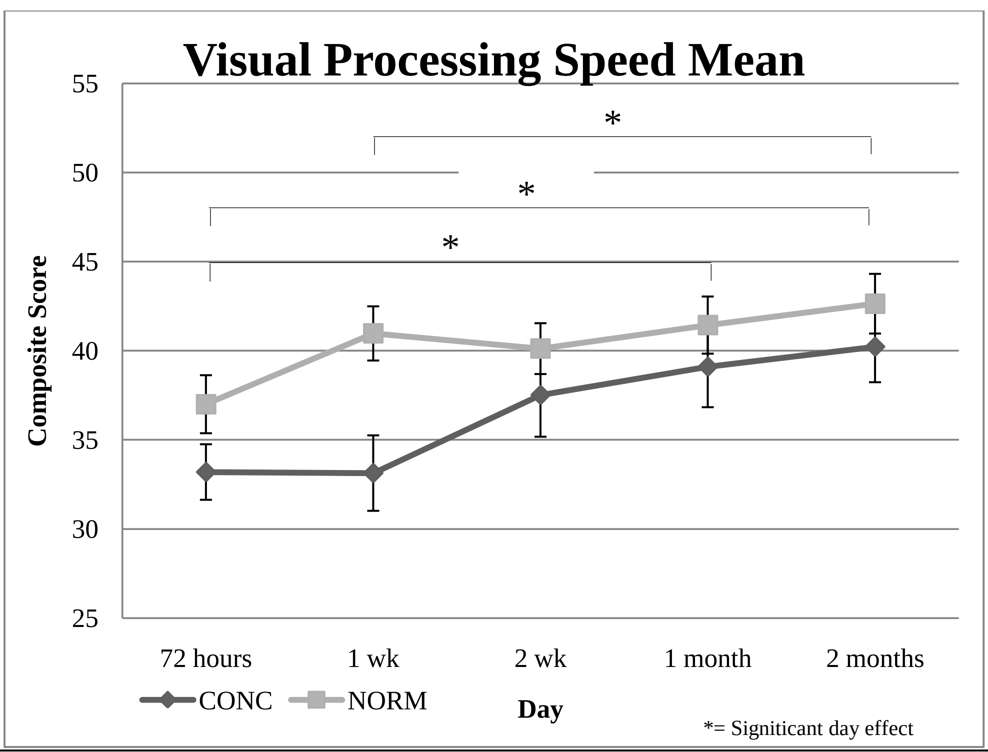


Figure 6: Concussion and control group means throughout each of the five testing days measured by the visual processing speed variable of the ImPACT.

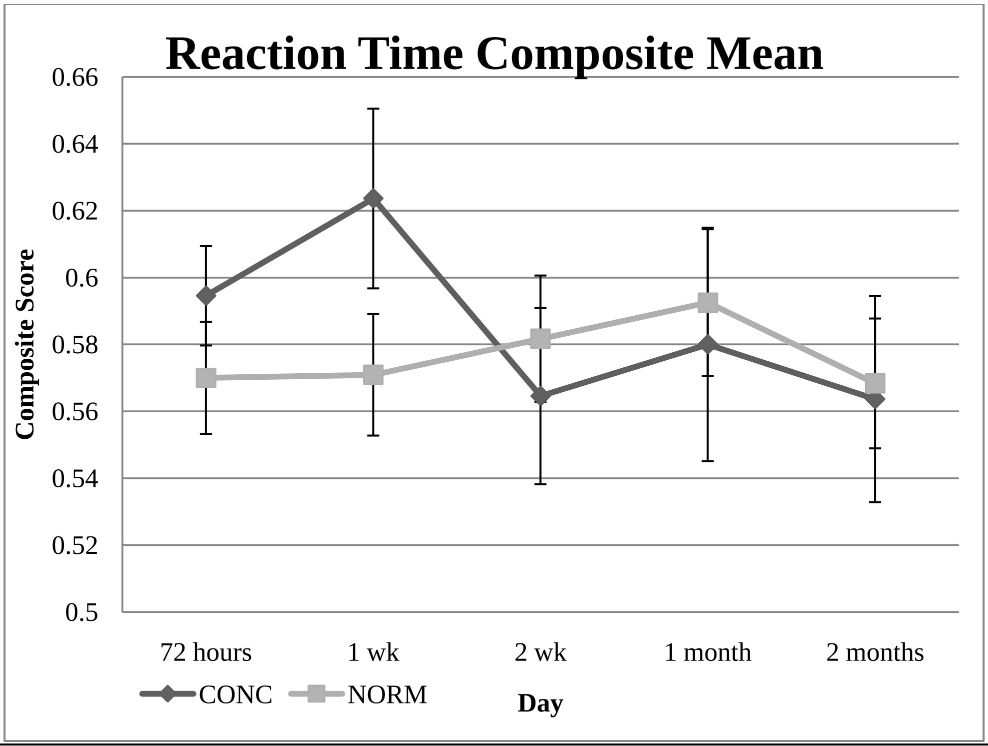


Figure 7: Concussion and control group means throughout each of the five testing days measured by the reaction time composite variable of the ImPACT.

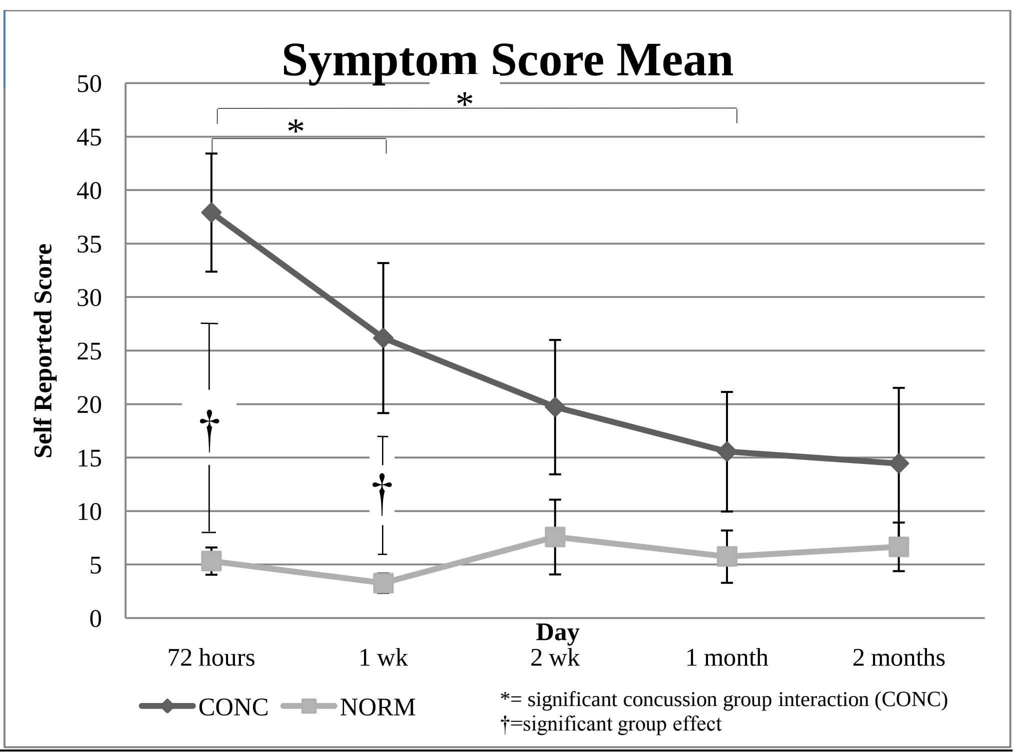


Figure 8: Concussion and control group means throughout each of the five testing days measured by the symptom score variable of the ImPACT.

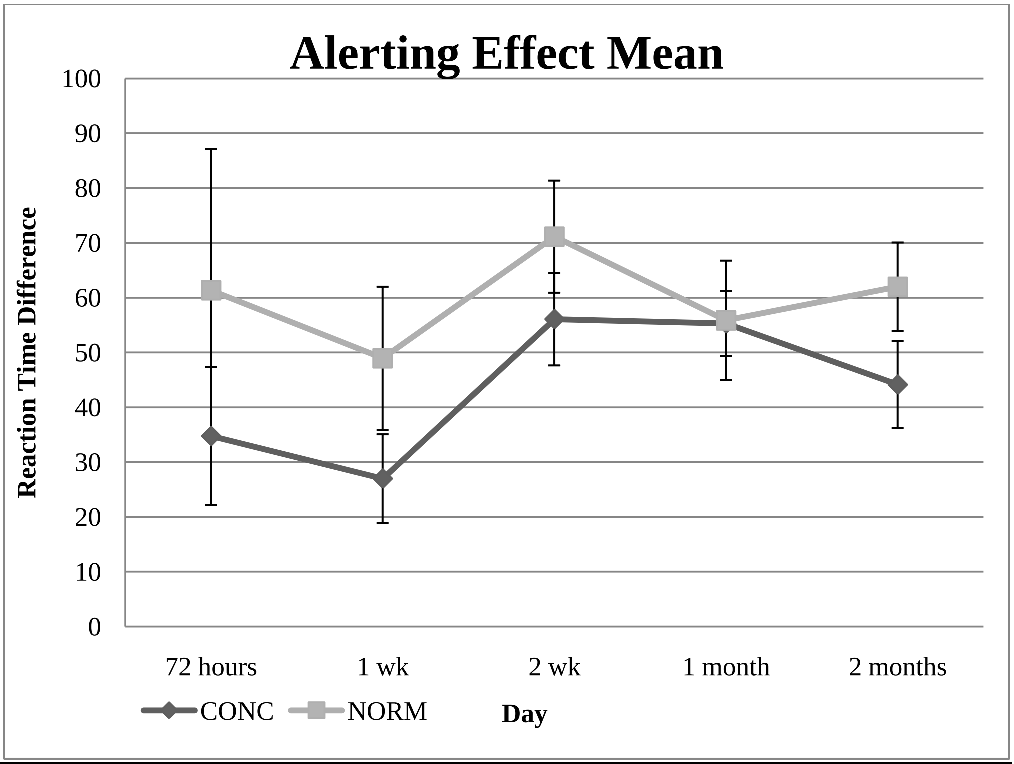


Figure 9: Concussion and control group means throughout each of the five testing days measured by the alerting effect variable of the ANT.

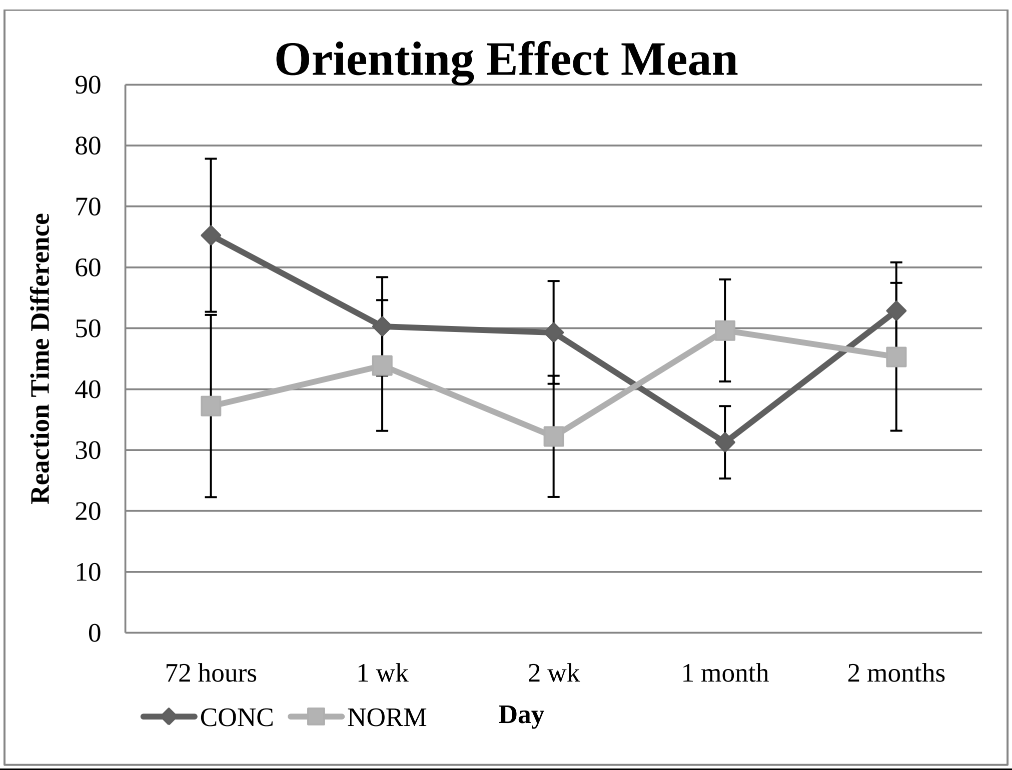


Figure 10: Concussion and control group means throughout each of the five testing days measured by the orienting effect variable of the ANT

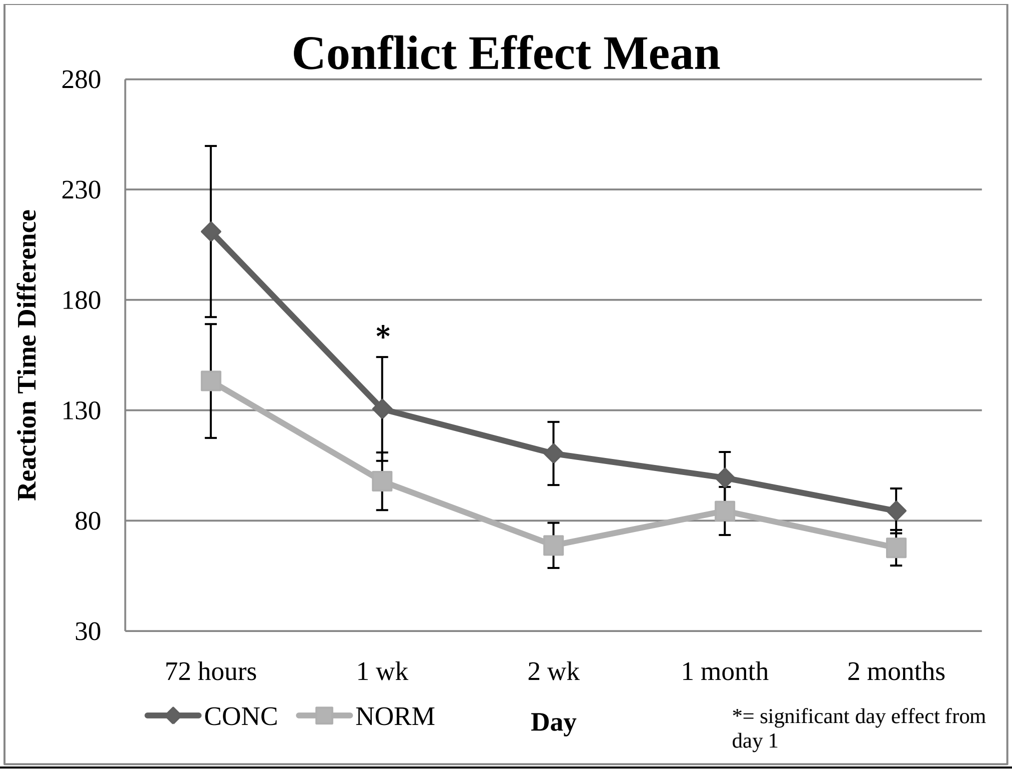


Figure 11: Concussion and control group means throughout each of the five testing days measured by the conflict effect variable of the ANT.

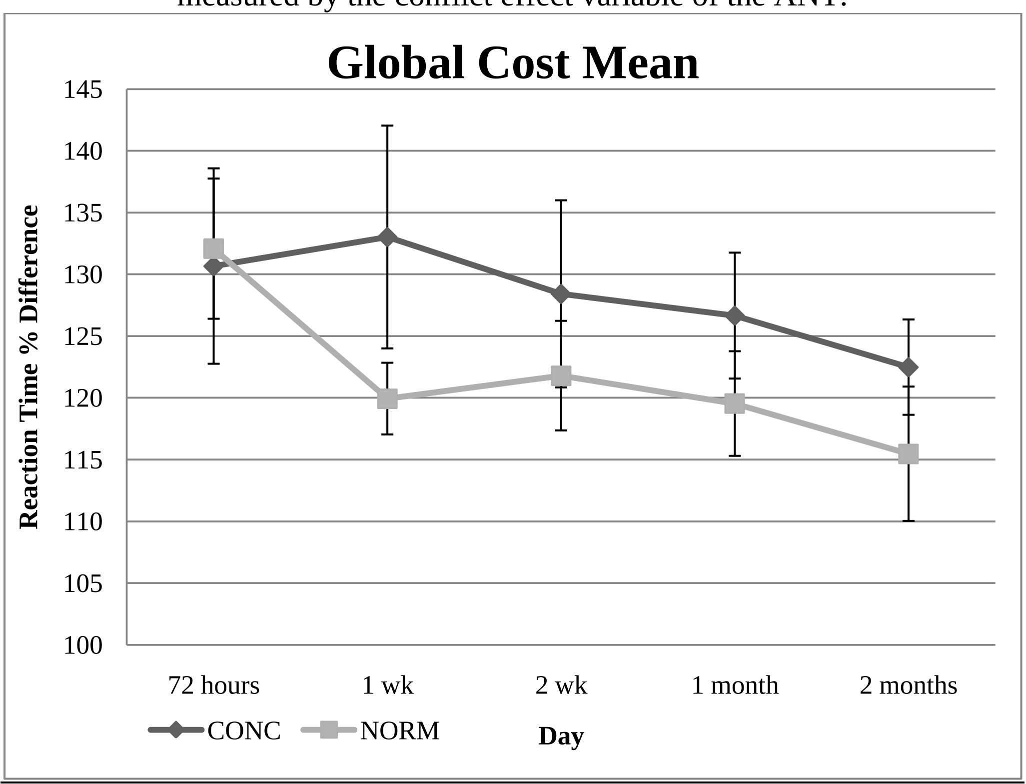


Figure 12: Concussion and control group means throughout each of the five testing days measured by the global cost variable of the TS.

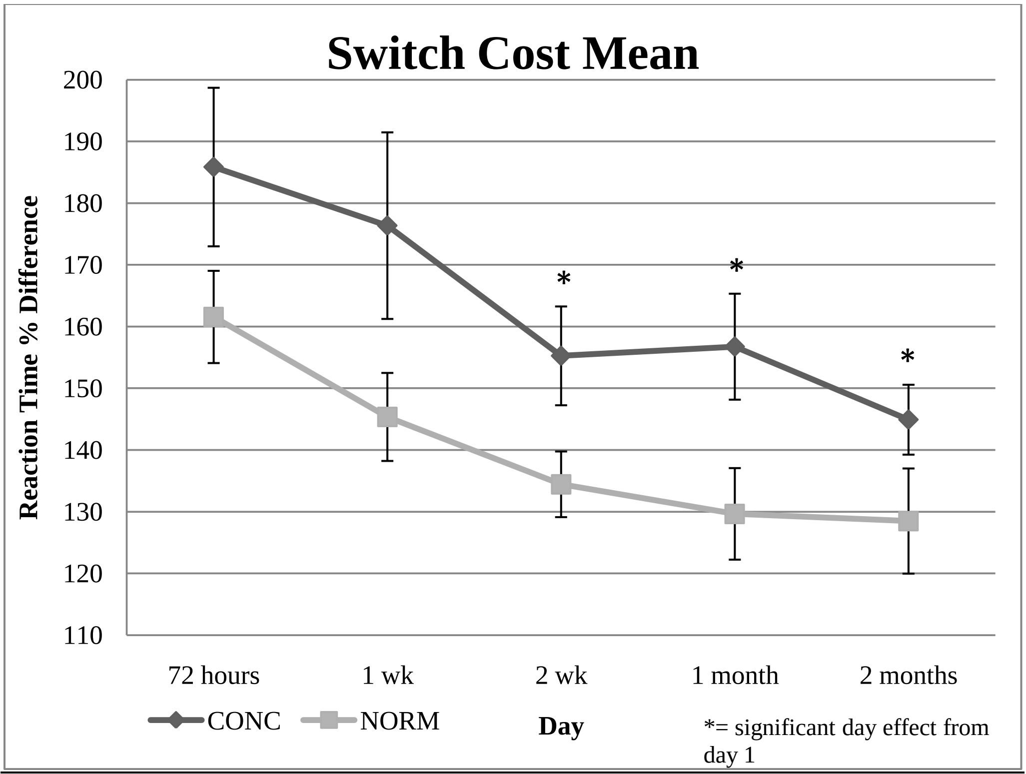


Figure 13: Concussion and control group means throughout each of the five testing days measured by the switch cost variable of the TS.

APPENDIX B

GROUP AND INDIVIDUAL COMPARISON TABLES

ImPACT Group Statistical Analysis Tables

Verbal Memory

Source	df	SS	MS	F
Between Subjects				
Group	1	315.864	315.864	.975
Error between	17	5507.757	323.986	
Within Subjects				
Day	4	815.625	203.906	2.557*
Day*Group	4	252.341	63.085	.791
Error Within	68	5422.459	79.742	
Total	**94**	**12314.05**	**986.583**	

**p<.05*

Table 4: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Verbal Memory Composite Score (ImPACT)

Day	Day	Mean Diff.	Std. Error	Sig.
1	5	-9.193	2.822	.046

**p<.002*

Table 5: Pairwise Comparison with Bonferroni Adjustment: Within Day Group Comparison of verbal memory

Visual Memory

Source	df	SS	MS	F
Between Subjects				
Group	1	1198.990	1198.990	3.056
Error between	17	6669.136	392.302	
Within Subjects				
Day	4	770.191	192.548	2.219
Day*Group	4	1504.717	376.179	4.335*
Error Within	68	5900.841	86.777	
Total	**94**	**16043.88**	**2246.796**	

**p<.05*

Table 6: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Visual Memory Composite Score (ImPACT)

Group	Day	Day	Mean Diff.	Std. Error	Sig.
CONC	1	4	-12.375	5.386	.035
CONC	1	5	-14.625	5.644	.019
CONC	2	4	-13.375	4.272	.006
CONC	2	5	-15.625	3.917	.001*
CONC	3	5	-10.125	4.738	.047

**p<.002*

Table 7: Pairwise Comparison with Bonferroni Adjustment: Day*Group Comparison of visual memory

Day	Group	Group	Mean Diff.	Std. Error	Sig.
1	CONC	NORM	-17.841	4.728	.002*
2	CONC	NORM	-14.568	5.723	.021

**p<.002*

Table 8: Pairwise Comparison with Bonferroni Adjustment Group*Day Comparison of visual memory

Visual Processing Speed

Source	df	SS	MS	F
Between Subjects				
Group	1	271.895	271.895	1.761
Error between	17	2625.072	154.416	
Within Subjects				
Day	4	500.150	125.037	13.709*
Day*Group	4	65.030	16.257	1.782
Error Within	68	620.198	9.121	
Total	**94**	**4082.345**	**576.726**	

**p<.05*

Table 9: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Visual Motor Speed Composite Score (ImPACT)

Day	Day	Mean Difference	Std. Error	Sig.
1	4	-5.176	1.111	.002*
1	5	-6.698	.776	.000*
2	5	-4.428	.942	.002*

**p<.002*

Table 10: Pairwise Comparison with Bonferroni Adjustment: within day group comparison of visual processing speed

Reaction Time

Source	df	SS	MS	F
Between Subjects				
Group	1	.000	.000	.009
Error between	17	.337	.020	
Within Subjects				
Day	4	.006	.002	.498
Day*Group	4	.010	.003	.791
Error Within	68	.216	.003	
Total	**94**	**0.569**	**0.028**	

**p<.05*

Table 11: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Reaction Time Composite Score (ImPACT)

Symptom Score

Source	**df**	**SS**	**MS**	**F**
Between Subjects				
Group	1	11389.780	11389.780	22.506*
Error between	17	8603.209	506.071	
Within Subjects				
Day	4	1805.361	451.340	3.043*
Day*Group	4	1718.666	429.666	2.897*
Error Within	68	10086.450	148.330	
Total	**94**	**33603.47**	**12925.19**	

**p<.05*

Table 12: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Symptom Score (ImPACT)

Group	**Group**	**Mean Diff.**	**Std. Error**	**Sig.**
CONC	NORM	22.177	4.675	.000*

**p<.002*

Table 13: Pairwise Comparison with Bonferroni Adjustment: Between Subject Comparison of symptom score

Day	**Day**	**Mean Diff.**	**Std. Error**	**Sig.**
1	2	6.733	1.821	.018
1	4	12.960	3.347	.012

**p<.002*

Table 14: Pairwise Comparison with Bonferroni Adjustment: Within Day Group Comparison of symptom score

Group	**Day**	**Day**	**Mean Diff.**	**Std. Error**	**Sig.**
CONC	1	2	11.375	2.772	.001*
CONC	1	3	15.125	5.093	.009
CONC	1	4	24.375	5.094	.000*
CONC	1	5	22.000	7.934	.013

**p<.002*

Table 15: Pairwise Comparison with Bonferroni Adjustment: Day*Group Comparison of symptom score

Day	**Group**	**Group**	**Mean Diff.**	**Std. Error**	**Sig.**
1	CONC	NORM	36.261	6.134	.000*
2	CONC	NORM	26.977	6.927	.001*
3	CONC	NORM	20.409	7.399	.013
4	CONC	NORM	13.432	5.451	.025

**p<.002*

Table 16: Pairwise Comparison with Bonferroni Adjustment: Group*Day Comparison of symptom score

ImPACT Individual Tables compared to Group Mean

Verbal Memory	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	76	-6.75	67	-19.91						
2			62	-24.91	93	9.08			88	0.08
3	68	-14.75	82	-4.91	99	15.08	77	-8.00	100	12.08
4	48	-34.75	49	-37.91	85	1.08	90	5.00	82	-5.92
5	99	16.25	99	12.09	87	3.08	97	12.00	99	11.08
7	67	-15.75	80	-6.91	74	-9.92	70	-15.00	83	-4.92
8	71	-11.75	84	-2.91	70	-13.92	64	-21.00	64	-23.92
9	77	-5.75	89	2.09	85	1.08	91	6.00	96	8.08
10	93	10.25	95	8.09	82	-1.92			68	-19.92
11	81	-1.75	69	-17.91	86	2.08	91	6.00	84	-3.92
12	68	-14.75			76	-7.92	78	-7.00	74	-13.92
13	85	2.25	85	-1.91	91	7.08	81	-4.00	90	2.08
NORM Mean	82.75		86.91		83.92		85.00		87.92	

Table 17: Individual Verbal Memory Composite scores compared to the control mean

Visual Memory	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	60	-20.00	58	-16.82						
2			67	-7.82	84	11.17			89	12.24
3	64	-16.00	69	-5.82	71	-1.83	60	-10.00	73	-3.76
4	59	-21.00	33	-41.82	70	-2.83	73	3.00	68	-8.76
5	57	-23.00	74	-0.82	76	3.17	86	16.00	86	9.24
7	74	-6.00	67	-7.82	53	-19.83	61	-9.00	79	2.24
8	69	-11.00	56	-18.82	61	-11.83	71	1.00	60	-16.76
9	68	-12.00	72	-2.82	72	-0.83	79	9.00	97	20.24
10	52	-28.00	63	-11.82	55	-17.83			74	-2.76
11	53	-27.00	58	-16.82	58	-14.83	74	4.00	80	3.24
12	64				94		78	8.00	75	-1.76
13	46	-34.00	53	-21.82	65	-7.83	85	15.00	64	-12.76
NORM Mean	80.00		74.82		72.83		70.00		76.76	

Table 18: Individual Visual Memory Composite scores compared to the control mean

Visual Processing Speed	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	29.33	-7.67	29.8	-11.17						
2			24.1	-16.87	29.85	-10.27			30.42	-12.22
3	39.95	2.95	44.6	3.63	47.88	7.76	48.28	6.84	47.55	4.91
4	28.45	-8.55	26.08	-14.89	42.13	2.01	41.72	0.28	41.28	-1.36
5	28.53	-8.47	35.28	-5.69	32.6	-7.52	38.88	-2.56	37.48	-5.16
7	35.25	-1.75	29.1	-11.87	35.38	-4.74	31.98	-9.46	39.78	-2.86
8	23.33	-13.67	24.55	-16.42	24.75	-15.37	26.2	-15.24	28.08	-14.56
9	39.22	2.22	42.38	1.41	50.75	10.63	45.03	3.59	50.5	7.86
10	33.78	-3.22	33.53	-7.44	34.42	-5.70			44.1	1.46
11	35.48	-1.52	37.9	-3.07	42.6	2.48	44.03	2.59	42.95	0.31
12	34.42	-2.58			38.58	-1.54	37.25	-4.19	38.97	-3.67
13	37.38	0.38	37.15	-3.82	33.75	-6.37	38.55	-2.89	41.38	-1.26
NORM Mean	37.00		40.97		40.12		41.44		42.64	

Table 19: Individual Visual Processing Speed Composite scores compared to the control mean

Symptom Score	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	38	32.67	0	-3.27						
2			44	40.73	1	-6.58			0	-6.67
3	25	19.67	1	-2.27	0	-7.58	0	-15.56	0	-6.67
4	52	46.67	46	42.73	11	3.42	25	9.44	23	16.33
5	40	34.67	32	28.73	42	34.42	3	-12.56	26	19.33
7	59	53.67	31	27.73	25	17.42	34	18.44	0	-6.67
8	61	55.67	55	51.73	33	25.42	26	10.44	25	18.33
9	9	3.67	12	8.73	3	-4.58	2	-13.56	0	-6.67
10	18	12.67	2	-1.27	1	-6.58			0	-6.67
11	61	55.67	61	57.73	59	51.42	4	-11.56	6	-0.67
12	28	22.67			3	-4.58	2	-13.56	2	-4.67
13	26	20.67	4	0.73	39	31.42	44	28.44	77	70.33
NORM Mean	5.33		3.27		7.58		15.56		6.67	

Table 20: Individual Symptom Scores compared to the control group mean

ANT Group Comparison Tables

Grand Median

Source	**df**	**SS**	**MS**	**F**
Between Subjects				
Group	1	8965.452	8965.452	.292
Error between	19	583475.262	30709.224	
Within Subjects				
Day	4	31445.314	7861.328	5.194*
Day*Group	4	28501.809	7125.452	4.708*
Error Within	76	115030.025	1513.553	
Total	**104**	**767418**	**56175**	

**p<.05*

Table 21: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Grand Median (Attentional Network Test)

Day	**Day**	**Mean Diff.**	**Std. Error**	**Sig.**
1	3	38.641	10.389	.015
1	4	51.611	11.344	.002*

**p<.002*

Table 22: Pairwise Comparison with Bonferroni Adjustment Within Day Comparison of Grand Median

Group	Day	Day	Mean Diff.	Std. Error	Sig.
CONC	1	2	39.773	14.977	.016
CONC	1	3	66.682	14.338	.000*
CONC	1	4	83.273	15.656	.000*
CONC	1	5	83.182	20.239	.001*
CONC	2	3	26.909	12.572	.046
CONC	2	4	43.500	14.819	.008

**p<.002*

Table 23: Pairwise Comparison with Bonferroni Adjustment Day by Group Comparison of Grand Median

Alerting Effect

Source	df	Sum of Squares	Mean Square	F
Between Subjects				
Group	1	9520.017	9520.017	4.676*
Error between	19	38679.116	2035.743	
Within Subjects				
Day	4	7531.001	1882.750	1.408
Day*Group	4	1928.649	482.162	0.361
Error Within	76	101607.670	1336.943	
Total	**104**	**159266.45**	**15257.6**	

**p<.05*

Table 24: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Alerting Effect (Attentional Network Test)

Orienting Effect

Source	df	SS	MS	F
Between Subjects				
Group	1	2519.068	2519.068	1.209
Error between	19	39604.689	2084.457	
Within Subjects				
Day	4	4947.388	1236.847	1.177
Day*Group	4	7024.245	1756.061	1.671
Error Within	76	79888.188	1051.160	
Total	**104**	**133984**	**8647.59**	

**p<.05*

Table 25: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Orienting Effect (Attentional Network Test)

Conflict Effect

Source	df	SS	MS	F
Between Subjects				
Group	1	37278.139	37278.139	3.419
Error between	19	207161.409	10903.232	
Within Subjects				
Day	1.265	164628.004	130095.449	14.639*
Day*Group	1.265	8976.242	7093.376	1.671
Error Within	24.043	213672.686	8886.972	
Total	**46.573**	**631716**	**194257**	

**p<.05*

Table 26: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Conflict Effect (Attentional Network Test)

Day	Day	Mean Diff.	Std. Error	Sig.
72 hrs	1 week	72.164	13.418	.000*
72 hrs	1 week	95.380	24.976	.012
72 hrs	1 month	95.448	22.741	.005
72 hrs	2 months	112.293	25.310	.003
1 week	2 months	16.914	4.491	.013

**p<.002*

Table 27: Pairwise Comparison with Bonferroni Adjustment Within Day Group Comparison on Conflict Effect

ANT Individual Comparison Tables

Alerting Effect	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	47	-14.33	70	21.05	70.5	-0.64	47	-8.88	24	-38.00
2	46	-15.33	7.5	-41.45	31	-40.14	94	38.12		
3	78	16.67	15.5	-33.45	63	-8.14	46	-9.88	47	-15.00
4	62.5	1.17	-24	-72.95	31	-40.14	16	-39.88	101.5	39.50
5	16	-45.33	31	-17.95	55.5	-15.64	48	-7.88	62	0.00
7	0.5	-60.83	23.5	-25.45	46.5	-24.64	70.5	14.62	39	-23.00
8	62.5	1.17	16.5	-32.45	62.5	-8.64	78	22.12	-23.5	-85.50
9	47	-14.33	23.5	-25.45	63	-8.14	31	-24.88	16	-46.00
10	79	17.67	1	-47.95	62	-9.14	62.5	6.62	40	-22.00
11	-70	-131.33	124.5	75.55	62.5	-8.64	78	22.12	47	-15.00
12	15	-46.33	70.5	21.55	94.5	23.36	23	-32.88	77	15.00
13	33.5	-27.83	-35.5	-84.45	31	-40.14	69.5	13.62	55.5	-6.50
NORM Mean	61.33		48.95		71.14		55.88		62.00	

Table 28: Individual Alerting Effect scores compared to the control mean

Orienting Effect	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	94	56.79	93.5	49.64	62	29.77	55.5	5.88	47	1.71
2	22.5	-14.71	31	-12.86	47	14.77	41	-8.63		
3	31	-6.21	54.5	10.64	54.5	22.27	102	51.88	15.5	-29.79
4	16	-21.21	46.5	2.64	32	-0.23	55	5.38	54	8.71
5	29.5	-7.71	0	-43.86	26.5	-5.73	93	43.38	109	63.71
7	31	-6.21	46	2.14	15.5	-16.73	47	-2.63	39.5	-5.79
8	-5	-42.21	47	3.14	-46	-78.23	15.5	-34.13	-39	-83.79
9	23.5	-13.71	16	-27.86	38	5.77	24.5	-25.13	1	-44.29
10	78	40.79	63	19.14	31	-1.23	47	-2.63	70.5	25.21
11	16	-21.21	-23.5	-67.36	16	-16.23	14.5	-35.13	46	0.71
12	-47	-84.21	93.5	49.64	47	14.77	78	28.38	47	1.71
13	157	119.79	46	2.14	85.5	53.27	23	-26.63	114	68.71
NORM Mean	37.21		43.86		32.23		49.63		45.29	

Table 29: Individual Orienting Effect scores compared to the control mean

Conflict Effect	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	250	106.71	141	42.64	125	56.18	140	55.58	94	26.25
2	78	-65.29	62	-35.86	31	-37.82	31.5	-52.92		
3	109.5	-33.79	46	-51.86	62	-6.82	62	-22.42	70	2.25
4	437	293.71	266	168.14	63	-5.82	93	8.58	31	-36.75
5	148.5	5.21	95	-2.86	125	56.18	77.5	-6.92	93	25.25
7	32	-111.29	39	-58.86	62	-6.82	62	-22.42	47	-20.75
8	397.5	254.21	249	151.14	188	119.18	157	72.58	118	49.75
9	86.5	-56.79	55.5	-42.36	93	24.18	78	-6.42	47	-20.75
10	203	59.71	125	27.14	178.5	109.68	140	55.58	117	49.25
11	141	-2.29	102	3.64	109	40.18	94	9.58	86.5	18.75
12	344	200.71	242	143.64	140	71.18	156	71.58	85.5	17.75
13	305	161.71	147	48.64	149	80.18	102	17.08	141	72.75
NORM Mean	143.29		97.86		68.82		84.42		67.75	

Table 30: Individual Conflict Effect scores compared to the control mean

TS Group Comparison Tables

Global Cost

Source	df	SS	MS	F
Between Subjects				
Group	1	2187.869	2187.869	1.793
Error between	20	24397.969	1219.898	
Within Subjects				
Day	4	1602.389	400.597	.345
Day*Group	4	297.262	74.315	.791
Error Within	80	17247.708	215.596	
Total	**109**	**45733.20**	**4098.275**	

**p<.05*

Table 31: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Global Cost (Task Switching Test)

Switch Cost

Source	df	SS	MS	F
Between Subjects				
Group	1	19166.826	19166.826	5.944*
Error between	20	64489.679	3224.484	
Within Subjects				
Day	2.564	18496.438	7213.655	10.856*
Day*Group	2.564	838.331	326.951	.492
Error Within	51.282	34075.668	664.480	
Total	**77.41**	**137067**	**30596.4**	

**p<.05*

Table 32: Two-Way, Mixed-Effects Analysis of Variance Summary Table for the Effects of Day and Group on Switch Cost (Task Switching Test)

Group	Group	Mean Diff.	Std. Error	Sig.
CONC	NORM	26.510	10.873	.024

**p<.002*

Table 33: Pairwise Comparison with Bonferroni Adjustment Between Subject Comparison

TS Individual Comparison Tables

Global Cost	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	131.8	1.09	153.4	20.35	125.4	-2.98	155.7	29.07	112.02	-10.46
2	124.76	-5.90	171.02	38.01	187.89	59.48	161.9	35.24	151.72	29.24
3	142.3	11.59	122.3	-10.75	117.9	-10.48	120.1	-6.55	127.66	5.18
4	121.5	-9.20	181.8	48.83	124.9	-3.49	123.5	-3.12	115.85	-6.63
5	121.5	-9.20	138.4	5.38	130.9	2.53	133.4	6.78	129.64	7.16
7	210.3	79.67	179	46.01	175.6	47.22	139.7	13.01	136.1	13.62
8	110.6	-20.08	105.4	-27.60	110.7	-17.70	116.4	-10.28	117.65	-4.83
9	107.7	-22.92	112.1	-20.93	117.9	-10.55	118	-8.68	116.16	-6.32
10	122.4	-8.28	115.7	-17.34	117.8	-10.63	122.1	-4.56	130.45	7.97
11	108.6	-22.07	91.62	-41.39	99.94	-28.47	108.9	-17.73	100.47	-22.01
12	139.6	8.92	122.7	-10.27	113.6	-14.82	112.1	-14.60	116.73	-5.75
13	127.1	-3.61	102.8	-30.26	118.3	-10.09	108.1	-18.58	115.28	-7.20
NORM Mean	130.66		133.01		128.41		126.65		122.48	

Table 34: Individual Global Cost scores compared to the control mean

Switch Cost	72 hours		1 week		2 weeks		1 month		2 months	
Subject	Score	Difference	Score	Difference	Score	Difference	Score	Difference	Score	Difference
1	233.2	71.67	164	18.64	179.9	45.50	147	17.38	143.97	15.49
2	167.04	5.48	216.06	70.71	177.48	43.05	209.7	80.05	162.49	34.01
3	215.9	54.31	205.8	60.46	177.4	42.99	163	33.37	134.29	5.81
4	159.9	-1.62	289.8	144.47	151.6	17.20	149.5	19.85	143.73	15.25
5	159.9	-1.62	147.7	2.30	146.2	11.78	139.4	9.73	134.82	6.34
7	290.6	129.02	240.5	95.14	210.7	76.24	215.1	85.49	186.04	57.56
8	154.3	-7.27	117.7	-27.61	132	-2.44	145.3	15.64	137.02	8.54
9	151.9	-9.63	118.3	-27.06	122	-12.48	126	-3.64	127.85	-0.63
10	148.5	-13.05	136.1	-9.22	143.7	9.30	148.5	18.81	149.57	21.09
11	162	0.46	163.8	18.42	125.5	-8.89	140.2	10.52	118.65	-9.83
12	163.7	2.17	142.2	-3.14	126.6	-7.88	121.4	-8.24	129.06	0.58
13	223	61.47	174.2	28.88	169.9	35.43	175.7	46.09	171.4	42.92
NORM Mean	161.56		145.35		134.43		129.65		128.48	

Table 35: Individual Switch Cost scores compared to the control mean

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