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Network Analysis of Concussion Symptoms in Collegiate Athletes

by

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**NETWORK ANALYSIS OF CONCUSSION SYMPTOMS
IN COLLEGIATE ATHLETES**

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I. Abstract

Concussions are a common brain injury, affecting millions of Americans each year, including military members and athletes. Following a concussion, athletes frequently experience a wide range of consequences including various changes in neurocognitive function and psychological symptoms. As a result, the recovery process varies widely from patient to patient with some patients recovering and returning to normal activity within 5 days while other patients experience symptoms for months. A patient's status, is determined using multiple variables measured through testing, including changes in neurocognitive function measured using the ImPACT test and changes in psychological symptoms measured using the Brief Symptom Inventory-18. This research develops a network model that examines the relationships among these variables over time so that we can analyze how these variables are interrelated, mutually reinforcing, and amplifying in an effort to better understand the concussion recovery process.

The NCAA-DOD Concussion Assessment, Research and Education (CARE) Consortium comprehensively collects concussion test results from college athletes and service academy cadets at 30 participating institutions. These tests include baseline assessments, assessments within 48 hours of an injury, and upon reaching asymptomatic. Using the CARE dataset, we develop a network that depicts the relationships between multiple variables at individuals timepoints and the evolution of each variable over time following an injury. The model demonstrates that there are significant interactions between psychological symptoms and neurocognitive functions as a result of a concussion that were not present prior to the concussion.

We further explore the relationships between variables and the effect of this relationship on groups of individuals by grouping individuals according to recovery time and performing trajectory analysis. By developing a better understanding of which variable relationships are most impactful for different subgroups of our population, we are able to demonstrate which underlying symptoms, emergent symptoms, and grouping of symptoms most affect concussion recovery times.

KEYWORDS: Concussions, Network, Concussion Healing Trajectory

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III. Introduction

After a concussion, patients can experience a wide range of symptoms, including psychiatric, cognitive, and physical symptoms. The recovery process can vary widely from patient to patient. Some individuals are cleared to return to normal activity within a few days after the initial injury, while others experience serious symptoms for months or longer. The NCAA-DOD Concussion Assessment, Research and Education (CARE) Consortium comprehensively collects concussion test results from thousands of athletes and service academy cadets, including baseline (pre-injury) assessments and re-testing at several points post injury. Using the CARE dataset, we develop a network model to analyze how concussion symptoms are interrelated, mutually reinforcing, and amplifying. We hypothesize that symptoms influence each other dynamically. Understanding this dynamic interaction might allow a better understanding of the concussion recovery process.

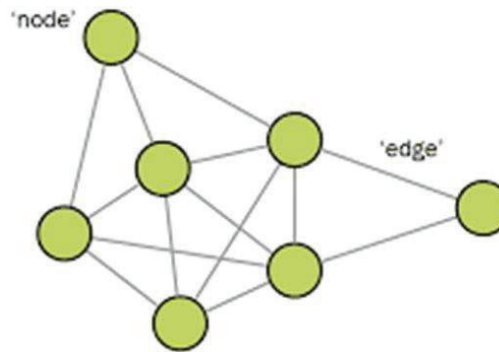
Temporal networks are a graphical method that can be used to illustrate and analyze the relationships that exist among various factors and how these relationships change over time. This method has previously been applied to various psychiatric conditions [1], [2] but to our knowledge, it has not been used to investigate concussions. This project extends the concepts of a temporal network by developing a weighted network that analyzes the relationship between concussion symptoms at multiple time points. Unlike traditional temporal networks, which generally depict graphical snapshots at many fixed time intervals, the network we develop represents three stages of a concussion: before injury, immediately following injury, and recovery from the injury. In addition, we add edges that span the time periods to allow for analysis of how individual symptoms evolve. Since the graph is weighted and the time intervals are non-homogenous, we adapt existing graphical and statistical measures to analyze the network.

These measures will illuminate the relationships between symptoms and how they evolve and influence one another. Additionally, to investigate different recovery paths, we will perform trajectory analysis by grouping athletes according to how long it took them to become asymptomatic. By constructing a weighted network for each of these groups, we can identify differences within the graphical structures. These differences will demonstrate which underlying symptoms, emergent symptoms, and groupings of symptoms most affect recovery times. This graph will allow for a novel analysis of concussion symptom architecture. While some analysis has been done on the interconnectedness of concussion symptoms for individual patients, to our knowledge, this has not been done on a large sample of patients nor considered most of the symptoms that appear in the standard concussion protocol assessments. Overall, this work is exploratory in nature and we hope to identify unique trends between variables over many healing timelines.

IV. Background

A concussion is a mild traumatic brain injury (mTBI) that can affect cognition, mood, and other brain activities. Symptoms can include headache, nausea, drowsiness, irritability, sadness, nervousness, mental foginess, poor memory, and others [2]. Concussions are very common in the United States. “Estimates suggest that up to 3.8 million sport and recreation-related concussions occur annually [3].” “86% of brain injuries in the military occurred during day-to-day activities unrelated to deployment [4].” Most people recover quickly, with serious symptoms resolving within 2 weeks [1], and are fully recovered by 3 months [5]. However, around 15-30% of people experience persistent symptoms. At the time of injury, it is hard to predict whether a patient will recover in a few weeks, will take longer to recover, or might never fully recover. Iverson posits that concussion symptoms “co-occur because they are strongly inter-related, activating, amplifying, and mutually reinforcing...” [2] and argues that investigating symptoms as a network might lead to new insights in care.

Figure 1: A simple network showing nodes and edges



A network graph, shown in Figure 1, is a visual representation of how units interact. The units are the nodes and the interactions are modeled by edges connecting the nodes. Nodes can represent people, computers, brain regions, etc. The edges might be weighted, indicating the strength of the connection, or unweighted, simply showing a connection exists. When nodes are connected by an edge, they are said to be adjacent. Many graphical measures, including paths between nodes and centrality, are based on adjacency. The relationships between nodes can change over time. For example, a person might recover from disease, friend groups may change, or new traffic patterns might develop in a city. “Networks in which the interactions among a set of elementary units change over time” [6] are called temporal networks.

Currently, functional brain networks are the primary tool used by scientists to study the effects of concussions through the use of networks. Such networks are built using data from imaging tools such as fMRI, EEG, or MEG. Physical regions of the brain are nodes and edges are “derived by correlating the brain’s activity over a period of time [7].” Virji-Babul and Hilderman found that for adolescents who recently experienced sports-related concussions, local networks of brain function significantly changed. They saw “altered activation in function networks related to memory and attention [8].” Messé and Caplain investigated changes in the functional brain networks of patients experiencing post-concussion syndrome. Post-concussion syndrome (PCS), while not well defined or understood, is “characterized by subjective complaints such as fatigue, headaches, sleep disturbance or poor concentration [9].” They found “PCS-specific alterations in the topological connectivity pattern following mild TBI and their evolution over time” [9] and that

there are changes to how different regions of the brain communicate with one another following a concussion.

Researchers in other fields have used networks to map the relationships between symptoms and psychological conditions. In these networks, nodes have represented symptoms and edges have connected nodes if a patient experiences both symptoms. The edges are typically unweighted and do not show the strength of the connection between symptoms. For example, Iverson views depression as an emergent phenomenon, issuing from the dynamic interactions among its constituent features, rather than conceptualizing depression as the underlying common cause of the symptoms that signal its presence. He calls this the hybrid disease model [10]. Boschloo and Borkulo constructed a network with emotional and behavioral problems, as assessed by the Youth Self-Report (YSR), as nodes. The YSR sorts problems into five domains: internalizing problems, externalizing problems, attention problems, thought problems, and social problems. Their network showed “problems within the same domain showed more and stronger connections than problems of different domains [1].” Due to these connections, Boschloo and Borkulo concluded that the way the YSR groups problems is reliable. They also state “it would be highly valuable if future studies could examine whether the network structure of emotional and behavioral problems changes over time [1].” The success in modeling psychological conditions with networks can be extended to concussions. Iverson also comments on the need to understand “inter-related and interacting between symptoms that are temporally sequenced and dynamic[2].” Our network allows researchers to investigate how networks, such as the one built by Boschloo and Borkulo, evolve.

Similar to Iverson, Rabinowitz and Fisher discuss the concept of hybrid models of disease. These are “conceptual models that describe symptoms arising from a common cause that are then maintained as a result of mutually reinforcing links between symptoms [11].” They believe concussions are a good fit for this hybrid model since the initial injury causes the symptoms, but resulting symptoms can mutually reinforce one another. They constructed networks of ten individual patients’ symptoms at multiple time points to investigate how each patient’s symptoms evolved over time. They found that “roughly half of the sample had more densely connected networks characterized by interconnected clusters of symptoms [11].” Of these symptoms, emotional, cognitive, and symptoms of hyperacusis (sensitivity to light, noise, etc), all appeared as clusters [11].

We create a network of concussion symptoms and investigate how they are related and interact with each other throughout the healing process. Our work adds to previous studies by considering psychological, cognitive, and executive processing symptoms throughout the entire healing process and a large sample group. Previous work either focused on functional brain networks, which do not address how symptoms are connected, or focused on psychological disorders which do not consider the full spectrum of concussion symptoms. Even Rabinowitz and Fisher’s work focused only on ten individual patients and relied on patient reported symptoms as opposed to symptoms measured in standard concussion assessments.

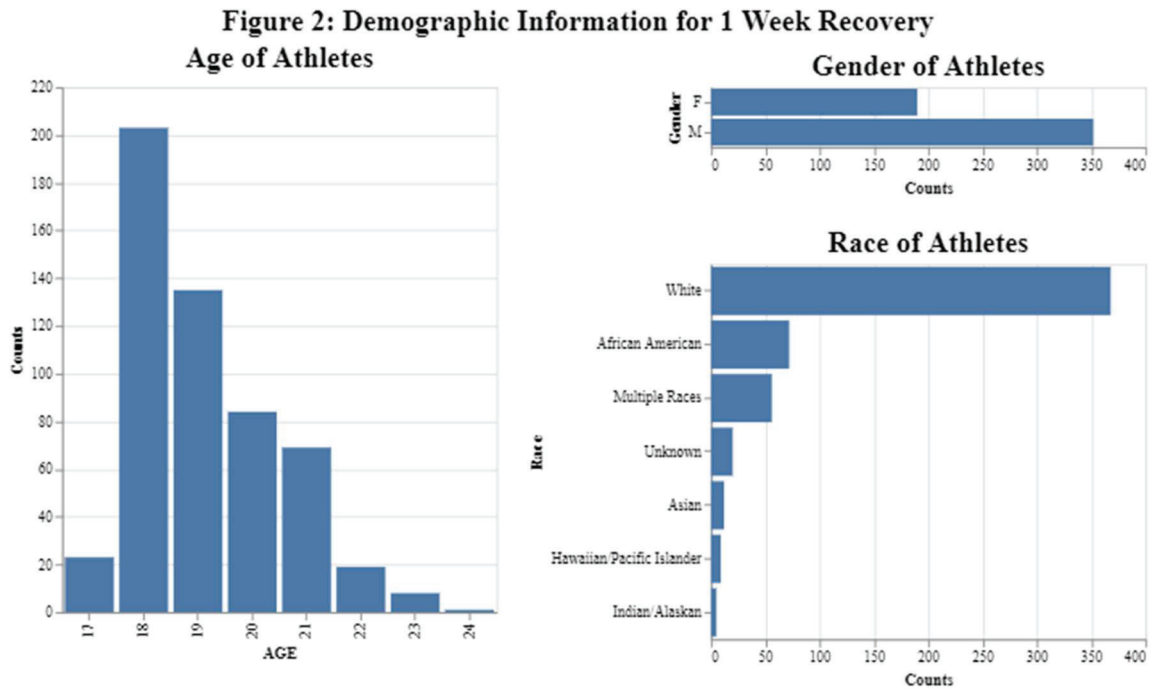
We will be using the Concussion Assessment, Research and Education (CARE) Consortium dataset. This is one of largest and most complete sources of data on concussion symptoms because it includes baseline testing as well as assessments at regular intervals post injury. Because we are investigating the entire healing process, we construct a network to map the relationships between symptoms throughout the concussion process and evaluate the change in a symptom over time. Additionally, to best capture the relationships between symptoms, we will weight the edges of the graph. Edge weights will be calculated differently depending on the type

of connection they are representing. For example, the connection between two symptoms at a single time point will be weighted differently than the connection between the same symptom across time points. Our network will therefore provide a novel way of viewing the concussion healing process and analyzing the changes in symptoms and their relationships over time.

V. Data Summary

The CARE Consortium collects information from various concussions assessments such as the Brief Symptom Inventory-18 (BSI-18) and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) tests to measure athletes' psychological and neurocognitive dispositions. We only consider athletes who had data recorded at three timepoints: baseline (pre-injury), 24-48 hours post injury, and asymptomatic. Additionally, if an athlete had multiple injuries recorded, we removed concussions after their first recorded injury to reduce confounding variables. Overall, we analyzed 1,382 collegiate varsity athletes and military service academy cadets.

The analysis shown below is for the 542 athletes in the first healing group which recovered within one week of their initial injury. Demographic information, including age, gender, and race, for these individuals is shown Figure 2.

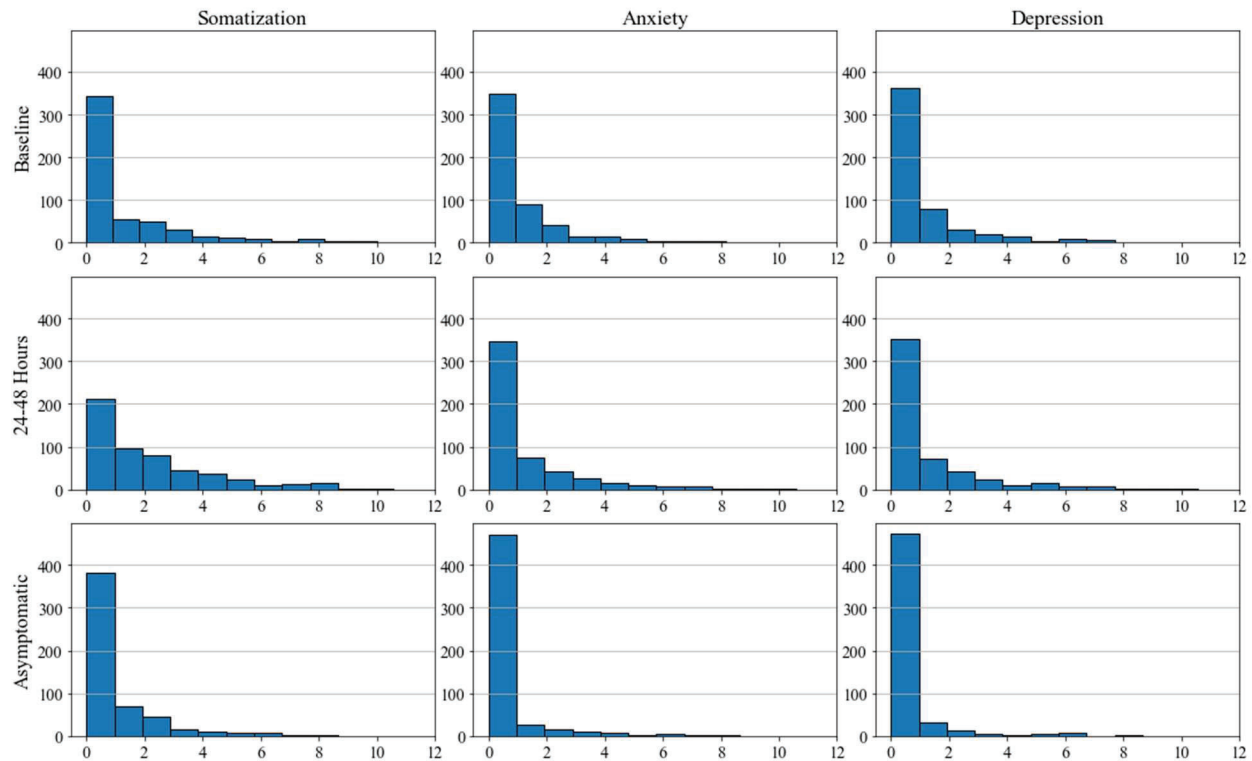


We considered three timepoints: baseline (pre-injury), 24-48 hours post injury, and asymptomatic. We utilize scores from the BSI-18 and ImPACT tests at each time point to depict the relationship between the types of symptoms and their evolution throughout the recovery process. All individuals are required to complete a baseline BSI-18 and ImPACT test upon arriving at their institution to participate in athletics. If an individual is suspected of having a concussion or diagnosed with a concussion, they take both tests in the 24 to 48 hours following their concussion. Upon test scores demonstrating that the subject is recovered, they are identified as asymptomatic. In our analysis, we only include athletes who have scores reported for both the BSI-18 and ImPACT tests at all three timepoints.

The BSI-18 asks patients to fill out an 18-question survey to measure their depressive, anxious, and somatic dispositions. We used a patient's somatic, anxiety, and depression scores from the dataset to understand the severity of these psychological symptoms. Somatization is the physical expression of psychological distress. For example, someone experiencing anxiety might also have headaches. Each symptom (somatization, anxiety, and depression) score is the sum of 6 question scores from the survey. Scores for each question range from 0 (not at all) to 4 (experienced nearly every day). Therefore, somatization, depression, and anxiety all range from 0 (no presence) to a maximum of 24 (severe distress). The average somatization, anxiety, and depression scores for the athletes in the dataset at baseline, 24-48 hours post injury, and asymptomatic are given in Table 1 with standard deviation provided in parentheses. Figure 3 shows the distributions of individual athlete's scores for each psychological symptom at each time point.

Table 1: Mean BSI-18 Scores for 1 Week Recovery			
	Somatization	Anxiety	Depression
Baseline	1.207 (2.25)	0.946 (2.01)	0.991 (2.37)
Post Injury	1.928 (2.48)	1.101 (2.41)	1.066 (2.20)
Asymptomatic	0.672 (1.41)	0.354 (1.21)	0.312 (1.08)

Figure 3: BSI-18 Scores for 1 Week Recovery



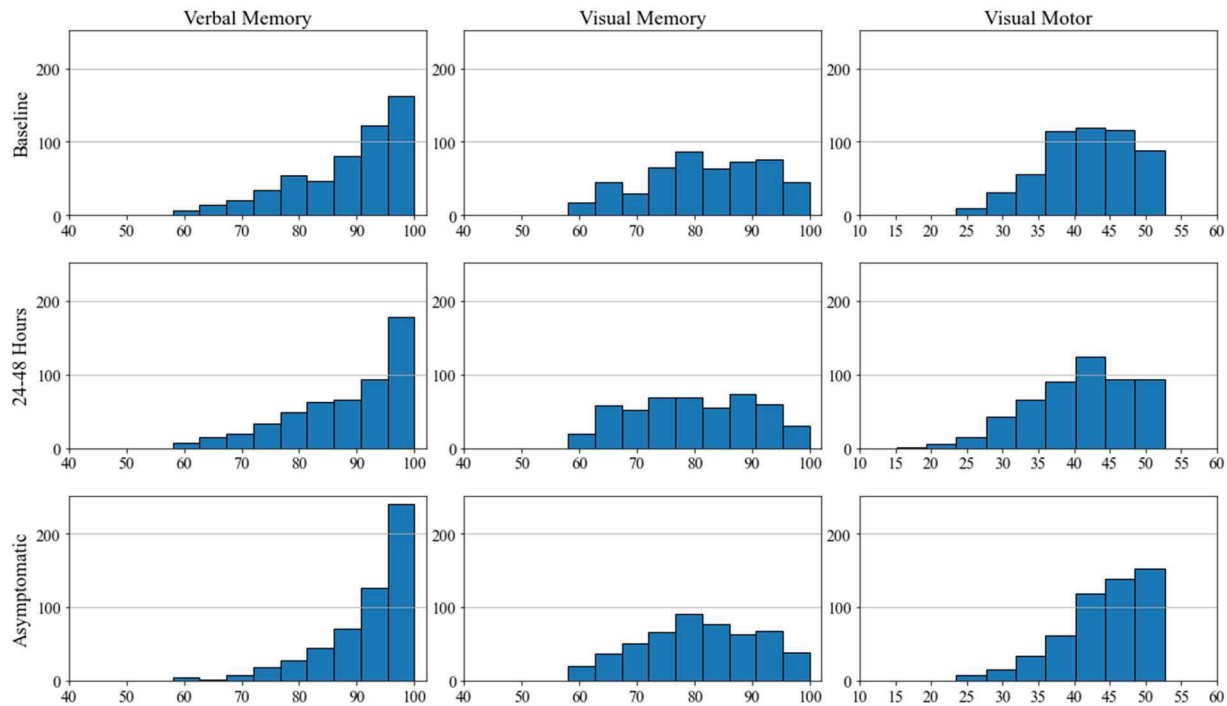
The ImpACT test is a computer-based assessment that takes an athlete approximately 45 minutes to complete. It measures executive processing and gives insight into any cognitive changes

throughout the concussion healing process. The test measures verbal memory, visual memory, visual motor speed, reaction time, and impulse control. The verbal memory, visual memory, visual motor speed, and reaction time scores are calculated using a combination of the number of correct answers on test modules while the impulse control score is calculated using the number of incorrect answers.

Verbal and visual memory scores both range from 0 to 100 and visual motor speed ranges from 0 to 60. For all three of these areas, higher scores are more desirable. Table 2 shows the average score for each of these neurocognitive domains at each timepoint. Standard deviations are shown in parentheses. Figure 4 shows the distribution of the population's scores for these symptoms.

Table 2: Mean Verbal Memory, Visual Memory, and Visual Motor Speed Scores for 1 Week Recovery			
	Verbal Memory	Visual Memory	Visual Motor
Baseline	88.434 (9.71)	79.415 (12.86)	41.918 (6.43)
Post Injury	87.162 (12.23)	76.339 (14.10)	41.176 (7.40)
Asymptomatic	91.862 (8.34)	78.847 (12.53)	44.424 (5.95)

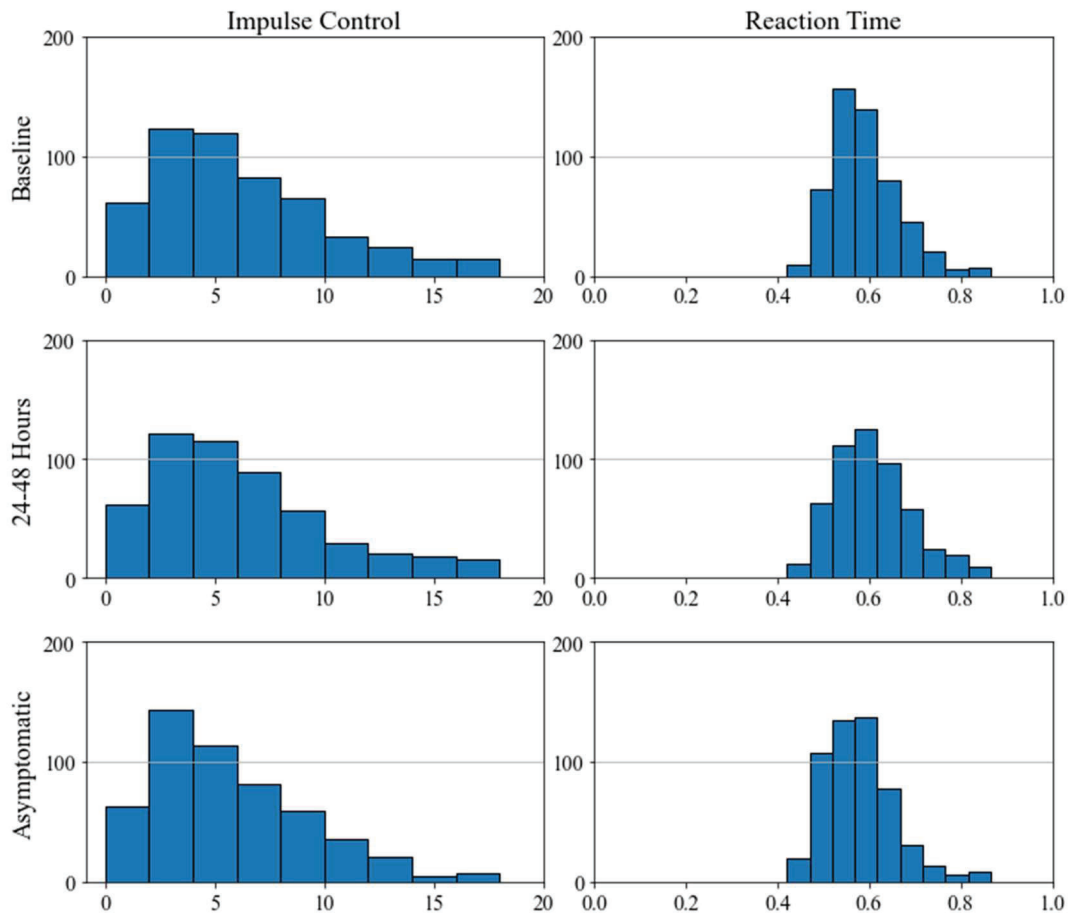
Figure 4: Verbal Memory, Visual Memory, and Visual Motor Speed Scores for 1 Week Recovery



Reaction time ranges from 0 to 1 and impulse control ranges from 0 to 30. For these areas, lower scores are more desirable. Table 3 shows the average score for reaction time and impulse control at each timepoint with standard deviation shown in parenthesis. Figure 5 shows the distribution of the population's score for these symptoms.

Table 3: Mean Impulse Control and Reaction Time Scores for 1 Week Recovery		
	Impulse Control	Reaction Time
Baseline	5.851 (4.29)	0.591 (0.09)
Post Injury	6.295 (5.90)	0.620 (0.13)
Asymptomatic	5.683 (5.03)	0.576 (0.08)

Figure 5: Impulse Control and Reaction Time Scores for 1 Week Recovery



Generally, we see scores at the asymptomatic timepoint improved compared to immediately after post-injury and baseline. This indicates that individuals are performing better on average upon reaching asymptomatic than they had previously performed at baseline. Any individual athlete might have taken many tests between the 24-48 hour post injury and asymptomatic time points to continually check if they were ready to return to play. Thus, improved scores at the asymptomatic timepoint can most likely be attributed to athletes becoming used to the BSI-18 and ImPACT tests and learning how to score better.

VI. Methods of Investigation

A. Graph Construction

As demonstrated in the data summary, athletes exhibit different psychological symptoms and neurocognitive changes to varying degrees throughout the recovery process. We will use a network to examine the relationships between these variables and how they change over time. We will construct a weighted graph:

$$G = (N, E, w),$$

where N , the set of nodes, is the Cartesian product $S \times T$ of the set of eight variables, S , and the set of three timepoints, T , where:

$$S = \{\text{Somatization, Anxiety, Depression, Impulse Control, Reaction Time, Verbal Memory, Visual Memory, Visual Motor Speed}\},$$

and:

$$T = \{\text{Baseline, 24 – 48 Hours Post Injury, Asymptomatic}\}.$$

That is, each element in the set of nodes, $i \in N$, will be a tuple of the form:

$$i = (s, t), s \in S, t \in T$$

The final graph will include all variables from the BSI-18 and the ImPACT tests at three timepoints respectively. Thus, in the final graph, $|S| = 8$ and $|T| = 3$ for a network with $|N| = 24$ nodes.

Each athlete, n , has a score associated with each node, i , that is denoted by v_i^n corresponding to the score of each athlete for variable s measured by its respective assessment given at time t . We define v_i as a vector of length 565 where the n^{th} entry is given by v_i^n . These values are used to calculate the edge weights between nodes in the network. For example, the values associated with somatization at baseline, $v_{(\text{Somatization}, 0)}$, would be of the form $\{2, 2, 6, 5, 4, \dots, 2\}$ where athlete 1 received a score of 2 for somatization at baseline, athlete 2 received a score of 2 for somatization at baseline, and athlete 3 received a score of 6 for somatization at baseline.

When constructing G , we use edge weights w_{ij} to capture (a) information about relationships between different variables at the same time point and (b) information about how variables change over time. Therefore, we define an edge, e_{ij} , between different modeling variables at the same timepoint (i.e. $i = (s, t)$ and $j = (s', t)$, $s \neq s'$) and between the same modeling variables at successive timepoints (i.e. $i = (s, t)$ and $j = (s, t + 1)$) to capture both relationships.

To understand the interactions between different variables, it is important to understand how the variables relate to each other and if they change in coordination. The correlation between two variables shows if a linear relationship is present and can be indicative of how variables relate to each other. Therefore, for edges connecting nodes $i = (s, t)$ and $j = (s', t)$, $s \neq s'$, we set $w_{ij} = \text{corr}(v_i, v_j)$, to measure the correlation between the athletes' scores of the two variables at the timepoint t .

To determine how an individual variable is affected by a concussion, we follow the evolution of that variable throughout the concussion recovery process. The information about the variable provided at all three timepoints can be used to determine the difference in the population

average scores between consecutive timepoints. These differences can indicate whether a given variable is worsening or improving. For edges connecting one variable between consecutive timepoints (nodes $i = (s, t)$ and $j = (s, t + 1)$), we set $w_{ij} = \frac{1}{N} \sum_{n=1}^N (v_{(s,t+1)}^n - v_{(s,t)}^n)$ to compare the average change between athletes' scores at consecutive timepoints. It is important to correctly interpret the sign of w_{ij} for edges connecting symptoms across time points. For example, for the edge connecting the average anxiety at baseline to the average anxiety 6 hours post injury, a negative value of w_{ij} would indicate improvement in the symptom because higher scores for anxiety on the BSI-18 indicate higher severity. However, for the edge connecting visual memory at baseline to visual memory 6 hours post injury, a negative value of w_{ij} would indicate a worsening in memory because higher scores on the ImPACT test for visual memory indicate better visual memory.

B. Graphical Measures

Our graph demonstrates the change in variables over time and the relationship between variables at each timepoint. The relationships between variables at each timepoint can be compared across timepoints to understand the change in variable interactions as a result of a concussion. We use statistical tests to determine if these changes are significant from baseline values.

We evaluate the impact of a concussion on an individual variable by performing a paired t -test. This test is used to determine whether the population average differs between two groups while exploiting the paired nature of our observations in order to improve statistical power and mitigate the effect of confounding factors. For each variable, s , we calculate the statistic $X_{(s,t)} = \frac{1}{N} \sum_{n=1}^N (v_{(s,t+1)}^n - v_{(s,t)}^n)$. Here, a small p -value indicates statistically significant evidence that the difference in the true population averages between two time periods is non-zero (i.e. that the true population average has changes from the previous time period).

To further investigate the effect size of a concussion on any given variable we also computed and reported Cohen's d statistic. Cohen's d statistic measures how many standard deviations lay between two sample means. In other words, it provides information on the effect size of the injury after 24-48 hours and on subsequent healing time. This quantifies the extent to which the null hypothesis, that a variable's prevalence does not change following the injury, is false.

We investigate changes in relationships between two variables by taking the correlation between the two variables at a fixed time point and determining if the change in that correlation across time is significant. For example, consider the correlation between anxiety and depression. We want to address the question: "does the correlation between anxiety and depression change significantly from baseline to 24-48 hours post injury?" To express this mathematically, consider the nodes $i = (s, t)$ and $j = (s', t)$, who have correlation $\text{corr}(v_{(s,t)}, v_{(s',t)})$. The difference in correlations at consecutive timepoints is given by

$$\text{corr}(v_{(s,t+1)}, v_{(s',t+1)}) - \text{corr}(v_{(s,t)}, v_{(s',t)})$$

However, since correlation coefficients are not normally distributed, we cannot apply traditional comparison methods. Instead, we follow Steiger's method for non-overlapping, dependent variables. Our cohort is considered non-overlapping because we considering different, discrete periods of time (t and $t + 1$), and dependent because the population remains the same

between these timepoints. The resulting p -value (from Steiger's method) will determine if the change in the correlation is significant [12].

Additionally, we investigate centrality of the network at individual time points. A measure of centrality provides insight into the single most influential variable at each time point, and we use the sum of the absolute value of the correlations for each node to calculate it. Mathematically we use the equation:

$$c_{(s,t)} = \sum_{s \in S, s' \neq s} |w_{(s,t),(s',t)}|$$

This summation returns a value corresponding to the connectedness of a symptom with all other variables. The variable with the highest centrality measure at time t can be determined using the equation:

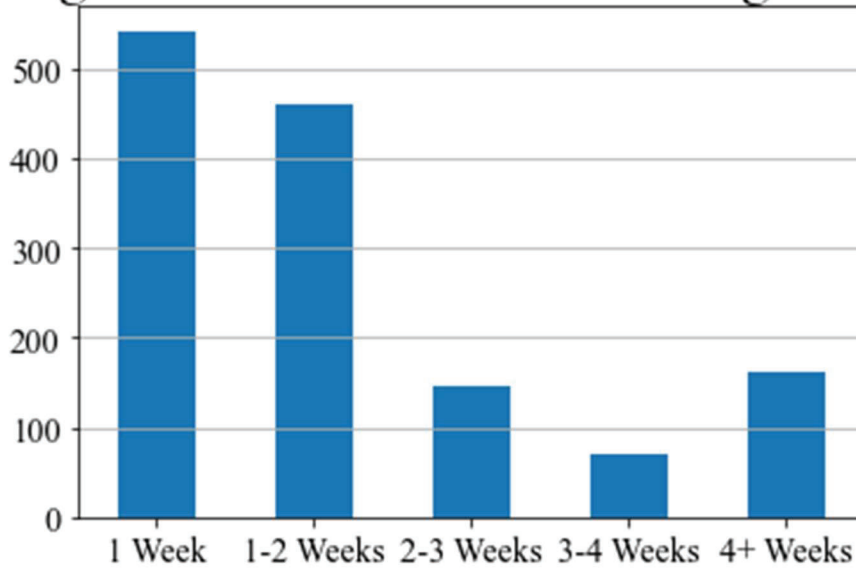
$$C_t = \operatorname{argmax}_{s \in S} \{c_{(s,t)}\}$$

This returns the variable (ie anxiety, reaction time, visual memory etc.) that corresponds to the highest centrality measure in each time point.

C. Trajectory Analysis

The current methodology provides a population level analysis of athletes that recover within one week of their injury. However, some athletes are ready to return to play much sooner than others. The interrelationship between variables for athletes that follow a different healing trajectory might be very different from those athletes that recover in one week. We group athletes based on the duration of their symptoms and create a network for each group to determine differences in variable changes and variable relationships for athletes in each group. Such information might provide more insight into the concussion healing process for both physicians providing treatment and injured athletes.

Figure 6: Counts in Each Healing Group



VII. Results

A. Network Graph

Figure 7 shows the baseline network for the 565 athletes that reached asymptomatic within one week. BSI-18 psychologic symptoms are shown in red and ImPACT neurocognitive domains are shown in blue. This graph only shows edges of the form e_{ij} where $i = (s, t)$ and $j = (s', t)$, $s \neq s'$ at baseline. Edges connecting two BSI-18 variables are red, edges connecting two ImPACT variables are blue, and edges connecting variables from different tests are shown in purple. The width of the edge indicates the strength of the correlation between the two symptoms: the thicker the edge, the stronger the correlation.

Figure 7

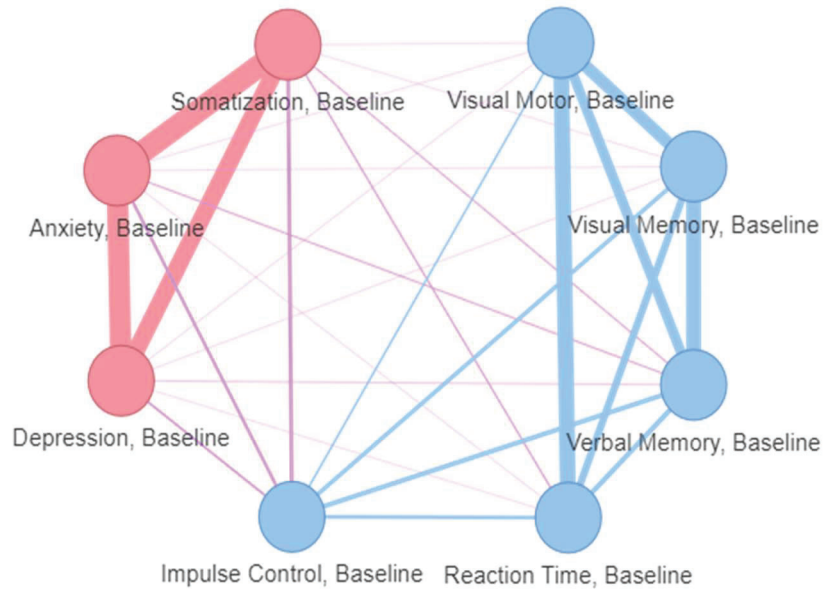
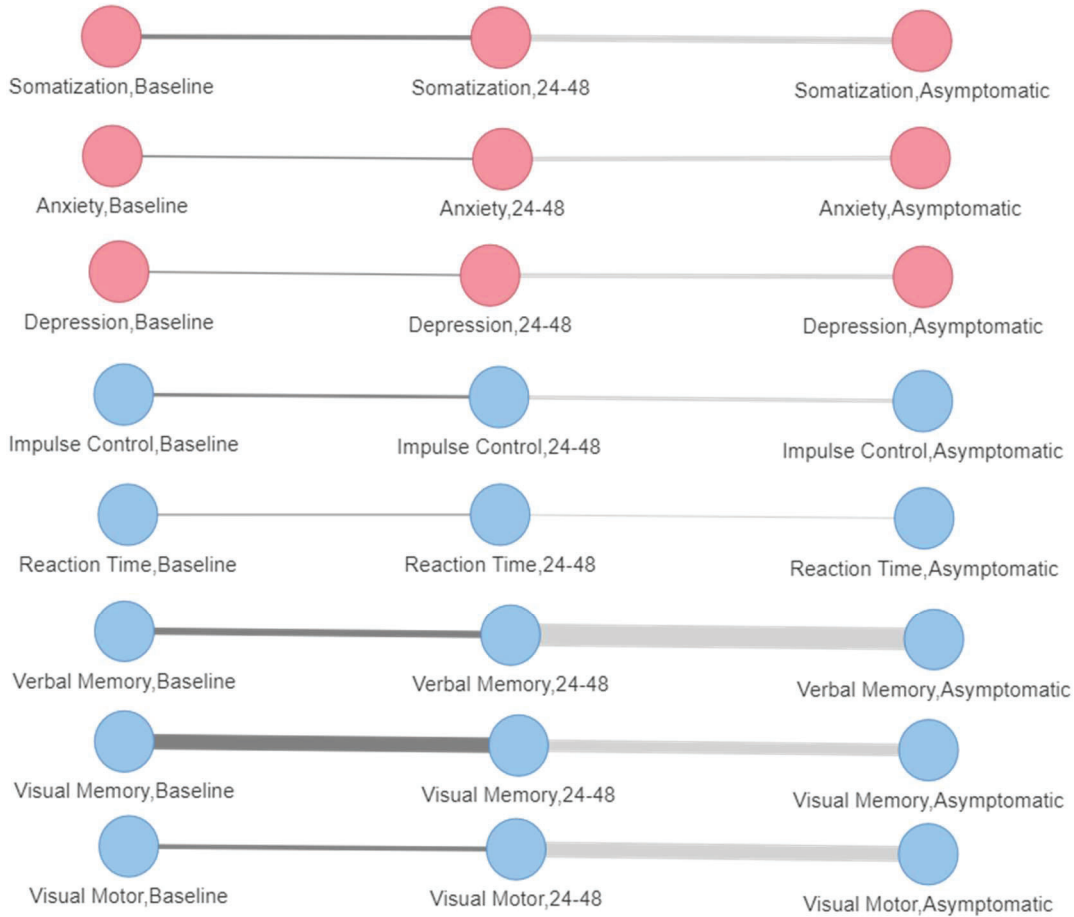


Figure 8 shows all three timepoints and edges of the form e_{ij} where $i = (s, t)$ and $j = (s, t + 1)$. The purpose of these edges is to show a variable's evolution over time. If an edge is dark grey, this indicates worsening from timepoint 1 to timepoint 2. If the edge is light grey, this indicates improvement from timepoint 1 to timepoint 2. The thicker the edge, the larger the change between the two timepoints regardless of whether the variable is worsening or improving.

Figure 8



The full graph with all three timepoints and all edges is shown in Figure 9. Table 4 contains the statistics for the changes in variables over time and Table 5 shows the correlations between variables at each timepoint. In each cell in Table 5 there are three numbers listed in the order: correlation between the variables at baseline, correlation at 24-48 hours post injury, and correlation between the variables at asymptomatic. What stands out in Figure 9 is the between group, purple edges, are much thicker at the 24-48 hour post injury time point than either the baseline or asymptomatic timepoints. The mechanisms underlying these relationships remain unknown, however, our findings provide support for our hypothesis: subjects experienced increased interactions between symptoms immediately following a concussion.

24-28 Hours Post Injury

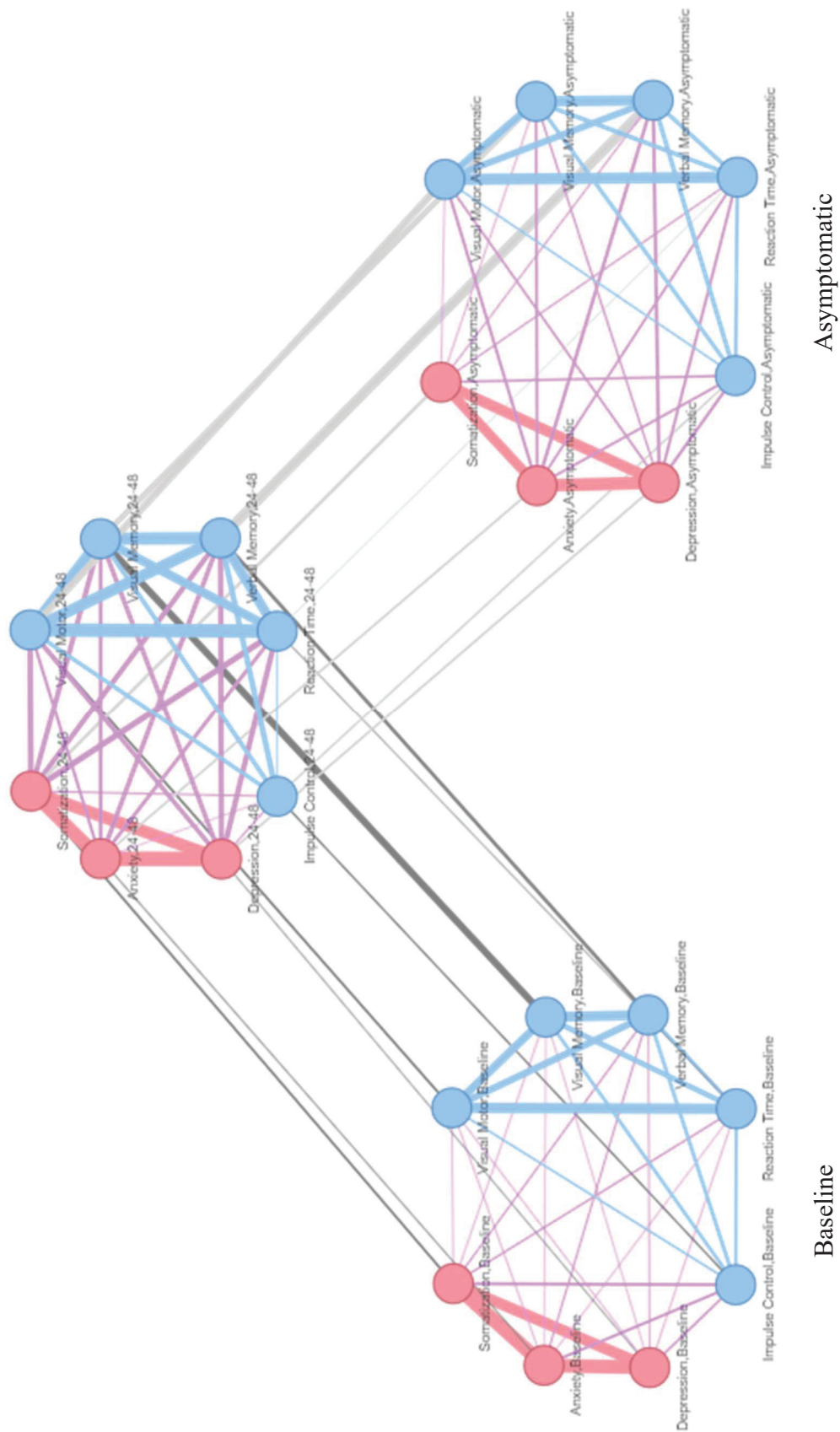


Figure 9

B. Statistics and Analysis for 1 Week Recovery

Table 4: Significant Changes in Variables contains information about the average change between athletes' scores at consecutive timepoints as well as the standard deviation of these differences (shown in parentheses). An asterisk indicates that the change is significant according to the paired *t*-test. Cohen's *d* is also listed. We apply a Bonferroni correction to all hypothesis tests to guarantee a family-wise significance level of 0.05. Although the Bonferroni correction is considered over-conservative, other correction methods had similar results.

Table 4: Significant Changes in Variables for 1 Week Recovery				
	Baseline to Post Injury		Post Injury to Asymptomatic	
	Mean (SD)	Effect Size	Mean (SD)	Effect Size
Somatization	0.721* (2.896)	-0.305	-1.256* (2.219)	0.624
Anxiety	0.155 (2.734)	-0.070	-0.747* (2.003)	0.392
Depression	0.076 (2.826)	-0.033	-0.755* (1.893)	0.436
Impulse Control	0.445 (5.609)	-0.086	-0.613 (5.547)	0.112
Reaction Time	0.029* (0.131)	-0.260	-0.044* (0.125)	0.398
Verbal Memory	-1.271* (12.268)	0.115	4.699* (10.974)	-0.449
Visual Memory	-3.076* (13.58)	0.228	2.507* (13.325)	-0.188
Visual Motor	-0.742* (6.152)	0.107	3.248* (5.442)	-0.483

Table 5: Correlations Between Variables for 1 Week Correlations								
	Somatization	Anxiety	Depression	Impulse Control	Reaction Time	Verbal Memory	Visual Memory	Visual Motor
Somatization	1.000	0.660 0.625 0.454	0.520 0.571 0.506	-0.115 0.037 0.073	0.046 0.255 -0.036	0.039 -0.206 -0.028	-0.009 -0.202 -0.014	-0.008 -0.226 0.008
Anxiety	—	1.000	0.645 0.699 0.599	-0.091 -0.002 0.075	0.005 0.136 0.071	0.039 -0.181 -0.121	0.000 -0.134 -0.086	-0.012 -0.100 -0.099
Depression	—	—	1.000	-0.063 0.033 0.101	-0.010 0.217 0.089	0.024 -0.212 -0.120	0.007 -0.179 -0.051	0.009 -0.174 -0.066
Impulse Control	—	—	—	1.000	-0.101 -0.028 -0.125	-0.135 -0.227 -0.174	-0.121 -0.175 -0.143	-0.059 -0.157 -0.051
Reaction Time	—	—	—	—	1.000	-0.144 -0.442 -0.156	-0.220 -0.401 -0.172	-0.477 -0.633 -0.514
Verbal Memory	—	—	—	—	—	1.000	0.453 0.568 0.474	0.303 0.522 0.286
Visual Memory	—	—	—	—	—	—	1.000	0.363 0.486 0.324

Table 5 provides the correlation of two pairs of symptoms at every time point. We compare the correlations between timepoints to identify which pairs of variables have a significant changes in correlation using Steiger's method. Table 6 shows the p -values for all pairs. Pairs which experience significant change at a family-wise significant level of 0.05 are denoted by an asterisk.

Table 6: Table Significant Changes in Correlations for 1 Week Recovery		
	Baseline to Post Injury	Post Injury to Asymptomatic
Somatization/Anxiety	0.3048	0.0000*
Somatization/Depression	0.2219	0.0894
Somatization/Impulse Control	0.0084	0.4963
Somatization/Reaction Time	0.0002*	0.0000*
Somatization/Verbal Memory	0.0000*	0.0008*
Somatization/Visual Memory	0.0007*	0.0004*
Somatization/Visual Motor	0.0001*	0.0000*
Anxiety/Depression	0.1037	0.0013*
Anxiety/Impulse Control	0.1226	0.136
Anxiety/Reaction Time	0.0241	0.2222
Anxiety/Verbal Memory	0.0001*	0.2417
Anxiety/Visual Memory	0.0191	0.3519
Anxiety/Visual Motor	0.1165	0.9918
Depression/Impulse Control	0.0962	0.0000
Depression/Reaction Time	0.0001*	0.0155
Depression/Verbal Memory	0.0000*	0.0751
Depression/Visual Memory	0.0011*	0.0135
Depression/Visual Motor	0.001*	0.0265
Impulse Control/Reaction Time	0.1916	0.0729
Impulse Control/Verbal Memory	0.0881	0.2967
Impulse Control/Visual Memory	0.3095	0.5378
Impulse Control/Visual Motor	0.0572	0.0314
Reaction Time/Verbal Memory	0.0000*	0.0000*
Reaction Time/Visual Memory	0.0003*	0.0000*
Reaction Time/Visual Motor	0.0000*	0.0008*
Verbal Memory/Visual Memory	0.0055	0.0189
Verbal Memory/Visual Motor	0.0000*	0.0000*
Visual Memory/Visual Motor	0.0041	0.0001*

Figure 9 and Table 4 both show that somatization is strongly correlated to reaction time, verbal and visual memory, and visual motor speed at the 24-48 hours post injury and asymptomatic timepoints. Additionally, as seen in Table 6, 6 of the 7 pairs of variable correlations including somatization change significantly from baseline to post injury and 5 of the 7 pairs of variable correlations including somatization change significantly from post injury to asymptomatic. This suggests that somatization may play an important role in concussion recovery and might provide an avenue for treatment in athletes experiencing prolonged recovery. Another interesting point, particularly for those athletes that recover in 1 week, is that all variables significantly improve from 24-48 hours post injury to asymptomatic timepoints (shown in Table 4). While we expect these variables to improve—it is necessary for them to do so for the athletes to reach asymptomatic status—the extent of the improvement of the variable further demonstrates their interconnected nature since it appears unlikely an athlete will reach asymptomatic status with only a few variables significantly improved.

Additionally, verbal memory, visual memory, and visual motor speed exhibit significant changes across time as well as significant changes in correlation with other variables across time. From baseline to 24-48 hours post injury, verbal memory and visual memory have significant changes in correlation eight times (out of 13 total significant changes) and visual motor speed has a significant change in correlation 4 times. These findings indicate that neurocognitive domains are critical in the healing process and are highly connected and interrelated to other variables in the concussion.

Table 7: Centrality of Variables for 1 Week Recovery

	Baseline	Post Injury	Asymptomatic
Somatization	1.398	2.121	1.118
Anxiety	1.454	1.876	1.506
Depression	1.278	2.086	1.532
Impulse Control	0.684	0.659	0.741
Reaction Time	1.003	2.111	1.163
Verbal Memory	1.137	2.358	1.359
Visual Memory	1.175	2.144	1.265
Visual Motor	1.231	2.297	1.349

Table 7 shows the centrality calculations for the athletes that recovered within 1 week of their injury. The most central variable in each timepoint is bolded. Interestingly, anxiety is the most central symptom twice, at baseline and asymptomatic, despite the fact that Table 6 shows that variable pair correlations containing anxiety do not typically change significantly between consecutive timepoints. Table 7 also shows that verbal memory is the most central variable at the 24-48 hours post injury timepoint. Table 6 shows that verbal memory changes significantly in 5 of the 13 pairs of variables with significantly different correlations between baseline and 24-48 hours post injury. These results suggest that verbal memory is highly connected to other variables and might suggest that it is critical in treatment following a concussion.

C. Trajectory Analysis

Figure 10 shows the full network for all 5 healing groups constructed in the same manner as presented in Section VIII Part A. For readability the node labels have been removed. However, the nodes follow the same order in every healing group and timepoints as provided in the legend in the upper left-hand corner of the figure.

Legend:

- 1: Somatization
- 2: Anxiety
- 3: Depression
- 4: Impulse Control
- 5: Reaction Time
- 6: Verbal Memory
- 7: Visual Memory
- 8: Visual Motor

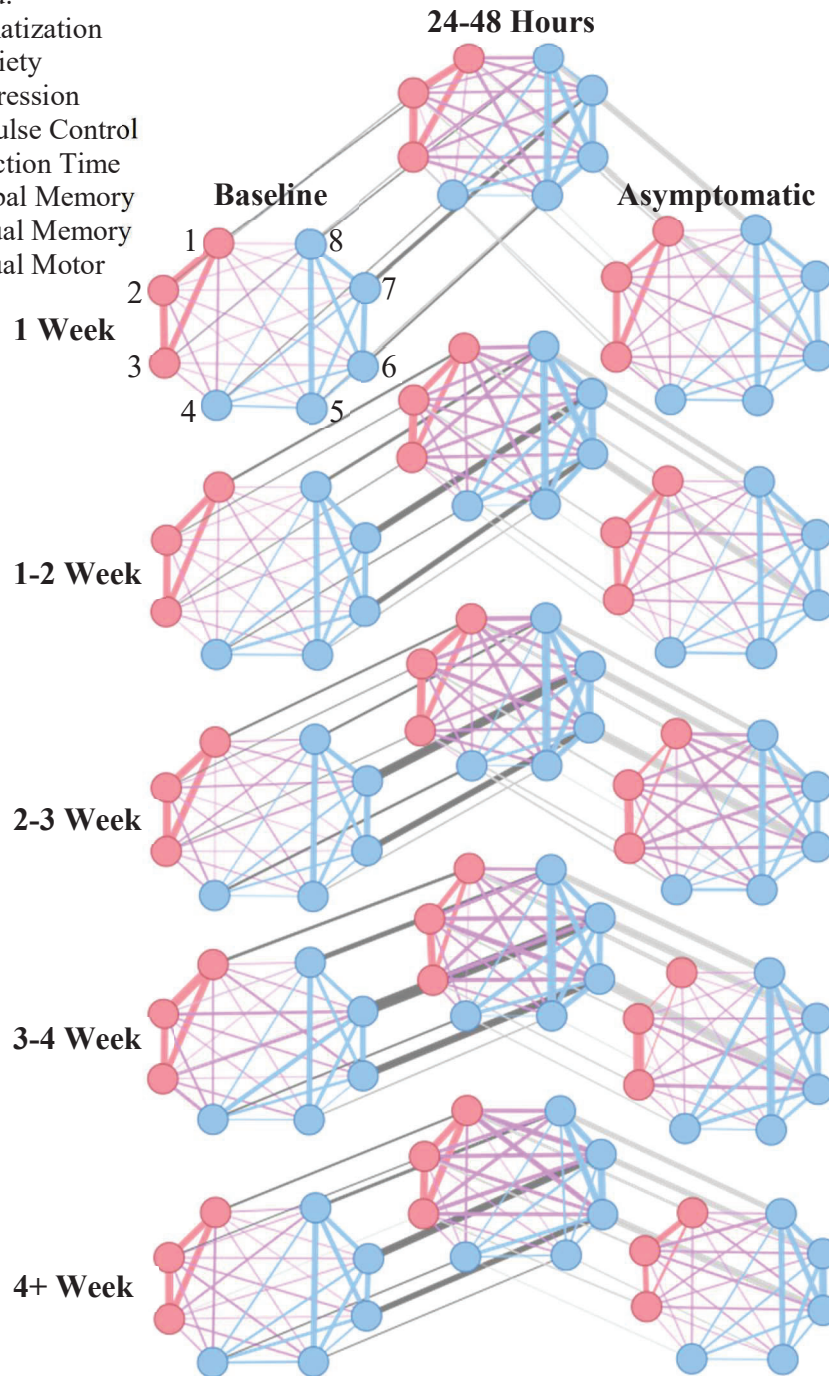


Figure 10

The statistics and measures, shown in Tables 4, 5, 6, and 7, were calculated for each healing group shown in Figure 10. Results for additional healing groups are shown in Appendences A, B, C, and D respectively.

Table 8: Summary of Results in Appendix A		
	Baseline to Post Injury	Post Injury to Asymptomatic
1 Week	5 of 8	7 of 8
1-2 Weeks	6 of 8	1 of 8
2-3 Weeks	5 of 8	1 of 8
3-4 Weeks	5 of 8	1 of 8
4+ Week	4 of 8	1 of 8

Table 8 shows how many of the 8-total variables changed significantly between each of the three timepoints for each healing group. For all healing groups, from baseline to 24-48 hours post injury, at least half of the variables change significantly. However, all healing groups except week 1, show only one variable, somatization, change significantly from 24-48 hours post injury. By nature, the timing of the tests at the asymptomatic status is increasing between healing groups and while the underlying mechanisms causing this change are unknown, at surface level, this provides more support for the hypothesis that targeting treatment of somatization might reduce the effects of other variables and allow for faster healing.

Table 9: Summary of Results in Appendix B		
	Baseline to Post Injury	Post Injury to Asymptomatic
1 Week	13 of 28	11 of 28
1-2 Weeks	15 of 28	7 of 28
2-3 Weeks	1 of 28	2 of 28
3-4 Weeks	3 of 28	2 of 28
4+ Weeks	8 of 28	3 of 28

Table 9, a summary of the results in Appendix B, gives the number of pairs of variables that demonstrate significant changes in correlation across timepoints. This highlights another interesting phenomenon: as healing times extend, there are fewer changes in the correlations between variables across timepoints. Looking first at the baseline to 24-48 hour post injury timepoints, there is a significant drop in the number of pairs of variables that exhibit significant changes in correlation — from 15 at 1-2 weeks to 1 at 2-3 weeks — over this period of time. The 24-48 hours post injury to asymptomatic time period follows a roughly similar trend. The number of pairs of variables that show significant changes in correlation over time decreases from a high of 11 pairs in the first healing group to 2 pairs in the 2-3 and 3-4 week healing groups. We hypothesize that changes in the correlations for pairs of variables are still occurring for all healing groups but might be occurring more than 48 hours following the initial injury. For the 4+ week healing group, since these are typically the most severe concussions, it is possible that all of the variables interact more closely than what is observed for other healing groups, which would

explain why more pairs of variables demonstrate significant changes in correlation than many of the prior healing groups.

Table 10: Summary of Results in Appendix C

	Baseline	Post Injury	Asymptomatic
1 Week	Anxiety	Verbal Memory	Anxiety
1-2 Weeks	Visual Motor	Visual Motor	Visual Memory
2-3 Weeks	Depression	Visual Motor	Visual Memory
3-4 Weeks	Visual Memory	Verbal Memory	Verbal Memory
4+ Weeks	Anxiety	Verbal Memory	Visual Motor

Table 10 gives the most central symptom for each healing group at each timepoint. At the baseline timepoint the majority of these variables are psychological symptoms but for the 24-48 hours post injury and asymptomatic timepoints the majority of these variables are neurocognitive domains. This evidence indicates that the neurocognitive domains are the most interconnected and might need to be more targeted in treatment.

VIII. Conclusion

This work has three key objectives:

1. Build a network using the CARE dataset to visualize the relationship between concussion symptoms over multiple time points.
2. Use graphical measures to understand the changes in symptoms and interactions of symptoms over time.
3. Perform trajectory analysis to develop insights into which symptom interactions might indicate delays in recovery.

We have developed the methodology to construct a network graph and we have created the graph for patients from the CARE dataset who were asymptomatic in one week. We analyzed the graph using graphical measures that compare the evolution of each symptom over time and the evolution of symptom relationships over time. We extended this work to construct networks and analyze the networks for subject based on their healing trajectory. While exploratory in nature, this methodology has provided unique insight into the complex interactions between concussion symptoms during the healing process.

The present work warrants considering several limitations. First, for simplicity, we did not control for gender or sport. For example, it is possible that football players experience different concussion recovery timelines and variable interactions than swimmers due to the nature of contact experience in the sport. Additionally, we did not consider the affect of any prior existing mental health condition in our samples. For example, there might be athletes diagnosed with clinical depression who experience a concussion. This would skew the results obtained in each healing group. In future work, we hope to address these limitations.

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X. Appendix A

Significant Changes in Variables for 1-2 Week Recovery				
	Baseline to Post Injury		24-48h to Post Injury	
	Mean (SD)	Effect Size	Mean (SD)	Effect Size
Somatization	1.681* (3.411)	-0.641	-2.219* (2.884)	0.940
Anxiety	0.412* (2.958)	-0.179	-1.111 (2.284)	0.578
Depression	0.354 (2.891)	-0.149	-1.009 (2.351)	0.507
Impulse Control	0.599 (5.137)	-0.126	-0.345 (6.449)	0.062
Reaction Time	0.055* (0.140)	-0.482	-0.066 (0.135)	0.569
Verbal Memory	-4.338* (13.249)	0.369	6.614 (12.507)	-0.569
Visual Memory	-5.662* (13.757)	0.403	3.746 (13.908)	-0.272
Visual Motor	-2.274* (6.903)	0.306	4.259 (6.551)	-0.576

Significant Changes in Variables for 2-3 Week Recovery				
	Baseline to Post Injury		24-48h to Post Injury	
	Mean (SD)	Effect Size	Mean (SD)	Effect Size
Somatization	1.541* (3.533)	-0.534	-2.788* (2.809)	1.314
Anxiety	0.404 (3.308)	-0.148	-1.390 (2.509)	0.647
Depression	0.322 (3.094)	-0.125	-1.219 (2.342)	0.594
Impulse Control	1.795* (6.298)	-0.325	-1.288 (5.776)	0.228
Reaction Time	0.032 (0.154)	-0.266	-0.050 (0.123)	0.413
Verbal Memory	-5.363* (15.416)	0.431	8.459 (14.362)	-0.708
Visual Memory	-7.863* (13.747)	0.549	6.500 (15.726)	-0.446
Visual Motor	-1.653* (8.123)	0.224	4.033 (6.941)	-0.532

Significant Changes in Variables for 3-4 Week Recovery				
	Baseline to Post Injury		24-48h to Post Injury	
	Mean (SD)	Effect Size	Mean (SD)	Effect Size
Somatization	2.197* (4.221)	-0.642	-3.606* (3.705)	1.307
Anxiety	-0.056 (4.529)	0.018	-1.225 (2.537)	0.571
Depression	0.000 (3.571)	0.000	-0.944 (2.484)	0.407
Impulse Control	1.183 (4.072)	-0.252	-0.718 (4.754)	0.142
Reaction Time	0.085* (0.180)	-0.594	-0.092 (0.157)	0.639
Verbal Memory	-6.352* (12.457)	0.518	9.423 (12.971)	-0.801
Visual Memory	-9.831* (13.228)	0.738	6.986 (14.892)	-0.491
Visual Motor	-4.121* (7.214)	0.539	5.705 (6.948)	-0.733

Significant Changes in Variables for 4+ Week Recovery				
	Baseline to Post Injury		24-48h to Post Injury	
	Mean (SD)	Effect Size	Mean (SD)	Effect Size
Somatization	1.383* (3.344)	-0.489	-2.265* (3.239)	0.947
Anxiety	0.660* (2.926)	-0.290	-1.296 (2.354)	0.641
Depression	-0.006 (2.446)	0.003	-0.864 (1.617)	0.583
Impulse Control	0.815 (5.875)	-0.166	-0.037 (5.057)	0.007
Reaction Time	0.565 (6.474)	-0.124	-0.577 (6.481)	0.126
Verbal Memory	-4.920* (12.631)	0.452	6.333 (11.805)	-0.566
Visual Memory	-6.537* (16.853)	0.472	5.056 (15.580)	-0.348
Visual Motor	-2.470* (7.391)	0.334	4.544 (6.754)	-0.596

XI. Appendix B

Correlations for 1-2 Week Recovery								
	Somatization	Anxiety	Depression	Impulse Control	Reaction Time	Verbal Memory	Visual Memory	Visual Motor
Somatization	1.000	0.626 0.536 0.548	0.520 0.453 0.424	-0.038 0.132 -0.062	-0.070 0.272 0.093	0.006 -0.204 -0.050	0.017 -0.267 -0.047	0.004 -0.294 -0.025
Anxiety	—	1.000	0.704 0.706 0.593	-0.043 0.105 -0.018	-0.012 0.166 0.041	-0.025 -0.181 -0.070	0.025 -0.219 -0.156	-0.012 -0.210 -0.093
Depression	—	—	1.000	-0.002 0.029 0.030	-0.051 0.250 0.030	0.009 -0.224 -0.102	0.055 -0.234 -0.145	0.048 -0.260 -0.096
Impulse Control	—	—	—	1.000	-0.100 -0.007 -0.172	-0.221 -0.303 -0.143	-0.158 -0.260 -0.162	-0.069 -0.224 -0.053
Reaction Time	—	—	—	—	1.000	-0.210 -0.466 -0.191	-0.260 -0.419 -0.270	-0.497 -0.634 -0.474
Verbal Memory	—	—	—	—	—	1.000	0.490 0.655 0.479	0.416 0.607 0.354
Visual Memory	—	—	—	—	—	—	1.000	0.418 0.594 0.422

Correlations for 2-3 Week Recovery								
	Somatization	Anxiety	Depression	Impulse Control	Reaction Time	Verbal Memory	Visual Memory	Visual Motor
Somatization	1.000	0.651 0.653 0.253	0.605 0.488 0.177	0.001 0.088 0.058	-0.067 0.278 0.160	-0.003 -0.316 -0.245	-0.086 -0.281 -0.247	-0.057 -0.384 -0.225
Anxiety	—	1.000	0.784 0.704 0.784	0.111 0.132 0.098	0.047 0.174 0.196	-0.003 -0.312 -0.149	-0.104 -0.207 -0.191	-0.028 -0.285 -0.187
Depression	—	—	1.000	0.107 -0.006 0.119	0.046 0.183 0.132	-0.003 -0.181 -0.217	-0.109 -0.177 -0.250	-0.094 -0.184 -0.201
Impulse Control	—	—	—	1.000	0.026 -0.035 -0.196	-0.138 -0.241 -0.084	-0.119 -0.228 -0.095	0.063 -0.069 0.051
Reaction Time	—	—	—	—	1.000	-0.104 -0.449 -0.216	-0.264 -0.463 -0.277	-0.519 -0.717 -0.577
Verbal Memory	—	—	—	—	—	1.000	0.527 0.643 0.531	0.292 0.514 0.337
Visual Memory	—	—	—	—	—	—	1.000	0.396 0.528 0.352

Correlations for 3-4 Week Recovery								
	Somatization	Anxiety	Depression	Impulse Control	Reaction Time	Verbal Memory	Visual Memory	Visual Motor
Somatization	1.000	0.793 0.455 -0.043	0.610 0.365 -0.053	0.097 0.002 -0.043	-0.031 0.220 0.021	0.161 -0.216 0.062	-0.072 -0.177 -0.012	0.022 -0.221 0.026
Anxiety	—	1.000	0.592 0.646 0.949	0.139 0.111 -0.009	-0.039 0.135 -0.051	0.094 -0.439 -0.237	-0.204 -0.339 -0.099	-0.026 -0.230 0.040
Depression	—	—	1.000	0.222 0.092 0.048	-0.100 0.132 -0.063	0.002 -0.310 -0.270	-0.239 -0.294 -0.155	-0.005 -0.245 0.053
Impulse Control	—	—	—	1.000	-0.038 0.026 0.059	-0.196 -0.273 -0.295	-0.361 -0.341 -0.258	-0.082 -0.126 -0.296
Reaction Time	—	—	—	—	1.000	-0.045 -0.458 -0.236	-0.295 -0.408 -0.239	-0.476 -0.776 -0.685
Verbal Memory	—	—	—	—	—	1.000	0.471 0.487 0.545	0.254 0.484 0.450
Visual Memory	—	—	—	—	—	—	1.000	0.296 0.464 0.348

Correlations for 4+ Week Recovery								
	Somatization	Anxiety	Depression	Impulse Control	Reaction Time	Verbal Memory	Visual Memory	Visual Motor
Somatization	1.000	0.581 0.602 0.519	0.555 0.623 0.180	-0.147 0.148 0.080	0.037 -0.008 0.031	0.011 -0.424 -0.127	0.030 -0.449 -0.046	0.058 -0.307 -0.075
Anxiety	—	1.000	0.675 0.643 0.456	-0.098 -0.038 0.038	0.134 -0.042 0.074	0.094 -0.265 -0.145	0.048 -0.316 -0.130	0.046 -0.260 -0.210
Depression	—	—	1.000	-0.054 0.056 0.011	0.107 0.087 0.032	0.008 -0.281 -0.119	0.043 -0.328 -0.071	0.134 -0.266 -0.099
Impulse Control	—	—	—	1.000	-0.146 0.094 -0.051	-0.239 -0.282 -0.176	-0.154 -0.169 -0.120	-0.121 -0.077 -0.101
Reaction Time	—	—	—	—	1.000	-0.104 -0.138 -0.127	-0.285 -0.135 -0.323	-0.512 -0.147 -0.483
Verbal Memory	—	—	—	—	—	1.000	0.425 0.625 0.655	0.379 0.559 0.444
Visual Memory	—	—	—	—	—	—	1.000	0.363 0.538 0.430

XII. Appendix C

Significant Changes in Correlations for 1-2 Week Recovery		
	Baseline to Post Injury	Post Injury to Asymptomatic
Somatization/Anxiety	0.0364	0.7715
Somatization/Depression	0.1743	0.5532
Somatization/Impulse Control	0.0075	0.0018
Somatization/Reaction Time	0.0000*	0.0029
Somatization/Verbal Memory	0.0016*	0.0102
Somatization/Visual Memory	0.0000*	0.0002*
Somatization/Visual Motor	0.0000*	0.0000*
Anxiety/Depression	0.9427	0.0013*
Anxiety/Impulse Control	0.0196	0.0448
Anxiety/Reaction Time	0.0054	0.0394
Anxiety/Verbal Memory	0.0133	0.0588
Anxiety/Visual Memory	0.0001*	0.2771
Anxiety/Visual Motor	0.0014*	0.0361
Depression/Impulse Control	0.6202	0.9882
Depression/Reaction Time	0.0000*	0.0002*
Depression/Verbal Memory	0.0005*	0.0364
Depression/Visual Memory	0.0000*	0.1211
Depression/Visual Motor	0.0000*	0.0032
Impulse Control/Reaction Time	0.1326	0.0073
Impulse Control/Verbal Memory	0.1436	0.0056
Impulse Control/Visual Memory	0.0674	0.0893
Impulse Control/Visual Motor	0.0057	0.0030
Reaction Time/Verbal Memory	0.0000*	0.0000*
Reaction Time/Visual Memory	0.0035*	0.0050
Reaction Time/Visual Motor	0.0010	0.0001*
Verbal Memory/Visual Memory	0.0000*	0.0000
Verbal Memory/Visual Motor	0.0000*	0.0000
Visual Memory/Visual Motor	0.0000*	0.0000*

Significant Changes in Correlations for 2-3 Week Recovery		
	Baseline to Post Injury	Post Injury to Asymptomatic
Somatization/Anxiety	0.9771	0.0000*
Somatization/Depression	0.1426	0.0015*
Somatization/Impulse Control	0.4354	0.7826
Somatization/Reaction Time	0.0023	0.2639
Somatization/Verbal Memory	0.0045	0.4959
Somatization/Visual Memory	0.0669	0.7413
Somatization/Visual Motor	0.0020	0.1119
Anxiety/Depression	0.1207	0.0991
Anxiety/Impulse Control	0.8517	0.7389
Anxiety/Reaction Time	0.2647	0.8267
Anxiety/Verbal Memory	0.0050	0.1152
Anxiety/Visual Memory	0.3385	0.8791
Anxiety/Visual Motor	0.0175	0.3065
Depression/Impulse Control	0.3140	0.2095
Depression/Reaction Time	0.2265	0.6118
Depression/Verbal Memory	0.1167	0.7338
Depression/Visual Memory	0.5321	0.4603
Depression/Visual Motor	0.4045	0.8583
Impulse Control/Reaction Time	0.5894	0.1133
Impulse Control/Verbal Memory	0.3442	0.1381
Impulse Control/Visual Memory	0.2876	0.1970
Impulse Control/Visual Motor	0.2267	0.2290
Reaction Time/Verbal Memory	0.0011*	0.0165
Reaction Time/Visual Memory	0.0420	0.0403
Reaction Time/Visual Motor	0.0042	0.0162
Verbal Memory/Visual Memory	0.1160	0.1236
Verbal Memory/Visual Motor	0.0160	0.0448
Visual Memory/Visual Motor	0.1113	0.0359

Significant Changes in Correlations for 3-4 Week Recovery		
	Baseline to Post Injury	Post Injury to Asymptomatic
Somatization/Anxiety	0.0007*	0.0010*
Somatization/Depression	0.0521	0.0065
Somatization/Impulse Control	0.5397	0.776
Somatization/Reaction Time	0.1249	0.1944
Somatization/Verbal Memory	0.0177	0.0781
Somatization/Visual Memory	0.5073	0.2925
Somatization/Visual Motor	0.1212	0.1036
Anxiety/Depression	0.6091	0.0000*
Anxiety/Impulse Control	0.8724	0.4289
Anxiety/Reaction Time	0.3122	0.2282
Anxiety/Verbal Memory	0.0017*	0.1485
Anxiety/Visual Memory	0.4042	0.1045
Anxiety/Visual Motor	0.2374	0.0698
Depression/Impulse Control	0.4266	0.7635
Depression/Reaction Time	0.1668	0.1966
Depression/Verbal Memory	0.0582	0.7749
Depression/Visual Memory	0.7215	0.3440
Depression/Visual Motor	0.1465	0.0399
Impulse Control/Reaction Time	0.6823	0.8212
Impulse Control/Verbal Memory	0.5707	0.8705
Impulse Control/Visual Memory	0.8739	0.5455
Impulse Control/Visual Motor	0.7472	0.2033
Reaction Time/Verbal Memory	0.0051	0.1021
Reaction Time/Visual Memory	0.4281	0.2157
Reaction Time/Visual Motor	0.0013*	0.1881
Verbal Memory/Visual Memory	0.8859	0.6159
Verbal Memory/Visual Motor	0.0665	0.7735
Visual Memory/Visual Motor	0.1762	0.3460

Significant Changes in Correlations for 4+ Week Recovery		
	Baseline to Post Injury	Post Injury to Asymptomatic
Somatization/Anxiety	0.7688	0.2652
Somatization/Depression	0.3381	0.0000*
Somatization/Impulse Control	0.0054	0.5210
Somatization/Reaction Time	0.6856	0.7286
Somatization/Verbal Memory	0.0000*	0.0026
Somatization/Visual Memory	0.0000*	0.0000*
Somatization/Visual Motor	0.0002*	0.0224
Anxiety/Depression	0.6026	0.0061
Anxiety/Impulse Control	0.5798	0.4385
Anxiety/Reaction Time	0.1146	0.3091
Anxiety/Verbal Memory	0.0007*	0.2045
Anxiety/Visual Memory	0.0006*	0.0459
Anxiety/Visual Motor	0.0033	0.5712
Depression/Impulse Control	0.3112	0.6492
Depression/Reaction Time	0.8601	0.6283
Depression/Verbal Memory	0.0060	0.0930
Depression/Visual Memory	0.0004*	0.0069
Depression/Visual Motor	0.0001*	0.0665
Impulse Control/Reaction Time	0.0320	0.2055
Impulse Control/Verbal Memory	0.6713	0.2588
Impulse Control/Visual Memory	0.8892	0.6229
Impulse Control/Visual Motor	0.6668	0.7982
Reaction Time/Verbal Memory	0.7593	0.9267
Reaction Time/Visual Memory	0.1637	0.0822
Reaction Time/Visual Motor	0.0002*	0.0013*
Verbal Memory/Visual Memory	0.0095	0.6213
Verbal Memory/Visual Motor	0.0230	0.1130
Visual Memory/Visual Motor	0.0352	0.1531

XIII. Appendix D

Centrality of Variables for 1-2 Week Recovery			
	Baseline	24-48 Hours Post Injury	Asymptomatic
Somatization	1.281	2.158	1.250
Anxiety	1.447	2.123	1.518
Depression	1.389	2.155	1.419
Impulse Control	0.631	1.060	0.64
Reaction Time	1.200	2.214	1.272
Verbal Memory	1.376	2.64	1.389
Visual Memory	1.423	2.647	1.681
Visual Motor	1.465	2.824	1.517

Centrality of Variables for 2-3 Week Recovery			
	Baseline	24-48 Hours Post Injury	Asymptomatic
Somatization	1.470	2.488	1.364
Anxiety	1.727	2.466	1.857
Depression	1.747	1.924	1.880
Impulse Control	0.565	0.798	0.701
Reaction Time	1.073	2.297	1.754
Verbal Memory	1.070	2.657	1.779
Visual Memory	1.606	2.526	1.943
Visual Motor	1.448	2.681	1.930

Centrality of Variables for 3-4 Week Recovery			
	Baseline	24-48 Hours Post Injury	Asymptomatic
Somatization	1.786	1.655	0.259
Anxiety	1.888	2.356	1.428
Depression	1.769	2.086	1.590
Impulse Control	1.135	0.971	1.008
Reaction Time	1.024	2.156	1.355
Verbal Memory	1.222	2.667	2.095
Visual Memory	1.937	2.509	1.656
Visual Motor	1.162	2.546	1.897

Centrality of Variables for 4+ Week Recovery			
	Baseline	24-48 Hours Post Injury	Asymptomatic
Somatization	1.420	2.562	1.059
Anxiety	1.676	2.166	1.572
Depression	1.576	2.284	0.968
Impulse Control	0.958	0.863	0.578
Reaction Time	1.325	0.652	1.122
Verbal Memory	1.260	2.572	1.795
Visual Memory	1.348	2.560	1.776
Visual Motor	1.615	2.153	1.841