Manifestation of Higher-order Cognitive Processing Deficits Resulting from Concussion

by

Dena Berg

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Graduate Supervisory Committee:

Julie Liss, Chair
John Caviness
Tamiko Azuma

ARIZONA STATE UNIVERSITY

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ABSTRACT

Concussion, a subset of mild traumatic brain injury (mTBI), has recently been brought to the forefront of the media due to a large lawsuit filed against the National Football League. Concussion resulting from injury varies in severity, duration, and type, based on many characteristics about the individual that research does not presently understand. Chronic fatigue, poor working memory, impaired self-awareness, and lack of attention to task are symptoms commonly present post-concussion. Currently, there is not a standard method of assessing concussion, nor is there a way to track an individual's recovery, resulting in misguided treatment for better prognosis. The aim of the following study was to determine patient specific higher-order cognitive processing deficits for clinical diagnosis and prognosis of concussion. Six individuals (N=6) were seen during the acute phase of concussion, two of whom were seen subsequently when their symptoms were deemed clinically resolved. Subjective information was collected from both the patient and from neurology testing. Each individual completed a task, in which they were presented with degraded speech, taxing their higher-order cognitive processing. Patient specific behavioral patterns are noted, creating a unique paradigm for mapping subjective and objective data for each patient's strategy to compensate for deficits and understand speech in a difficult listening situation. *Keywords:* concussion, cognitive processing

DEDICATION

This master's thesis is dedicated to my phenomenal mentor and friend, Rene Utianski, for all of her hard work and dedication throughout my writing process. My gratitude for the support you have given me, both personally and professionally, is truly immeasurable.

I also want to dedicate this to my parents, Marsha and Joel Berg, for their unconditional love and support. I am honored that the apple did not fall far from the tree.

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Chapter 1

BACKGROUND

Concussion, also known as a mild traumatic brain injury (mTBI), refers to:

> a clinical syndrome characterized by immediate and transient alteration in brain function, including alteration of mental status and level of consciousness, resulting from mechanical force or trauma (AANS, 2011).

The exact prevalence of concussion is unknown because not all concussed individuals seek medical attention, but according to the American Association of Neurological Surgeons (AANS), more than 300,000 concussions occur annually in the United States alone. They also estimate that the likelihood of suffering from a sports-related concussion is close to 20%. Among college football players, 34% have had at least one concussion and 20% have had two or more (AANS, 2011).

Recently, concussion health has gained great awareness, due to a lawsuit filed against the National Football League (NFL). Thousands of current players, former players, and their families are suing the NFL for conspiracy and fraudulent concealment of the risk factors associated with concussion. Listed in this lawsuit are thousands of players, who have had anywhere from 1-300 concussions, stating their long-term symptoms of concussion after being allowed to return to play (Breslow, 2013). While the potential long-term impact of injury was not revealed to the athletes, there is a growing body of research to support the understanding of risks associated with concussion.

Many urban myths reside around concussion and the resulting consequences. Due to the neuroplasticity of the brain, many parents, sports coaches, etc. expect people to return back to their previous state of functioning sooner than they will. Newer studies have concluded that people with concussions are more susceptible to widespread damage, and that neurologists *need to assess each patient on an individual basis* because neuronal impact is unknown (McCrory, 2001). Another myth surrounding concussion arises from the belief that concussions cause only focal disturbances. However, the most current concussion research shows that functional damage can occur resulting in *a breakdown of communicative activity between multiple areas of the brain* (McCrory, 2001). This can cause a loss of efficiency and coordination between diverse cognitive functions.

Understanding the truth behind such myths is critical for treating patients with concussions. It is now widely supported that different behaviors are associated with concussion and vary from person to person. The American Speech-Language and Hearing Association organizes post-concussive symptoms into three categories: Somatic, Cognitive, Emotional/Behavioral (See Table 1, adapted from Duff, 2009). Recovery from these symptoms varies from patient to patient, with some symptoms lasting days and others lasting months. The impact of these symptoms can cause loss of time from work, missing or failing school, and high medical bills. It is for these reasons that the treatment of individuals with concussions is neither standardized, nor seemingly effective; individuals with concussions feel the impact of their injury longer than necessary because of the lack of research to reveal the way in which individual variability can be incorporated into treatment.

Impaired Self-Awareness

One of the most common clinically diagnosed symptoms of post-concussion is impaired self-awareness (ISA). ISA refers to the difference between the patient's level of functioning and their perceived level of functioning. The ability to increase self-awareness is important due to "its association with motivation for treatment and long-term functional outcome" (Sherer, Hart, Nick, Whyte, Thompson, Yablon, 2003, 168). A patient with ISA is more likely to experience a longer recovery due to an increase in overestimation of skills, often resulting in cognitive behaviors (Sherer, Hart, Whyte, Nick, & Yablon, 2005). Cognitive behaviors include delayed or increased response times, impulsivity, anger, and depression. The inconsistency between patient report and caregiver report is noted to impact familial relationships and compliance with clinical treatment. The lack of neurophysiological evidence of concussion prevents a quantifiable demonstration of impairment that might help patients better understand the impact of their injury.

Clinical Recovery: Current Treatment of Concussion

Overall, the current guidelines for clinical recovery carry no consensus. The American Speech-Language and Hearing Association (ASHA) states that there are up to twenty-two different guidelines currently used to assess the presence of injury and determine appropriateness of return to play post-injury (Duff, 2009). These guidelines do not always factor in age, gender or other variables, which play a key role in recovery. The American Academy of Neurology created the most commonly used assessment for rating concussion severity, which breaks down concussion into three subtypes. Grade 1 concussion is the most common type of concussion. Individuals do not lose consciousness and have only momentary confusion lasting less than fifteen minutes. Grade 2 concussions occur for longer than fifteen minutes, during which time the person does not lose consciousness but exhibits confusion and mental state abnormalities. In Grade 3 concussions, the person loses consciousness, lasting anywhere from seconds to minutes in duration (American Academy of Neurology, 1997, p. 583). Of course, the symptoms that result from different grades of concussion vary and the severity of resulting symptoms is related to, but not directly predicted by concussion-grade alone.

The most commonly used return to play guidelines were created by the Colorado Medical Society in 1991 (Collins, Lovell, & Mckeag, 1999). These guidelines factor in concussion grade (levels 1, 2 or 3) and also number of concussions the person has had. Due to this variability of both return to play and severity guidelines, *The International Conference on Concussion in Sport* convened in both 2001 and 2004 to create recommendations for individualizing return to play and steadily increasing return to play. The steps in the graduated return to play are:

1. No activity; person must rest until asymptomatic
2. Light aerobic exercise (e.g. walking)
3. Sport-specific training
4. Non-contact drills
5. Full contact Drills
6. Game play

However, these are only recommendations, and are not considered a rule, due to large inter-patient variability and subsequent lack of standardization. According to public media, these recommendations are not being followed, resulting in a large disservice to athletes across the country (Schwarz, 2009). The exact number of lawsuits filed against sports coaches, trainers and programs is unknown due to confidentiality agreements and limited availability of statistics. However, in 2009, La Salle University settled for $7.5 million with a former student after he was allowed to “return to play after having continuing symptoms” (Schwarz, 2009, pp. 1). The player ended up suffering another concussion that left him with serious brain damage resulting in the need for 24-hour care (Schwarz, 2009). The National Collegiate Athlete Association (N.C.A.A.) did not comment on this lawsuit because they do not have a set protocol for concussion assessment and treatment. Instead, “it devotes four pages of the 126-page Sports Medicine Handbook it publishes for students to the signs and seriousness of concussion” (Scwarz, 2009, pp. 1).

This lack of standardized assessment leaves athletes at risk for long-term impairments and frees the coaches and teams of any direct liability. Anecdotally, a patient in the current investigation (KC) was involved in a lawsuit after concussion. As a high school cheerleader, she was injured during a football game cheer routine. After falling from a stunt, she was removed from the game and determined to have a concussion, only to be put back in the game approximately 10 minutes later. This was the point at which the coach deemed her return to play acceptable. After a subsequent fall, KC was in a coma for several days. If there were stricter, reliable guidelines, it is possible that KC would not have been allowed to return to the game and would not be suffering from the long-term effects from her concussion and subsequent injury (parent report).

Commonly Used Assessments

A standard and reliable assessment of the severity of concussion is a critical first step in developing a gold standard of treatment. While there is not a single assessment that is used nationwide, there are several that are used, some of which require baseline testing and some that do not. Recognizing the impact of individual variability on the outcomes of concussion, and the range of "normal" behavior, it is important to recognize the critical need of a pre-injury point of comparison for test validity and reliability. However, it is similarly important to recognize the practical issues in obtaining pre-injury data. Several current assessments used to assess neurologic impairment post-concussion, include: the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT), Glasgow Coma Scale, and King-Devick Test (K-D Test). Each assessment is described below; the pros and cons to the current assessments are outlined in Table 2.

Glascow Coma Scale. The Glascow Coma Scale is a scaling system used to rank the severity of a patient during a moment in time (see Appendix). However, “discrepancies exist in the methods used to arrive at these scores” resulting in variability to patient diagnosis and reliance on estimation (Marion & Carlier, 1994, p. 90). Using the GCS, mild head injury accounts for a broad range of normal. Thinking of normal as a range, a person could fall at the bottom of normal and still exhibit major symptoms of neuronal damage. The GCS requires no baseline performance for comparison.

ImPACT. ImPACT takes approximately 20 minutes to complete. It measures a person’s attention span, working memory, sustained and selective attention time, response variability, non-verbal problem solving, and reaction time. This test requires baseline testing to be performed, in order to have a comparison for post-injury performance.

King-Devick Test. The K-D Test assesses the patient's reaction time in a series of tasks. This test is mainly used as a sideline screener and is often administered by coaches, parents and athlete trainers. This test is used to assess whether a patient should seek further medical attention.

Current Research

In addition to lacking standards of severity of impairment, there is a large deficit in objective concussion assessments that also incorporate subjective symptoms. This includes headaches, anxiety, depression, memory deficits, inability to concentrate, sleep problems, etc. Although many screeners and quick assessments are utilized, a large gap exists between current assessments and patient prognosis. To date, there is no literature that outlines the relationship between impact of injury and likelihood of recovery. This is preventing the implementation of timely treatment, as well as treatment target toward specific symptoms. A standardized method of assessment is needed in order to properly diagnose and treat patients with concussion (Marion and Carlier, 1994).

The Speech-Language Pathologist's Role

The main role of the SLP in concussion management is to provide treatment for post-concussive symptoms (Duff, 2009). Most treatment services provided focus on cognition tasks (e.g. attention) to help the patient compensate for their cognitive difficulties. However, without a baseline measurement for comparison, an SLP may never know when a client has recovered. A person can fall within normal limits on a standardized test but still not be back to baseline (e.g. a person who used to perform at high-normal and now performs at low-normal). Similarly, an individual may be scoring poorly, but is performing as they would pre-injury. For this reason, there is an economy of effort that must be addressed through defining a assessment of higher-order cognitive deficits post-concussion.

Chapter 2

AIM OF THE STUDY

The aim of the current study is to determine patient specific higher-order cognitive deficits for clinical diagnosis and prognosis of mild traumatic brain injury. Although the new concussion recommendations and SLP treatment are promising, they require baseline testing to be considered and utilized properly. Unfortunately, baseline data are often unavailable; therefore, new measurements must be researched to track individual concussion recovery across a timespan and to rely more on objective, patient-dependent, post-injury measures.

Chapter 3

METHOD

Study Overview

First the study utilized a within-subjects analyses comparing performance during acute concussion to clinical recovery. A post hoc analysis was completed across patients.

Participants

The following study evaluated behavioral profiles of concussed patients at two points following injury: acute concussion and clinical recovery. Data were collected at Mayo Clinic Hospital by Arizona State University investigators. Analysis and interpretation was conducted at ASU (Motor Speech Disorders Lab). A total of seven patients were recruited via the Mayo Concussion Program; however, only six of the patients' data were utilized for this study. One patient was unable to complete more than 50% of the task, thereby not providing sufficient data for subsequent analysis. The inclusion criterion included a recent concussion (< 6-8 weeks post injury), along with being a native English speaker. Individuals with concussion from age 14 to 65 were considered eligible for the study. This protocol allowed for both feasible and reasonable assessment during the critical period of injury. Patients who agreed to participate returned for an additional data collection session once the patient was deemed clinically back to baseline (including results of cognitive testing and self- and family- behavioral report) or clinically-cleared to return to work or school. The length of time between initial meeting and second appointment was approximately 1-4 months. Due to scheduling conflicts, and timing of recruitment, only two of seven participants completed their second-return visit.

Speech Stimuli

The patients listened to a series of short sentences that were of varying levels of intelligibility of noise vocoded speech (1-channel, unintelligible; 6 channel, moderately intelligible; 16 channel, intelligible), and the statements were either true or false. A list of stimuli can be found in Appendix A. Per level of intelligibility, 80 phrases (40 true, 40 false) were presented in randomized order, for a total of 240 phrases for which responses were elicited.

Procedure

At the start of each appointment, a hearing screening was conducted to determine current hearing threshold. All patients were within normal limits for hearing. The sound levels of the intra-aural headphones were set to 90 dB. The data were collected as part of a larger study in which electroencephalography (EEG) data were collected. For this reason, participants were seated in a hard-backed chair and situated at a comfortable distance from the computer screen. STIM2 was used to deliver the stimuli through inter-aural headphones.

Visual prompts were used to guide the participants through the experiment. After the phrase was played, participants were asked to make a decision as to whether the statements were true or false; following, they were asked to report, on a scale of one to four, how confident they were in their response (with 1, not confident; 2, slightly confident; 3, fairly confident; 4, very confident). This protocol, referred to as the "sentence verification" task, has been used in previous research that has allowed for assessment of behavioral data (original instructions available in Appendix 2). The patients were first given a trial period to practice the protocol before beginning the actual experiment. This allowed the experimenters to verify the participants' understanding of the instructions and the timelines of their responses. Each patient listened to six blocks of 40 sentences, for a total of 240 stimulus items. Breaks were allowed during testing in order to reduce patient fatigue.

Chapter 4

DATA AND ANALYSES

Quantitative Data

STIM2, which was utilized to present the stimuli, also recorded the data electronically, including patient response and response latency (recorded from offset of the stimulus to the time at which a response was entered). The data was then transferred to Microsoft Excel for subsequent analyses. All participant data was coded in the Motor Speech Disorders Lab as follows: regardless of truth- value, statements were scored as "1" for correct and "-1" for incorrect. All no-responses were scored as a "0." For subsequent analyses, incorrect and no response items were considered as a single category, to account for the patient missing the response interval. Although three levels of intelligibility were presented, detailed analyses of responses to only moderately intelligible (6-channel) and intelligible (16-channel) were performed. The data from the unintelligible phrases (1-channel), where performance is expected to be at chance, was used to gauge listening strategy and compliance with task instructions.

Qualitative Data

During data collection, patients were interviewed regarding their symptoms and experiences post-concussion. Standard questions included: what types of symptoms are you experiencing, what symptoms have resided, how had concussion occurred. Further, as a part of the Mayo Concussion Program, neuropsychological testing was completed and made available to the current investigator. This information was used to corroborate interpretation of quantitative data. For instance: when concussion occurred, past concussions, past medical testing, past medical history.

Chapter 5

RESULTS

Patient one (WA)

Patient one, 32 year-old male, reported having trouble sleeping and was experiencing mild headaches. He was observed to be very pleasant, explained his recovery very openly and seemed focused with high concentration to the task.

WA demonstrated expected accuracies with quicker response times when speech was intelligible. He also attempted to answer even when speech was unintelligible, showing attention to task and a strength in cognition. Examining response time further, it was noted that for the intelligible phrases, WA's response time was similar when he responded accurately (1052ms) and when he responded inaccurately (1160ms). Interestingly, for the moderately intelligible phrases, there was a large discrepancy in his average response time when he was accurate (946ms) and inaccurate (1374ms). Further, he demonstrated the greatest amount of variability in response time during the moderately intelligible phrases, when he was inaccurate (standard deviation of response times = 651ms).

WA was one of two patients who were assessed twice. During WA's second visit, his data show an increase in response time from. During WA's first visit, he was confident in 77% of responses when speech was moderately intelligible or intelligible, with an accuracy of 91% when he was confident. During his return visit, outcomes exhibited an increase in both confidence (85% of responses) and accuracy (98% of confident responses).

Patient two (MP)

Patient two, 15-year-old male, reported having one previous concussion with associated headaches, decreased concentration and difficulty recalling dates. At the time of testing, the patient was unable to recall his school schedule in order. The patient seemed to understand his deficit. Even though the patient had a difficult time with the task, he showed an intact self-awareness, both subjectively and objectively.

Similar to MR, LW and KV's data for 1-channel responses, MP chose false for 89% of responses showing a lack of task effort. Interestingly, his response times did not vary with task difficulty level; however, comparable to KV, MP's response times were consistent, taking into account his accuracy (as outlined in Table 3), regardless of intelligibility level. Given the high number of no responses, it is difficult to gain insight from the data for which he provided answers; it appears as if the no responses are a result of low confidence in responses.

Patient three (JC)

Patient three is a 50-year-old female four months post concussion. JC complained of loss of concentration, executive functioning deficits and word finding issues. However, she performed within normal limits (WNL), usually in the high-average range, on all norm-references tests given (e.g. Wechsler Memory Scale, Boston Naming Test, Token Test, Controlled Oral Word Association Test, etc.). These results show a discrepancy between the patient's complaints and her neuropsychological language summary. JC has not been able to work more than a half-day at work, which has been hard for her because she has a very busy and high-paying job. Recently, JC's daughter also suffered from a concussion Her daughter has required her care, and this has only caused an increase in her fatigue and anxiety.

JC exhibited intact self-awareness by rating herself confident parallel to her accuracy scores. JC had trouble completing the task as fatigue, anxiety and concentration only allowed her to complete 4/6 total blocks. Even thought the task was not 100% completed, the data were still analyzed for behavioral patterns to compare to subjective impressions.

Patient four (MR)

Patient four, 17-year-old female, was seen three months post concussion with a history of two previous concussions. The patient complained of severe headache, anxiety, trouble sleeping, depression, poor grades, trouble concentrating and dizziness. Prior to her concussion, MR had an anxiety disorder and a troubled home life. Her brother recently became suicidal, and she is not close with her parents. After the concussion, MR stated that her symptoms have only worsened and that she is having an even harder time sleeping through the night, experiencing severe anxiety attacks daily.

Overall, MR demonstrated high accuracy when confident; however, she was overly confident with 1-channel responses (32% confident). In moderately and more so intelligible speech, her response times were slower with increased task difficulty. In other words, she responded, on average, in 433ms for moderately intelligible stimuli (6-channel) and responded, on average, in 383ms for intelligible stimuli (16 channel). In both intelligibility conditions, there were no noticeable differences in her response times or variability of response times when she was accurate or inaccurate.

Patient five (LW)

Patient five, 16-year-old male, was assessed two-weeks post- concussion. The patient self reported memory and concentration problems secondary to his concussion.

The patient showed no differences in response time, regardless of level of intelligibility. He was overly confident for 1-channel responses (confident 48/53 responses) and chose true 100% of the time. It was observed during data collection that the patient used verbal rehearsal by repeating out-loud what he heard. Watching the patient, it appeared he had difficulty with the task; this is corroborated by unexpected patterns of accuracy, including lower accuracy than the design of the stimuli generally elicits. Namely, the patient's accuracy dropped from 49% listening to moderately intelligible speech to 12.5% when speech was entirely intelligible. This suggests LW may not have remembered the task, and reversed the true/false dichotomy. As a result of this concern, with no way to validate this speculation, the data were not subjected to further analysis.

Patient five was one of two patients that were seen for a second time. Patient five's data for his second visit show an increase in accuracy suggesting that he retained the task directions. However, for 1-channel responses, the same pattern exists, where the patient selected one response 88% of the time. This response continues to show a lack of attempt at the task. During LW's second visit he was able to complete all six blocks.

Patient six (KV)

Patient six, 20-year-old male, reported six concussions since age seventeen. He complained of memory loss and fatigue. The patient's neurologist recommended that the patient not return to playing.

KV demonstrated expected accuracies with quicker response times when speech was intelligible. Interestingly, regardless of intelligibility level, his response times were consistent, taking into account his accuracy. That is, his response times were similar for inaccurate responses for both 16- channel (809ms) and 6- channel (762ms); the same is true when he was accurate for 16- channel (435ms) and 6- channel (516ms). The variability of his response times was similar across intelligibility conditions when he was correct, but subjectively much larger for 16- channel responses when he was inaccurate (865ms) compared to inaccurate responses to 6-channel stimuli (682ms). For 1-channel response, the patient selected false 94.73% of the time (72/74 attempts), suggesting that he was not attempting to process the delivered stimuli, but rather providing a default response.

Chapter 6

DISCUSSION

Individuals with concussion show a broad range of symptoms post concussion, which are specific to each patient. Current assessments for severity and prognosis are based either on normative data, which largely ignores the range of normal performance, or via a comparison with an individual's performance prior to injury. Patients with concussion often exhibit many different post-concussive behaviors that need to be better assessed both subjectively and objectively, ideally without reference to their behavior prior to injury, as baseline scores pose large practicality obstacles.

Self-awareness

Impaired self-awareness has been linked to poor patient outcomes for treatment (Sherer, et al., 2003). Patient 4 was confident over 30% of the time during unintelligible speech, even though she was systematically answering false for every response. Given the discrepancy between the patient's data and her confidence, increasing her self-awareness may create a more favorable prognosis, as it is believed that her performance may serve as a microcosm of her general self-awareness. Although patients 3 and 5 did not complete the task, they exhibited high self-awareness (noted in their confidence levels). First trial data for patient 5 exhibits intact self-awareness, even though he most likely misunderstood the task. His intact self-awareness suggests why he was cleared to return to play and why second trial data show a large increase in accuracy, task completion, and task attention.

Task completion

In the current investigation, we were able to relate subjective assessment of patient recovery to their performance on a task that incrementally taxes their higher-order cognitive processing. In patients 2, 4, 5 and 6 the objective data demonstrated that these patients did not attempt to process unintelligible speech, suggesting a failure to exert effort during a cognitively challenging task. Patients 1 and 3 attempted to process the unintelligible speech, suggesting higher cognitive efforts. Patient 1 had both intact self-awareness and intact attention to task during both first and second trial data; however, an increase in confidence and accuracy is noted during second trial data, when the patient was deemed recovered. Patients 3 and 5 did not complete all blocks during first trial data due to fatigue, which is consistent with the subjective information obtained during interview.

Summary

Each patient showed individual patterns with regards to response time, accuracy, confidence and task completion. However, there are clear signs that patients also exhibit overlap with each other both subjectively and objectively. While qualitatively and subjectively a trend, this offers justification for further investigation of the paradigm and offers insights as to the way in which it should be expanded.

Our findings are consistent with the notion that individuals are differentially affected by concussion. The findings of this study are informative, yet inconclusive. It is suggested that a larger patient pool is required, assessed across multiple stages of injury, to account for both subjective and objective symptoms of concussion and prognosis for recovery. It is important for concussion research to continue to focus on creating a standardized protocol for concussion assessment and treatment in order to better predict patient prognosis. This study shows a great lack of consistency across practices with regards to assessment of symptoms. The results of this study indicate the need for patient specific testing to better identify symptoms and inform decisions regarding the need for clinical intervention.

Future Directions

In the current investigation, we learned about the different strategies used by patients with concussion to try and understand degraded speech. Impulsivity, deficit awareness, lack of attention and difficulty with retention of task instructions all contributed to the inconclusive results of the study. However, it is promising to see the subjective differences in patient demeanor and recovery are reflected in the results. To generalize these findings, more patients will need to be examined. Further, the continued enrollment of the patients examined thus far is critical for the investigation of the predictive nature of an individual's differences in performance across the course of recovery.

REFERENCES

American Academy of Neurology. (1997). Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. *Neurology*, *48*(3), 581-585.

American Association of Neurological Surgeons (AANS). (2011). Retrieved, 2013, from http://www.aans.org/Patient%20Information/Conditions%20and%20Treatments/Concussion.

Anderson, S.W. & Trumel, D. (1989) Awareness of disease states following cerebral infarction, dementia, and head trauma: Standardized assessment. *Clinical Neurophysiology, 3,* 327-329.

ASHA. (2011). Retrieved, 2013, from Breslow, J.M. (2013). Retrieved, 2013 from: http://www.pbs.org/wgbh/pages/frontline/sports/concussion-watch/family-of-junior-seau-files-wrongful-death-suit-against-nfl/on.aspx

Casson, I.R., Pellman, E.J. & Viano, D.C. (2010). Concussion in athletes: information for team physicians on the neurologic evaluation. *Seminars in Spine Injury, 22,* 234-244.

Chan, R. (2001). Attentional deficits in patients with post-concussion symptoms: a componential perspective. *Brain Injury, 15*(1), 71-94.

Collins, M.W., Lovell, M.R., Mckeag, D.B. (1999). Current issues in managing sports-related concussion. *JAMA, 282*(24), 2283-2285.

Duff, M. (2009). Retrieved, 2013, from: http://www.asha.org/Publications/leader/2009/090714/f090714a.htm

Hickok G, Poeppel D. The cortical organization of speech processing. *Nature Reviews Neuroscience*;8(5):393–402.

Leclerc, S., Lassonde, M., Delaney, S., Lacroix, V.J., & Johnston, K.M. (2001). Recommendations for grading of concussion in athletes. Sports *Medicine, 31*(8), 629-636.

Marion, D.W. & Carlier, P.M. (1994). Problems with initial Glasgow Coma Scale assessment cause by prehospital treatment of patients with head injuries: Results of a national survey. *The Journal of Trauma, 36* (1), 89-95.

McCrory. (2001). Evidence-based review of sport-related concussion: Basic science. *Clinical Journal of Sport Medicine, 11*(3), 160-165.

Savola, O. & Hillbom, M. (2003). Early predictors of post concussion symptoms in patients with mild head injury. *European Journal of Neurology, 10,* 175-181.

Schmidt, J. Lannin, N., Fleming, J, Ownsworth, T. (2011). Feedback interventions for impaired self-awareness following brain injury: A systematic review. *Journal of Rehabilitation Medicine, 43,* 673-680.

Schwarz, A. (2009, December 1). La Salle settles lawsuit with injured player for $7.5 million. *New York Times.* Retrieved from: http://www.nytimes.com/2009/12/1/sports/ncaafootball/01lasalle.html?_r=0.

Sherer, M., Hart, T., Whyte, J., Nick, T., Whyte, J., Thompson, R.N., Yabalon, S.A. (2003). Early impaired self-awareness after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 84,* 168-176.

Sherer, M., Hart, T., Whyte, J., Nick, T., & Yablon, S. (2005). Neuroanatomic basis of impaired self-awareness after traumatic brain injury: Findings from early computed tomography. *Journal of Head Trauma Rehabilitation, 20*(4), 287-300.

Table 1

Symptoms of concussion

Somatic	Cognitive	Emotional Behavioral
Headaches Nausea Fatigue Sleep Disturbances Vision Changes Tinnitus Dizziness Sensitivity to light	Slowed thinking, confusion Slowed reaction times Impaired judgment Impaired attention Distractibility Impaired learning and memory Disorganization Problem-solving difficulties	Frustration Irritability Restlessness Lability Depression Anxiety Personality changes (Duff, 2009, p. 11)

Table 2

Commonly used assessments

Assessments	Pros	Cons
IMPACT	Visuo-spatial skills, deduction	Baseline needed; fatiguing
Glasgow Coma Scale	Commonly used—easy to administer	Subjective to a moment in time; large range of normal
King-Devick Test	Easy to administer	Screener; Baseline is recorded by the fastest time

Table 3

Patient accuracy and response time

	Patient 1 (WA)	Patient 2 (MP)	Patient 3 (JC)	Patient 4 (MR)	Patient 5 (LW)	Patient 6 (KV)
Accuracy 1-channel	45%	53.22%	52.9%	67.1%	49%	51.3%
Accuracy 6 channel	76%	61.76%	77.08%	71.79%	19.6%	77.9%%
Accuracy 16 channel	90.9%	82.67%	96.07%	92.3%	12.5%	94.87%%
Response time 1-channel	859.481815ms	677.868825ms	556.6667ms	383.65789ms	505.1886ms	517.592ms
Response time 6 channel	989.2ms	951.8529412ms	619.0208ms	432.85897ms	503.245ms	525.0129ms
Response time 16 channel	887.4675325ms	904.826667ms	560.3725ms	383.3205ms	463.589ms	436.41ms

APPENDIX A

PHRASES USED IN TASK

AND TASK DESRIPTION

PHRASES

Apples are fruit
Apples are grapes
Authors write novels
Babies often drive
Babies often play
Babies sometimes teethe
Babies wear clothes
Bacon is chicken
Bakers make coats
Bakers make cookies
Balls can roll
Balls can run
Bananas are fruit
Bears eat cars
Bears eat fish
Bikes have doors
Bikes have pedals
Birds eat seeds
Birds have jewelry
Birds have wings
Blankets are cold
Blankets are soft
Boats can sail
Bombs can explode
Books have money
Books have pages
Boots are furniture
Bowls are dishes
Boys wear jeans
Bricks are heavy
Bricks are wooden
Butterflies can flutter
Butterflies can run
Butter is creamy
Butter is green
Candy is healthy
Candy is sweet
Carrots are blue
Carrots are healthy
Cars have headlights
Cars have paddles
Cats are pets
Cats carry people
Cats drink milk
Cats have feathers
Cats have teeth
Cats raise money
Cats chase mice
Cheetahs have feathers
Cheetahs have legs
Chickens have fingers
Chickens have beaks
Chickens lay eggs
Children fly jets
Children fly kites
Children wear sneakers
Circles are square
Circles are shapes
Coal is dirty
Coal is white
Coffee is yellow
Composers write music
Concrete is hard
Concrete is soft
Cotton is hard
Cotton is soft
Cowboys ride cats
Cowboys ride horses
Cowboys wear boots
Cows can bark
Cows chew grass
Cows chew gum
Cows drink coffee
Cows drink water
Cows have fingers
Cows make milk
Cows make quilts
Crackers are dry
Crackers are fruit
Diamonds are shiny
Diamonds are soft
Doctors help patients
Doctors help dirt
Doctors give drugs
Dogs drive cars
Dogs chew bones
Dogs can jump
Dogs can talk
Dogs chase cats
Dogs play chess
Dogs have ears
Dogs have jets
Dogs have paws
Dogs play piano
Dogs can bark
Dogs throw darts
Dogs wear collars
Eagles can hunt
Eagles can swim
Elephants have ears
Elephants wear shoes
Farmers eat dinner
Farmers eat hay
Farmers grow cabbage
Farmers grow houses
Farmers plow fields
Farmers plow cities
Farmers sow seeds
Farmers sow bricks
Fire can destroy
Fire is cold
Fish can swim
Fish can talk
Fish ride bikes
Flies are annoying
Flies are human
Flies catch baseballs
Flies have eyes
Flies have fingers
Flowers have colors
Flowers have toes
Footballs are square
Forests have animals
Forests have beards
Frisbees are balls
Frisbees are toys
Frogs build fires
Frogs can jump
Frogs can run

Frogs catch bugs
Frogs take leaps
Frogs wear clothes
Giraffes are short
Giraffes have spots
Girls are male
Girls wear jets
Girls wear clothes
Grass is sky
Grass is green
Headaches are bad
Headaches are fun
Helping is good
Helium can drive
Honey is sour
Honey is sticky
Horses can trot
Horses have beaks
Horses have paws
Horses have tails
Horses pull carts
Horses pull pranks
Ice is cold
Ice is liquid
Infants can write
Infants can run
Jails are friendly
Jails have guards
Jails have bars
Kangaroos can bounce
Kangaroos can sing
Kids chew gum
Kids chew soap
Kids have hands
Kids jump around
Kids move mountains
Kings are poor
Kings have power
Kings are royal
Ladies are men
Leaves are people
Lemons are sour
Lemons are sweet
Leopards have fingers
Leopards have tails
Lettuce is green
Lettuce is hot
Libraries are loud
Libraries have shelves
Mushrooms are soft
Mice are huge
Mice are rodents
Mice are fast
Mice can squeak
Mice can drive
Mice eat rocks
Mice have ears
Mice have feathers
Mice buy cars
Money buys food
Monkeys eat bananas
Notebooks are paper
Notebooks have feelings
Oranges are round
Oranges are meat
People are fish
People are human
People build homes
People build trees
People can drive
People cook homes
People cook meals
People drive cars
People eat food
People eat dirt
People have arms
People knit clothes
People ride bikes
People ride Dogs
People shout quietly
People smell flowers
People take showers
People write letters
People write carrots
Pillows are fluffy
Pillows are wooden
Rabbits can fly
Rabbits can hop
Rabbits jump rope
Raindrops are dry
Rocks are hard
Rocks are soft
Rocks can fall
Rocks can talk
Roses can feel
Roses have thorns
Sandpaper is rough
Sandpaper is smooth
Scissors cut hair
Scissors cut rocks
Screaming is loud
Sharks have fins
Sharks have legs
Sheep have money
Sheep have noses
Skyscrapers are tall
Skyscrapers are short
Snails are fruit
Snails are slimy
Snakes are reptiles
Snakes shed skin
Snakes ride bikes
Snow is cold
Soldiers shoot guns
Spiders are people
Spinach is red
Spoons are silver
Spoons are square
Squares are shapes
Squares are circles
Steak is fruit
Stores sell gifts
Students read books
Students take breaks
Sugar is bitter
Sugar is sweet
Teachers give lectures
Thorns are dull
Thorns are sharp
Toddlers can play
Trees grow leaves
Turtles wear clothes
Turtles have mouths
Vegetables have fins
Water is dry

Yards have fences
Yarn is hard
Yarn is soft
Zebras are animals
Zebras have spots
Zoos have visitors

SENTENCE VERIFICATION TASK

Today you will hear a series of spoken sentences that are either true (like the sky is blue) or false (like donkeys have wings). The sentences have been altered such that some are harder to understand than others. It will be your job to listen very carefully to every sentence and decide whether it is true or false with a button press. Then you'll make a second button press that tells us how confident you were in that response. Visual prompts will be used to guide you through the experiment. When you see an X on the screen you should attentively listen to the sentence played over the ear buds. Your eyes should remain gently fixed on the X, with your face and body relaxed and still. As long as the X remains on the screen, even when the sentence is over, it is very important that you do not blink, or swallow, or move at all, as this is when we are collecting data from the EEG cap. When you see a circle appear around the X, this is your cue to make your button-press responses for that sentence. Using the response pad, you should press 1 if the sentence just heard was true and 4 if it was false. You must pick true or false, even if you didn't understand what was said. While the circle remains on the screen it is ok to blink and swallow. When you make your true or false button press, a square will appear around the X letting you know it's time to make your confidence rating on the button pad. The buttons range from one on the left, to four on the far right. Enter zero when you have no confidence in the accuracy of your response, and four when you have high confidence in the accuracy of your responses. So the buttons, from left to right, correspond with no confidence, slight confidence, fair confidence, and high confidence. While the square remains on the screen it is ok to blink and swallow. We will begin today with a training set in order to help you get used to the procedure.

APPENDIX B

GLASCOW COMA SCALE

Eye Opening Response

- Spontaneous--open with blinking at baseline 4 points
- To verbal stimuli, command, speech 3 points
- To pain only (not applied to face) 2 points
- No response 1 point

Verbal Response

- Oriented 5 points
- Confused conversation, but able to answer questions 4 points
- Inappropriate words 3 points
- Incomprehensible speech 2 points
- No response 1 point

Motor Response

- Obeys commands for movement 6 points
- Purposeful movement to painful stimulus 5 points
- Withdraws in response to pain 4 points
- Flexion in response to pain (decorticate posturing) 3 points
- Extension response in response to pain (decerebrate posturing) 2 points
- No response 1 point

Head Injury Classification:

- Severe Head Injury----GCS score of 8 or less
- Moderate Head Injury----GCS score of 9 to 12
- Mild Head Injury----GCS score of 13 to 15

APPENDIX C

JUSTIFICATION FOR PARADIGM

Hickok and Poeppel (2007) proposed a dual stream model of speech processing, the first being "a ventral stream that processes speech signals" and the second being "a dorsal stream that maps acoustic signals to frontal lobe articulatory networks" (p. 393). This model accounts for the complex and diffuse nature of injury, allowing researchers to incrementally tax higher-order cognitive processes (e.g. speech), in order to look at higher cognitive levels, thereby differentiating if the deficit is a byproduct of semantic processing or higher-order cognition.

Speech processing is task-dependent and refers to aurally presented speech, while speech perception is the process of transforming this into a speech signal for comprehension (Hickok and Poeppel, 2007). Speech perception occurs through heavy reliance on the dorsal stream, whereas speech recognition relies mainly on the ventral stream. The ability to use this paradigm to study the perception and recognition of speech in individual people post-concussion allows researchers to tune into the area of associated deficit without having a baseline test for each individual. Knowing that concussion patients often experience diffuse injury, it is important to acknowledge multiple areas of the brain in cognitive processing.