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Repeated Measures of ImPACT Verbal Memory Scores Of Concussed And Non-Concussed Individuals

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REPEATED MEASURES OF ImPACT VERBAL MEMORY SCORES OF CONCUSSED
AND NON CONCUSSED INDIVIDUALS

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REPEATED MEASURES OF ImPACT VERBAL MEMORY SCORES OF CONCUSSED
AND NON CONCUSSED INDIVIDUALS

By

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CHAPTER 1

INTRODUCTION

Background

Concussion is defined as “any transient neurologic dysfunction resulting from a biomechanical force” (Giza & Hovda, 2001, p. 228). The American Academy of Neurology (AAN) defines concussion as “alteration of mental status due to biomechanical forces affecting the brain” (1997). For the purpose of this study, the terms concussion and mild traumatic brain injury (mTBI) may be used synonymously. The AAN classifies severity of concussion as grades with focus upon loss of consciousness, as opposed to amnesia. Within the realm of high school and collegiate sports, concussion is a commonly reported injury. The CDC (www.cdc.gov/nicpc/tbi/TBI.htm) reports that there are an estimated 1.6-3.8 million sports and recreation related concussions yearly in the United States and out of 2.4 million sports related emergency room visits yearly, 6% are concussion related. While concussions are reported frequently for many sports, such as bicycling, basketball, soccer and hockey, football related concussion injuries account for 60% of all reported sports related concussion events. It is likely that the frequency of sports related concussion is actually much higher when possible concussions that go unreported are considered. McCrea, Hammeke, Olsen, Leo, and Guskiewicz (2004) found that many concussions go unreported due to three major factors: 1. Athletes did not feel the injury serious enough to seek medical attention 2. Athletes did not want to be withheld from the game 3. The athletes did not recognize their symptoms as a concussion.

Failure of athletes, coaches, traainers, and potentially the speech-language pathologist, to recognize and properly manage concussion may lead to successive concussions and long term debilitating effects. Once concussion is diagnosed, a decision regarding an athlete’s ability to

return to the playing field must be made. Return-to-play decisions refer to clinical recommendations based on concussive symptoms, standardized and non-standardized assessment. Based on the results of this assessment the clinician makes a recommendation on when the athlete should be able to safely return to his/her sport. Historically, this decision has been based on the AAN's concussion grade scale and the return-to-play guidelines that are suggested with each grade. However, as will be discussed, concussion grades and the suggested return-to-play guidelines may be too liberal and may promote return-to-play decisions that may further endanger the concussed athlete. Indeed, sensitive and reliable instruments to measure the effects of concussion in the days following injury are warranted for safe return-to-play recommendations. One such instrument that may be used is the ImpACT battery (University of Pittsburgh, Pittsburgh, PA, 2005). The ImpACT consists of 5 subtests: verbal memory, visual memory, visual motor, impulse control, and reaction time. The available literature regarding post-concussion deficits and the clinician's role in concussion with regard to when the athlete may safely return-to-play will be discussed.

Pathophysiology of Concussion

Giza and Hovda (2001) describe the course of metabolic changes and recovery in the human brain following concussion.

“Immediately after the biomechanical injury to the brain, abrupt, indiscriminate release of neurotransmitters and unchecked ionic fluxes occur. The binding of excitatory transmitters, such as glutamate, to the N-methyl-D aspartate (NMDA) receptor leads to further neuronal depolarization with efflux of potassium and influx

of calcium. These ionic shifts lead to acute and sub-acute changes in cellular physiology. Acutely, in an effort to restore the neuronal membrane potential, the sodium-potassium pump works overtime. The sodium-potassium pump requires increasing amounts of adenosine triphosphate (ATP), triggering a dramatic jump in glucose metabolism. This “hypermetabolism” occurs in the setting of diminished cerebral blood flow, and the disparity between glucose supply and demand trigger an energy crisis” (p. 229).

This energy crisis makes the brain increasingly vulnerable to subsequent injury, with decreased ability to respond to subsequent injury, potentially leading to devastating effects. The metabolic changes which occur in the brain immediately following concussion may contribute to deficits, such as in memory, processing speed, and reaction time. Allowing the athlete to return to their sport before the metabolic processes of concussion have resolved may result in death or serious disability for the athlete.

Risks

Researchers in the field of sports concussion have found that collegiate football players who have sustained one concussion are more likely to sustain another concussion at some time in the future than their peers who have not sustained a concussion. (Guskiewicz, McCrea, and Marshall, 2003). Guskiewicz and colleagues (2003) followed 4251 football players and found 6.3% had one concussion and 6.5% reported a second concussion in the same season. Those that have sustained a concussion may be at three to six times the risk of a second concussion than those who have not had a concussion. In fact, Guskiewicz and colleagues (2003) report that 1

out of 15 players will not only receive a second concussion, but will do so during the same playing season. They found that in-season concussions often take place within 7-10 days of each other. They report that 91.7% of athletes who report a second in-season concussion will do so within 10 days of the 1st concussion. 75% will report a second concussion within 7 days. This is a significant concern since metabolic processes taking place in the brain have yet to fully resolve. Although the results of studies examining the long term effects of multiple concussions are inconclusive at this time, Iverson, Gaetz, Lovell, and Collins (2004) found that amateur athletes who sustain multiple concussions (n=19, high school and college) report more concussive symptoms and demonstrate lower memory scores when tested via ImPACT battery at 5 days post injury. In fact, they report verbal memory scores that demonstrate as much as a 14 point decline. However, a study by Iverson, Brooks, Lovell and Collins (2006) of 30 amateur athletes found that no long term effects were recognized following only one or two concussions. They found verbal memory scores to be significantly lower at day one and day five post injury, but no significant difference in pre-season baseline and post concussion verbal memory scores at day ten.

Second Impact Syndrome

In addition to the possible risks associated with one or two concussions is the risk of “second impact syndrome”. Second impact syndrome is associated with athletes who receive a second concussion while still in the recovery process from a previous concussion, as described by Giza and Hovda (2001). Second impact syndrome consists of a rapid deterioration of neural function often with no time for medical intervention resulting in death or severe impairments. McCrea (2008) describes the course of second impact syndrome as coma followed by respiratory

failure as a result of increased intracranial pressure. Although rare, McCrea and colleagues (2004) report the occurrence of second impact syndrome is directly linked to athletes not reporting concussive symptoms or being improperly assessed and managed by coaches, trainers, or other health professionals. Therefore, health professionals must be familiar with the reliability of the instruments being used to make crucial return-to-play decisions. No one instrument should be used in isolation to make return-to-play decisions. It is crucial to concussion management that the instrument that is utilized is reliable and able to detect subtle changes in cognitive functions, such as changes in verbal memory. Failure to detect such changes and to properly manage concussive symptoms may result in more devastating effects for the athlete in quality of life and academic pursuits.

Cognitive Linguistic Tests

Cognitive linguistic tests assess the domains of cognitions that are affected frequently by concussion, such as memory, attention, processing of information, and motor speed (Collins and Hawn, 2002). Prior to the utilization of computer based cognitive linguistic testing, assessment of sports concussion consisted of pen and paper tests. While these are as reliable as computer based tests, there are a number of disadvantages. Collins and Hawn (2002) cite disadvantages such as the requirement of such test to be administered by a neuropsychologist (which would not be available in many populations). Another drawback to the traditional pen and paper test is the amount of time these tests require for administration, often 4-5 hours. Finally, traditional pen and paper tests requires each athlete to be tested individually. The disadvantages associated with pen and paper cognitive linguistic tests make such tests impractical for most athletic settings and severely limit the number of athletes tested.

Schatz and Zillmer (2003) describe the advantages of computer based cognitive linguistic testing to include quick data collection and precise measurement for multiple domains. Lovell, Bradley and Collins (2004) include advantages such as the ability to obtain baseline and to test large numbers of participants with more accurate measurement of response times (up to 1/100th of a second). Increased accuracy allows the clinician to more easily detect subtle changes in performance. Computer based tests, such as the ImPACT battery, provide randomization of stimuli to decrease the probability of the “practice effect” thus increasing the reliability of the instrument. Evidence of the “practice effect” reduces the reliability as positive changes in performance as a result of repeated exposure to the instrument may make deficits less noticeable to the clinician (Collie, Maruff, Makdissi, McStephen, Darby, & McCrory, 2004). Changes in performance due to “practice effect” may be misinterpreted as improvement. Therefore the clinician does not have adequate information to make a valid return to play recommendation. Misinterpretation of performance may lead to a return-to-play recommendation that may further endanger the athlete. A return-to-play decision made too early and without adequate information increases the athlete’s chance of re-injury and potentially devastating effects.

Reliability

According to Hegde (2003), reliability is “consistency among repeated observations of the same phenomenon” (p. 204). Although fluctuations among values measured are to be expected, if they differ widely, then the measure should not be considered reliable. “Divergence in the values of repeated measures should remain within certain limits (p. 205). Therefore it is expected that scores should remain stable upon repeated measures. Stable scores demonstrate reliability of the measure for detecting cognitive change.

Randolph, McCrea and Barr (2005) reviewed the most widely used computer based cognitive linguistic tests, including the ImPACT (University of Pittsburgh, Pittsburgh, PA, 2005) Automated Neuropsychological Assessment Metrics (ANAM) (Falls Church, VA, n.d), CogSport (Cogstate Ltd, Victoria, Australia, 2010) and Headminder Concussion Resolution Index (Headminder Inc, New York, NY, 2001). These investigators concluded that none have met the criteria necessary to support their clinical use in assessment nor management of concussion due to lack of published validity and reliability data. Therefore, reliability for test-retest must be demonstrated for the use of tests such as ImPACT. This is necessary for clinical assessment and management of sports concussion in order to make a valid return-to-play decision.

One commonly used measure of reliability is the “Reliable Change Index” (RCI) (Jacobson & Traux, 1991). RCI is a mathematical calculation designed to aid the clinician in making decisions concerning return-to-play. It provides the clinician with a value which can be said to be representative of a statistical change in performance. Unreliable tests will result in a greater test-retest RCI score. However, RCI does not provide the clinician with information concerning practice effects as a result of repeated exposure or other variable that may have impacted performance (Collie et al. 2004).

Concussion Management

The athlete’s self-report of symptoms, in addition to cognitive performance on tests, should be considered when deciding when the athlete is appropriate to return to his/her sport safely. The athlete should be asymptomatic at rest and when participating in physical activity. The athlete should also be at or above baseline levels using cognitive linguistic tests, such as Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) (University of

Pittsburgh, Pittsburgh, PA, 2005), Cogsport (Cogstate Ltd, Victoria, Australia, 2010), and HeadMinder Concussion Resolution Index (HeadMinder Inc, New York, NY, 2001), prior to returning to the playing field to decrease the risks of re-injury. However, “it is imperative that clinicians understand that the cognitive data derived from these instruments is not a panacea for concussion management. Rather, these tools provide one piece of the clinical data for which to make complicated decisions regarding clinical management and eventual return to play options for the concussed athlete”(Lovell, Collins, Bradley, 2004, p.435) In regard to cognitive linguistic testing, specifically the ImPACT battery, Iverson, Lovell, and Colline (2003) emphasis that scores are meant to “supplement, not replace clinical judgment” (p.466)

Recovery

In order to properly assess and manage the concussive symptoms one must understand the expected course of recovery that takes place. The World Health Organization (WHO) Collaborating Center Task Force on Mild Traumatic Brain injury published a review of 120 articles meeting criteria on the recovery of mTBI. Findings suggest that for both children and adults, the symptoms following mTBI are transient with resolution of symptoms within 3 months post injury. Sixty-six studies were related to adult concussion (mTBI), and 11 of those studies directly dealt with sports related concussion. From the 11 sports concussion related articles, Carroll, Cassidy, Peloso, Borg, Holst, Holm, Paniak, and Pepin (2004) found that symptoms reported by athletes usually resolve quickly, however acknowledge that athletes often under report symptoms in order to return to the playing field. Additionally, the recovery of reported mTBI symptoms varies among individuals. Iverson, Brooks, and Lovell’s (2004) study of 30 concussed high school and collegiate athletes revealed that deficits and reported symptoms

related to concussion had mostly resolved by day 5 when compared to day 1. Full resolution of symptoms by day 10 post injury was observed based on comparison from scores on day 5. However, they did report that 2 of the athletes did not fully recovery by 3 weeks post injury. McCrea (2008) reported 85% of concussed athletes report full recovery within 1 week, with 21% reporting full recovery within 1 day. The 21% reporting recovery within 1 day demonstrated improvement in cognitive function within a few hours post injury. Fewer than 3% of subjects reported symptoms that persisted for more than one month. While much of the literature suggests recovery within 7-10 days post injury, McClincy, Lovell, Pardini, Collins and Spore (2006) hypothesized that concussion recovery may take significantly longer periods of time.

Recovery of Memory

McClincy and colleagues (2006) reported that deficits in the area of verbal memory persisted at 14 days post injury for both high school and collegiate athletes. Verbal memory refers to the encoding, storage and retrieval of words spoken and/or printed both for short and long term retrieval. Carroll, et al (2004) attributed post concussive symptoms which persist beyond 3 months to be associated with other factors, such as demographics, psychosocial, medical, or situational. The possibility of continued deficits in the area of verbal memory is significant to the amateur athletic population. Verbal memory is crucial to future learning ability. Deficits in verbal memory may affect academic performance and overall academic achievement. Therefore, verbal memory is a domain which research should focus attention. Currently, there is limited research dealing specifically with concussion and effects on verbal memory.

The AAN guidelines that are widely used fail to address the issue of verbal memory for return-to-play recommendations. McClincy and colleagues (2006) and Oliaro, Anderson, and Hooker (2001) criticized the widely used Colorado Guidelines and the American Academy of Neurology guidelines and the reliance on these grading scales for making return-to-play decisions, regardless of age, playing level or gender. Oliaro and colleagues (2001) point out that concussion grading scales are mostly focused on loss of consciousness, while ignoring other concussive symptoms that would warrant a longer removal time from play. Lovell, Collins, Iverson, Johnston, and Bradley (2004) used the ImPACT battery to test for deficits following AAN Grade 1 concussion in 43 high school athletes. According to AAN guidelines (1997), these athletes are permitted to return to play after 15 minutes. However, Lovell and colleagues (2004) found that these athletes demonstrated significant deficits in memory at 36 hours post concussion. Lovell and colleagues (2004) demonstrated that the AAN guidelines may be too liberal with regard to return-to-play decisions, ultimately endangering the athlete. Given the lack of supporting evidence for the current concussion guidelines, such as that of the AAN, instruments to detect more subtle changes in cognitive function are warranted for concussion management and safe return-to-play. Collins and colleagues (1999) found the use of cognitive linguistic tests useful in detecting subtle changes in cognitive performance following concussion.

Rationale for Study

Throughout the review of the available literature, investigators conclude that following concussion, memory is consistently the domain in which deficits are most evident (Kwapil, Geffen, McFarland, Demonte, 2003; Lovell et al., 2004; Collins, Lovell, Mckcag, 1999; Field et al., 2003) Memory consist of the encoding, storage, and retrieval of information at the short or

long term level. Memory appears to be impacted more so than processing speed and reaction time. Additionally, it is verbal memory that takes the longest amount of time to return to baseline levels following concussion. Verbal memory is salient to the amateur athletic population due to their age and academic status. The failure to recognize and manage deficits of verbal memory in the acute stages of concussion may impact the athlete's academic life and the attainment of academic and quality of life goals. The literature overwhelmingly supports the full resolution of concussive symptoms, as detected with cognitive linguistic tests, within 10 days of concussion. Therefore, it would be expected that verbal memory scores, as measured by ImPACT, will be stable following complete recovery of concussive symptoms (at least 6 months post injury in the current study). The clinician must integrate interpretation of cognitive linguistic tests with clinical judgment in order to properly manage concussion and make safe return-to-play decisions. Stable scores would indicate ImPACT is a reliable tool, in addition to clinical judgment, for concussion management and safe return-to-play recommendations.

Purpose of Study

The purpose of this study was to measure the stability of verbal memory scores using the ImPACT battery for concussed athletes and non-concussed control participants.

Hypothesis

Based on the current literature regarding concussion and the course of recovery, it is hypothesized that there will be no clinical difference between subsequent tests of verbal memory composite scores via ImPACT for concussed and non-concussed individuals over time.

The ImPACT battery normative data is divided into seven categories of severity rank ranging from impaired performance to very superior performance. For the purpose of this study, stability is operationally defined as ImPACT verbal memory scores that do not vary across more than 2 consecutive severity categories as defined by the normative data (Table 3). The range of severity categories used to define stability are based upon experience testing concussed athletes.

CHAPTER 2

METHODS

Institutional Review Board/Consent

The UTEP Institutional Review Board approved this study in January, 2010 (125836-1) Consent forms were also approved by both the UTEP Institutional Review Board and 3 members of the UTEP Health Sciences faculty.

Measures

This study utilized the ImPACT computerized cognitive linguistic test which was designed to identify impairment following concussion in the domains of visual and verbal memory, processing speed, visual motor skills, and reaction time. The ImPACT battery is a self-administered test, although test is overseen by a trained clinician. Scores are automatically generated via ImPACT software which allows for a complete report which includes normative data. Four composite scores are generated by the test: verbal memory, visual memory, reaction time, and processing speed. For the purposes of this study, only the composite scores for verbal memory were analyzed. ImPACT verbal memory composite is comprised of tests which include word learning and word/letter recognition memory. Administration of the ImPACT battery requires 20-30 minutes.

Participants

This study was comprised of 6 university students, 3 of whom were collegiate athletes with a history of at least 1 concussion. The control group consisted of 3 university students who had no self-reported history of concussion. Concussed athletes were chosen from the UTEP Concussion Management Clinic database based upon time post concussion (greater than 6

months) and presence of pre-season baseline data as well as post concussion data. Participants 1 and 3 reported history of 1 concussion. Participant 2 reported a history of a 2nd concussion (6 months prior to the beginning of the study. Concussed athletes participating in the current study were originally tested pre-season or off season for baseline using the ImPACT battery. At that time, participants signed informed consent documents stating that data generated from their participation data may be used for future research in the UTEP concussion management clinic. After injury, the concussed athletes were seen in the UTEP concussion management clinic for a minimum of 3 post concussive test administrations. Scores post concussion were then compared to baseline data, in addition to self-reported symptoms, in order to make a return-to-play recommendation. Prior to the beginning of the current study, participants were again asked to sign informed consent documents.

Control, non-concussed participants were selected based upon availability to participate in the study. All control participants were recruited from the UTEP College of Health Sciences. Each participant was asked to sign informed consent documents prior to participation in the current study. Control non concussed subjects were matched to the concussed subjects based on age and gender. All participants reported between 13 to 15 years of education not including kindergarten. Neither control nor concussed participants reported having a learning disability.

Table 1: Participants with pre-season baseline data and a history of concussion taken from the database of the UTEP Concussion Management Clinic.

| Participant (concussed) | Age | Gender | Years of Education | Time post injury |
|-------------------------|-----|--------|--------------------|------------------|
| 1 | 24 | Male | 15 | 18 months |
| 2 | 21 | Male | 15 | 6 months |
| 3 | 21 | Female | 14 | 24 months |

Table 2: Participants recruited from the College of Health Sciences with no reported history of concussion

| Participant (no concussion history) | Age | Gender | Years of Education |
|-------------------------------------|-----|--------|--------------------|
| 4 | 24 | Male | 13 |
| 5 | 21 | Male | 14 |
| 6 | 21 | Female | 13 |

Procedures

Concussed participants meeting the described criteria were asked to return to the UTEP Concussion Management Clinic at least 6 months post injury for reassessment using the ImPACT battery. Concussed participants and non concussed control participants were tested three times, with each testing session 7 days apart. Each participant was compensated in gift cards valued at a total \$50.00 over the course of the three testing sessions. All participants were tested in a noise and disruption free environment with a trained speech-language pathology graduate student present at all times. Each participant was advised to ask the clinician for verification of directions for each task if the participant was unsure of the task. When each participant completed the study composed of three consecutive tests, a report was generated to include the participant's scores as well as the ImPACT normative data. Each participant's scores were analyzed using the normative data published in the ImPACT testing manual to determine the severity category in which they fell. Then the participants' scores were analyzed to

determine whether they varied across more than two severity categories. Baseline scores for concussed individuals were not reported. Stability of scores was determined by comparison of participant's scores with the normative severity data for University Men and University Women published in the ImPACT test manual as well as visual inspection of the data.

Table 3: Normative data for University men and women published in the ImPACT testing manual

| Normative Date for University students | VERBAL MEMORY University Men | VERBAL MEMORY University Women |
|---|---|---|
| Impaired | ≤ 71 | ≤70 |
| Borderline | 72-77 | 71-82 |
| Low | 78-82 | 83-86 |
| Average | | |
| Average | 83-94 | 87-97 |
| High | 95-97 | 98-100 |
| Average | | |
| Superior | 98-99 | -- |
| Very | 100 | -- |
| Superior | | |

CHAPTER 3

RESULTS

In order to evaluate the stability of scores for the verbal memory portion the ImPACT test, each participant's scores were graphed individually and compared to the normative data for University men and women published in the ImPACT test manual. Stability is operationally defined for the purpose of this paper as scores that do not deviate between more than 2 consecutive categories of performance as described in Table 3. Three of the six participants demonstrated stable performance using the described definition for determination of stability.

Concussed participants 1, 2 and 3 were not stable over the three testing sessions (Table 4). Verbal memory composite scores for participant 1, a 25 year old male, were: 88, 89, and 98. Verbal memory composite scores for participant 2, a 21 year old male, were 89, 96, and 99. Verbal memory composite scores for participant 3, a 21 year old female, were: 70, 65, and 83.

Non-concussed participants 4, 5, and 6 were stable over the three testing sessions (Table 5). Verbal memory composites scores for participant 4, a 25 year old male, were: 94, 95, and 95. Verbal memory composite scores for participant 5, a 21 year old male were: 58, 91, and 89. Verbal memory composite scores for participant 6, a 21 year old female were: 88, 96, and 100.

Concussed participant 1, 2 and 3 (Table 4) did not demonstrate stable verbal memory scores. All concussed participants' scores fell outside of the two consecutive severity categories of performance. It is important to point out that concussed participant 2 reported a second concussion, but was at 6 months post injury at the time of the study. Concussed participant 1 demonstrated an increase in verbal memory scores from 88 (average) to 98 (superior). Concussed participant 2 also demonstrated an increase in verbal memory composite scores from

89 (average) to 99 (superior) over the 3 week testing period (Table 4). Concussed participant 3 demonstrated an increase in scores from 82 (borderline) to 91 (Average). Participant 3 then decreased from 91 (average) to 84 (low average).

Table 4: Scores for participants with history of concussion compared to the normative data for University men and women published in the ImpACT testing manual.

| Normative Date for University students | VERBAL MEMORY University Men | Scores for Participant 1 (male) | Scores for Participant 2 (male) | Scores for Participant 3 (female) | VERBAL MEMORY University Women |
|--|------------------------------|---------------------------------|---------------------------------|-----------------------------------|--------------------------------|
| Impaired | ≤71 | | | | ≤70 |
| Borderline | 72-77 | | | 82 | 71-82 |
| Low | 78-82 | | | 84 | 83-86 |
| Average | 83-94 | 88, 89 | 89 | 91 | 87-97 |
| Average | 95-97 | | 96 | | 98-100 |
| High | 98-99 | 98 | 99 | | -- |
| Average Superior | 100 | | | | -- |
| Very Superior | | | | | |

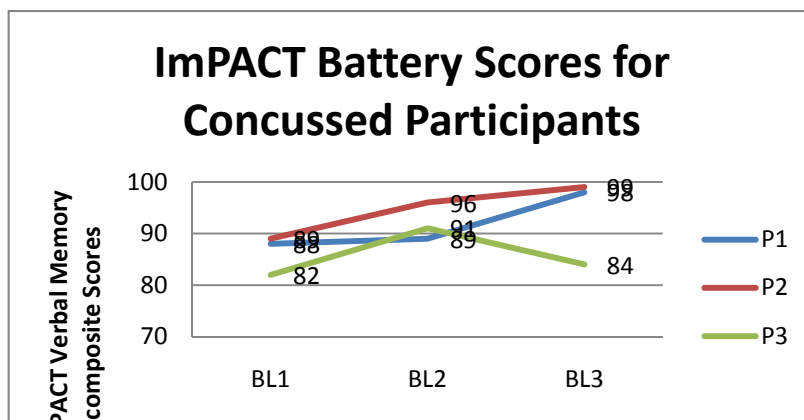


Figure 1: Scores for participants with history of concussion, including last post concussion testing session.

Table 5: Scores for controls without a history of concussion compared to the normative data for University men and women published in the ImpACT testing manual.

| Normative Date for University students | VERBAL MEMORY University Men | Scores for Participant 4 (male) | Scores for Participant 5 (male) | Scores for Participant 6 (female) | VERBAL MEMORY University Women |
|--|------------------------------|---------------------------------|---------------------------------|-----------------------------------|--------------------------------|
| Impaired | ≤ 71 | | | | ≤70 |
| Borderline | 72-77 | | | | 71-82 |
| Low | 78-82 | | | | 83-86 |
| Average | | | | | |
| Average | 83-94 | 94 | 85, 91, 89 | 88 | 87-97 |
| High | 95-97 | 95, 95 | | 96, 100 | 98-100 |
| Average Superior | 98-99 | | | | -- |
| Very Superior | 100 | | | | -- |

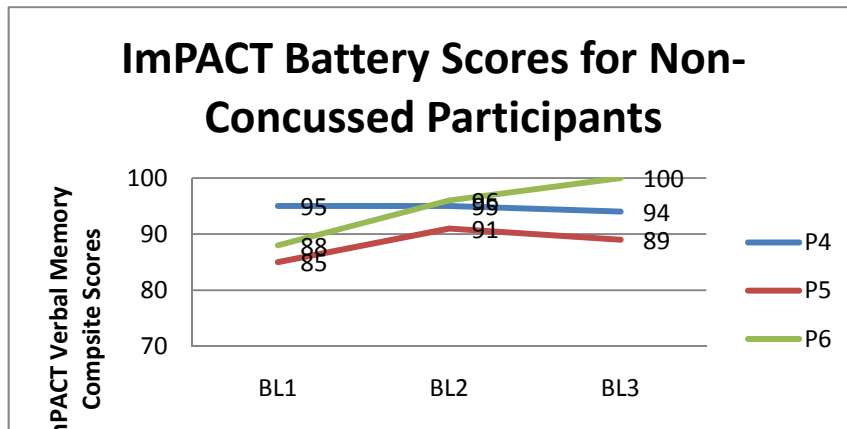


Figure 2: Scores for controls without reported history of concussion.

CHAPTER 4

DISCUSSION/IMPLICATIONS

Sports concussion is a significant concern within the amateur athlete population, although not a new one. The effects of concussion have been studied by investigators such as Iverson, Collins, McCrea and many others over the last 20 years. Given the large number of high school and collegiate students who participate in athletics that might experience a concussion, it is important that a concussion be managed appropriately so that the athlete's social and employment potential is not negatively impacted.

For the practicing clinician, it is important for concussion management that the implemented test instrument is valid and reliable. The clinician should feel confident when interpreting the reported scores. Since athletes often under report symptoms in order to quickly return to the field, the clinician must have a reliable test instrument capable of detecting the subtle changes associated with concussion recovery. Recovery of concussion may be noted as the player returns to or exceeds his/her baseline performance.

The results of this study provide important information. The results indicate ImPACT verbal memory scores are stable for the three non-concussed participants. The three concussed participants did not demonstrate stable verbal memory scores. Their scores varied outside of the two consecutive severity categories. Stability for this study was defined as ImPACT verbal memory scores that do not vary across more than two severity consecutive categories (Table 3). Therefore, for the concussed participants the research hypothesis is rejected based upon visual inspection of the data. However, this study does indicate that the non-concussed participants demonstrated stable verbal memory scores while the concussed participants' performance was not stable.

Interestingly, two of the three participants from the concussed group demonstrated an increase in scores over the three week testing period. The ImPACT battery attempts to minimize practice effect by randomization of stimuli during each test session since the ImPACT is designed to monitor a concussed athlete over time to document recovery from concussion. Additionally, the present study design attempted to decrease the probability of the practice effect by spacing the testing sessions seven days apart (Collie et al., 2004). However, the athletes may have become familiar with the test structure. In spite of these procedures, the concussed athletes showed evidence of learning. For example, Participant 2's scores were not stable; however his unstable scores may be a result of two self-reported concussions, the most recent occurring six months prior to this study. Current research reports that individuals with one or two concussion do not show any long-term effects of concussion (Iverson, Brooks, Lovell, and Collins, 2006).

Another factor that may contribute to the instability of concussed participants' scores may be repeated exposure to the test. All of the concussed participants had been previously tested a minimum of four times prior to the initiation of this study. This repeated exposure may have increased the probability of the practice effect. However, one would expect the non-concussed participants to benefit from repeated exposure to the test, but they did not. The role of "practice" is an open question requiring further research.

Interestingly, the non-concussed participants' stable verbal memory scores are consistent with the operational definition of stability. The problem of interpreting their performance in comparison to the concussed participants raises an important consideration. Could the performance of the concussed athletes be attributed to their history of concussion? On the other hand, considering the time post onset their performance should be not adversely affected. The

three concussed participants showed improvement in their performance suggesting there are no continuing adverse affects from their initial concussion. So is their performance a reflection of practice or fluctuations in cognitive status?

The results of this study indicate that ImPACT verbal memory scores may not be stable over time in participants recovering from concussion. It is the clinician's objective to make a recommendation, based on the available information, as to when the athlete can safely return to the playing field. The athlete may be held out one week or more depending on the results of the cognitive linguistic tests and symptoms reported.

The ImPACT test of verbal memory is only one piece of information used to make a return-to-play recommendation. This conclusion is consistent with the findings of other investigators as described in the literature (Lovell, et al, 2004; Iverson et al., 2003). Lovell et al. (2004) suggested that the cognitive information that is collected from test such as the ImPACT is not the perfect solution for concussion management. Iverson et al. (2003) states that scores are meant to "supplement, not replace clinical judgment (p. 466). The athlete's concussion history, post concussion sideline data (as measured by the AAN (1997), Colorado (1990), or Cantu guidelines (Cantu, 1988)), self-reported symptoms, cognitive linguistic test results, input from the athletic trainer, and the clinician's judgment and knowledge of expected recovery should all be considered when making a return-to-play recommendation.

Clinical judgment should play important role as to when the athlete may safely return to the playing field with decreased risks of life-threatening "Second Impact Syndrome". Although rare, the risks of "Second Impact Syndrome" can be avoided with the proper management of concussion (McCrea 2008). Proper management of the concussion may require the athlete to

refrain from the playing field until assessment measures indicate that the concussion has resolved and the athlete is safe to return to his/her sport. The symptoms reported by the athlete should be consistent with all other measures of assessment when making a return-to-play decision for the athlete who has been concussed to avoid death or disability as a result of playing too early and sustaining a second head injury prior to the full resolution of the first. This is especially important given the findings of Guskiewicz and colleagues (2003) that suggest that repeated in-season concussions often take place within 7-10 days of each other. This 7-10 day time frame is crucial due to the metabolic changes taking place in the brain described by Giza and Hovda (2001). These changes make the brain increasingly vulnerable to severe deficits or death should a second injury occur before the complete resolution of the first.

Conclusion

Best practices for concussion management include the integration of many test instruments to track both physical and cognitive linguistic change in the acute stage of concussion. The ImPACT battery scores, the athlete's reported symptoms, and the input of others involved in the care of the athlete should all be taken into consideration when deciding when the athlete's concussion has resolved completely and when he/she may safely return to his/her sport.

Limitations

Limitations of the current study include: 1. the small number of concussed participants 2. The number of concussions for each participant was based on self-report. 3. The current study focused only upon verbal memory scores. ImPACT assesses other domains associated

with concussion, such as response time and visual memory, which should also be studied for stability.

Future Directions

Future studies should strive for larger groups of concussed athletes and non-concussed participants to investigate the issue of stability across concussed and non-concussed participants for all domains assessed by ImPACT. Future studies should also explore the stability of ImPACT verbal memory for athletes reporting 3 or more concussions. The current study focused on the verbal memory scores obtained during a three week testing period; however future studies may benefit from the inclusion of baseline and post concussion tests when exploring the stability of ImPACT with concussed athletes.

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CURRICULUM VITA

DeShea Davis Gornowicz was born in Hattiesburg, Mississippi. The second daughter of Ray and Patricia Davis, she graduated from Perry Central High School in New Augusta, MS in 1996. In the fall of the same year, she was accepted to the University Of South Alabama (USA) where she pursued a Bachelor of the Arts in English Literature. DeShea graduated from USA in 2000.

Immediately following graduation, DeShea married Lieutenant Jeff Gornowicz. DeShea and Jeff soon after moved to Germany where they resided for 4 years. During her time in Germany, DeShea traveled extensively, immersing herself into the European culture and volunteering her time with the US ARMY helping the families of deployed soldiers.

After returning to the United States in January of 2005, DeShea made the decision to return to school to pursue a Master's in Speech-Language Pathology at the University of Texas at El Paso. She was accepted to the program and began her graduate studies in the fall of 2008. She completed her graduate degree studies in the spring of 2010.

Following graduation, DeShea looks forward to a rewarding career in Speech-Language Pathology with a particular interest in adult rehabilitation of cognitive communication, specifically Soldiers, who have sustained a TBI as a result of combat duties. She also looks forward to continuing travel within and outside of the United States.