AN ABSTRACT OF THE THESIS OF

Diana M. Padilla for the degree of Master of Science in Exercise and Sport Science presented on July 20, 2005.

Title: A Comparison of Two Neuropsychological Concussion Assessment Batteries

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Abstract approved: ______________________

Mark A. Hoffman

Objectives: To compare the neuropsychological concussion assessment testing batteries of the Standardized Assessment of Concussion (SAC™) test and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT™) test and determine if the tests measure similar neuropsychological functions as well as determine the test-retest reliability of the pre and post season measures in non-concussed athletes.

Design: Neurocognitive assessment was performed via the Standardized Assessment of Concussion (SAC™) test and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT™) with pre-season and post-season

measures during one competitive athletic season on healthy non-concussed athletes.

Participants: A total of 74 healthy, non-concussed collegiate athletes ($N_{\text{Men's Basketball (MBB)}} = 12$, $N_{\text{Men's Soccer (MS)}} = 22$, $N_{\text{Women's Soccer (WS)}} = 19$ $N_{\text{Volleyball (VB)}} = 14$) were studied over the course of the 2004 competitive intercollegiate athletic season. An additional subset group of 20 non-competitive college age and gender matched ($N_{\text{Men's Control (MC)}} = 10$, $N_{\text{Women's Control (WC)}} = 10$) controls volunteered for participation in the study.

Main Outcome Measures: Performance on the Immediate Post Concussion Assessment Test and the Standardized Assessment of Concussion were measured. Data from subcomponents of each test including the learning memory (VML= ImPACT Learning Word Memory; SIM= SAC™ Immediate Memory), Delayed Memory (VMD= ImPACT™ Delayed Word Memory; SDM= SAC™ Delayed Memory), and Composite (VMC= ImPACT™ word memory composite; SC= SAC™ Immediate Memory Composite) scores were utilized for comparison in this analysis.

Data Analysis: To determine if group differences existed between the pre and post season baseline scores, three separate 2 (time) x 2 (test) x 2 (gender) mixed design analysis of variance (ANOVAs) were calculated for the composite scores of the SAC™ and ImPACT™ tests. To determine the strength of the relationship between the SAC™ and ImPACT™ scores a bivariate Pearson Product Moment Correlation was calculated for both the pre measurements as well as for the post measurements. Reliability of each subcomponent was analyzed utilizing interclass

correlation coefficients. Significance level ($\alpha = 0.05$) for all assessments was set a priori for all statistical analyses.

Results: The main effect for time was significant (p= 0.04) for the variable of Immediate Memory while the main effect of gender was significant (p=0.096) for the composite variable. Results of the Delayed Memory analysis indicate a significant 2 way interaction test x time (p=0.031). Non-significant findings were reported for all other main effects, 2-way and 3-way interactions. A statistically correlation (r=0.302) was shown between the mean performance during test time one (VML1, MSIM1), and (r=0.223) between tests on test time two (VML2, MSIM2). Non-significant interclass correlations were demonstrated for all measures excluding the ImPACT™ 3 Letter Average Counted test (R= 0.6909), and the ImPACT™ Delayed Memory component (R= 0.5828) which had statistical significance, but lacked clinical significance when comparing each individual component at a baseline assessment re-test interval.

Conclusions: Our results revealed a statistically poor relationship between the two testing batteries in their consistency in baseline measurements over time. The results of this study allow us to suggest that both assessments' verbal memory components assess similar brain functions, with score performance varying at similar rates between tests over time. The low reliability of the testing components over an extended time period emphasizes that clinicians must acknowledge the importance of the stability of these scores over time as the baseline measurement is the measure in which data are compared following

concussive injury, and is a key factor in tracking the recovery of an athlete and guiding return-to-play decisions.

A Comparison of Two Neuropsychological Concussion Assessment Batteries

by
Diana M. Padilla

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Contribution of Authors

Dr. Mark A. Hoffman assisted in the conception and design, writing, analysis and interpretation of the data for this Master's of Science thesis.

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CHAPTER I: INTRODUCTION

Introduction

Concussion commonly results from trauma to the head incurred during athletic participation. Over the past decade, assessment of sports related concussion has received a considerable amount of attention. With the incidence of sports related concussion reaching over 300,000 cases per year[2, 6, 40], a consensus on assessment and guidelines for management of this potentially life threatening injury is necessary. According to the National Collegiate Athletic Association Injury Surveillance System, the incidence of head injury ranges from 0.06-0.55 per every 1,000 athletic exposures per year[3]. Due to the cumulative neuropsychological deficits following concussion, assessment and close observation of the injured athlete is critical in the prevention of catastrophic brain injury[25].

One of the biggest challenges faced by athletic trainers, physicians, and other medical professionals involved in the health care of athletes is the recognition and management of mild concussion[37]. The persistence of post-traumatic symptoms after mild head injury has long been recognized, and concern remains that sustaining repetitive concussions or returning to play prior to complete resolution of post concussive symptoms can have a potential catastrophic or long term effect on cognitive functioning[19]. Second impact syndrome is an incident in which an individual returns to participation and sustains another head injury prior to the total resolution of the first, causing a serious injury or death[12].

Currently, the evaluation and treatment of cerebral concussion is clinically challenging due to a substantial level of confusion and disagreement regarding the definition of concussion, establishment of return to play guidelines, and the use of standardized assessment measures. The 1966 Committee on Head Injury Nomenclature Congress of Neurological Surgeons[1] defined a cerebral concussion as a clinical syndrome characterized by an "immediate and transient impairment of neural functions, such as alterations of consciousness, disturbances of vision and equilibrium due to brain stem involvement." Despite its long term acceptance, this definition is not universally accepted. This definition, as with most others was constructed with return-to-play guidelines, none of which specifically designed on the basis of scientific knowledge, rather they were formulated based upon anecdotal or clinical experience[23, 31].

Current guidelines for grading sports-related concussion are based on the parameters of the severity of injury and the patient's history of concussion[26]. The three most widely used guidelines are those proposed by the American Academy of Neurologists[25], the Colorado guidelines[4], and those proposed by Cantu[10, 11]. In the assessment of injury severity, all three grading systems take into account the nature and duration of the key injury characteristics of concussion. To date no one scale or set of guidelines are consistently followed, nor has one emerged as a gold standard in sports medicine[23].

The lack of agreement regarding the management of sports related concussion can be partially attributed to the general lack of objective research correlating post concussion outcome to the initial signs and symptoms of the injury[15]. Current research reflects the importance of sideline assessment measures, the inclusion of baseline assessments, and the introduction and utilization of computerized neuropsychological assessment testing batteries[5, 16-18, 22, 24, 25, 30, 38, 39].

An objective, quantifiable initial concussion assessment tool needs to be developed in order to determine return-to-play criteria[37], thus possibly decreasing the incidence of long-term decreased cognitive functioning. Neuropsychological assessment is one plausible objective method of assessing the resolution of concussion in athletes. As reported by Barr[8], it is common knowledge among neuropyschologists and sports medicine professionals alike that no single test is effective in diagnosing the presence or absence of concussion. Rather neuropsychological tests are administered in collective groups called testing batteries[7]. Neuropsychological assessment batteries have been developed in order to evaluate consistencies in symptoms exhibited in variation among a variety of different test scores[7]. The field of neuropsychology has recently devoted time and effort to clinical and scientific research to meet the demands of an athletic setting[7]. One advantage to neuropsychological tests in the athletic training setting is their standardized administration and use. Additionally these tests offer a means to observe concussive symptoms in a controlled manner[7].

If pre-injury evaluations have been performed, neuropsychological testing may be one of the most sensitive methods of detecting post-concussive dysfunction. These testing instruments have been demonstrated to be sensitive to subtle changes in attention, concentration, memory, information processing, and motor speed or coordination[28, 41]. Contrary to other neurodiagnostic procedures that provide information on brain structure such as computed tomography or traditional magnetic resonance imaging, neuropsychologic testing has the capacity to provide information on an athlete's functional status.

Neuropsychological testing batteries utilize numerical scales that can be compared to previously obtained test scores from the individual either through baseline measures, or in comparison with a population norm. Collectively, the information obtained from these cognitive testing batteries can be utilized to help make decisions regarding return to play criteria, or the need for further neuropsychological assessment or evaluation. Recent research using neuropsychological assessment techniques in athletes with mild cerebral concussions in college-aged athletes has shown decreased neurocognitive performance[9, 14-16, 20, 28, 32-37]. Currently, neuropsychological assessment using comparisons of pre-injury baselines and post concussion assessment is considered to be the most sensitive objective method of detecting the presence and resolution of cognitive post-concussion symptoms[21, 28].

Preseason baseline evaluation of athletes is recommended when possible as individual players vary greatly with respect to their level of performance on tests of memory, attention, concentration, mental processing speed, and motor speed[41]. It can be difficult to determine whether testing deficits are due to the effects of that concussion or are caused by secondary factors such as pre-injury learning disabilities, attention deficit disorder, or test-taking anxiety. Baseline assessment may be most useful if an athlete has a history of previous concussions, as a baseline examination can help distinguish between cognitive difficulties that are secondary to recent concussion versus those brought on by the current injury.

The aforementioned approach that recognizes the need for baseline assessments has been utilized by the Pittsburgh Steelers since 1993 and was designed based on a study conducted at the University of Virginia[29]. This protocol involves the systematic testing of the athlete at set times prior to and post concussion, and involves the evaluation of each athlete before the beginning of the season, in the event that a concussion is sustained during the season. This protocol requires that testing is repeated within 24 hours after a suspected concussion, and again approximately 5 days post injury[29].

The Standardized Assessment of Concussion (SAC™) was developed in accordance to the guidelines set forward by the American Academy of Neurologists[34] and was created in order to provide clinicians with an objective and standardized method to immediately assess mental status within minutes of sustaining concussion[33]. The SAC™ consists of four performance components, assessing orientation, immediate memory, concentration, and delayed memory[37]. These cognitive functions are representative as the most sensitive to the general effects of mild brain injury. Deficits in these cognitive functions are most often associated with mild concussive syndromes. The SAC™ takes approximately five minutes to administer and includes assessment of orientation, immediate memory, neurological function, concentration, delayed recall, and symptoms demonstrated during exertion. The SAC™ is scored from zero to 30, and can be administered in three varying, but equivalent test forms (A, B, and C). Recent validation studies have demonstrated that the SAC is accurate in classification of concussed athletes from a non-concussed control group with a 95% sensitivity and 76% specificity[8,

[32]. Additionally, concussed athletes have displayed deficits in immediate memory, delayed recall, and have demonstrated a decreased performance on post-concussive assessments when compared to their own pre-injury baseline measurements on the SAC™[37].

The Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™)[27] is a computer based neuropsychological test battery that measures attention, memory, processing speed, and reaction time to 1/100th of a second[15, 31, 39]. This test battery was designed to evaluate the multiple aspects of neuropsychological and cognitive functioning associated with mild traumatic brain injury (MTBI). The ImPACT™ test consists of three basic post concussion analysis forms, which can be transformed into an infinite number of variations by manually varying the order of stimuli administered in the test[28].

The common problem of a lack of consensus on the definitive diagnosis of concussion, and the parameters regarding the return to participation post concussion needs to be assessed in order to help prevent some of the short-term and long-term neurological consequences associated with premature return to play following concussion. Currently, sports medicine professionals are in need of an objective, quantifiable assessment protocol that can accurately help in the determination of return to play criteria that can be utilized consistently as a "gold standard" of evaluation of concussed athletes. Despite the recent success in the utilization of these two testing batteries, no test to date has evaluated the agreement of the two tests in their assessment of similar neurological assessment components.

When measuring neuropsychological performance specific assumptions must be made regarding the administration of each assessment. In this study, it was assumed that all participating subjects were honest about the presence of symptoms, and not withholding of information because they were afraid that they would be held from play, or be pressured by other teammates or coaches. Additionally, it was also assumed that each subject is experienced in the basic usage of a Windows® formatted personal computer and the operation of an optical or roller ball mouse, because the ImPACT™ assessment is performed on a computer. The final assumption of this study is that subjects would provide an accurate judge of neuropsychological functioning, and would not rush through the computerized assessment protocol due to boredom, disinterest, or conflicting or ongoing unrelated events.

Conventional neurological and neuropsychological testing techniques have significant limitations for the accurate evaluation of these conditions in athletics. Neuropsychological tests require extensive time requirements, and require a certain degree of skilled labor, and to date most tests do not have sufficient normative and test-retest reliability, nor are validated against other conventional neuropsychological measures[13]. Even if sufficient resources are available to baseline test an entire competitive team before the start of a season, the measurement properties are not ideal for repeated measure testing. This limitation was not highly evident in this study as all subjects underwent testing on specific days within the University's sports medicine setting. This limitation pertains specifically to the ImPACT™ assessment battery which is computerized, and may not be portable or accessible to the evaluating athletic trainer at an away contest. An additional limitation specific to the population assessed in this study is the availability of the same athletic trainer to perform the baseline, and post-concussion follow-up screenings. This limitation was present when a specific evaluator is away traveling with another team, or is involved with the evaluation of another athlete.

The current study was designed to investigate the relationship between the on the field Standardized Assessment of Concussion, and the computerized neuropsychological Immediate Post Concussion Assessment and Cognitive Functioning Test in their ability to identify changes in memory functioning as demonstrated in competitive collegiate athletes. An additional aim of the study was to determine the relationship of pre-season baseline assessment scores and post-season baseline assessment scores. Manuscripts from this thesis will be submitted for publication in the American Journal of Sports Medicine.

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CHAPTER II: MANUSCRIPT I

A Comparison of the Memory Components of Two Concussion Assessment Batteries

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Running Head: Concussion and Neuropsychological Testing

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A Comparison of the Memory Components of Two Concussion Assessment Batteries

Key words: concussion, neuropsychological assessment, athletic head injury

Abstract

Background: Neuropsychological testing, once available only to elite athletes, has become more accessible to an increasing number of sports medicine groups. Although many sports medicine physicians and athletic trainers currently use standardized concussion assessment measures, it may be too soon for an individual testing format to be solely recommended by sports medicine organizations. Such recognition may imply that the specific neuropsychological tests are a standard of care. There is a need to determine if specific neuropsychological concussion assessment testing batteries aimed at measuring similar neurocognitive processes are equally reliable over an extended time interval in non-concussed athletes.

Hypothesis: No significant differences will be detected between baseline assessments on the verbal memory components of the Standardized Assessment of Concussion (SAC™) as compared with the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™) assessment.

Study Design: Prospective cross-sectional study designed to evaluate neuropsychological functioning in non-concussed athletes during a test-retest time interval.

Methods: Seventy-four healthy non-concussed collegiate athletes and twenty non-competitive college age and gender matched controls completed the Standardized Assessment of Concussion (SAC™) and Immediate Post-Concussion Assessment and Cognitive Functioning (ImPACT™) tests prior to and following their respective competitive athletic season. Data from each tests verbal memory components and memory composites were utilized in this analysis.

Results: The main effect of time was significant (p= 0.04) for the variable of Immediate Memory while the main effect of gender was significant (p=0.096) for the composite variable. Results of the Delayed Memory analysis indicate a significant 2 way interaction amongst the variables of test x time (p=0.031). Non-significant findings were reported for all other main effect, 2 way and 3 way interactions. A statistically low correlation (r=0.302) was shown between the mean performance during test time one (VML1, MSIM1), and (r=0.223) between tests on test time two (VML2, MSIM2).

Conclusions: The results revealed a statistically low relationship between the two testing batteries in their consistency in baseline measurements overtime. The results of this study demonstrated that both assessments verbal memory components comparably assess similar brain functions, with score performance varying at similar rates amongst tests over time. Overall, clinicians must acknowledge the limited reliability of these scores over time among non-concussed athletes when utilizing previously measured baseline assessments as an indicator of normal un-concussed cognition.

Sports medicine professionals often struggle with concussion management decisions. The complication in decision making may stem from the wide variation in symptom presentation and the presence of a limited amount of clinical research serving as a guide to treatment. Recently, a group of concussion experts assembled by the National Athletic Trainers' Association (NATA) reviewed the latest findings in concussion research and issued a position statement[11]. The NATA statement is the first national recommendation that suggests clinicians use neuropsychological and postural-stability tests to assist in the diagnosis and treatment of concussion. The statement urges clinicians to conduct baseline testing for athletes in high-risk sports, and to conduct serial neuropsychological and postural-stability testing along with a thorough clinical evaluation in all athletes who sustain head injuries.

Neuropsychological testing is currently being used clinically across varying athletic levels including professional, collegiate and high school. Currently there is support by sports medicine professionals on the use of standardized concussion assessment measures that serve to assist clinicians in the diagnosis and management of concussion in athletes[3, 4, 6, 7, 9, 11, 19, 22]. After it has been determined that an athlete has sustained a concussion, the challenge for the clinician lies in the tracking of the athlete's recovery and determining whether it is safe for the athlete to return to athletic participation. Recent findings suggest that the use of standardized concussion assessment batteries may be helpful as a quantifiable index in which the resolution of acute and post-concussive cognitive and neuropsychological deficits can be tracked[2, 5, 11, 13, 20, 25-27, 30-32].

The two most serious effects of concussive injury are irreversible cognitive deficits, and death[10]. Returning to activity prior to the resolution of concussive symptoms can lead to either one of these complications. Due to the potential for these serious effects, clinicians must recognize and monitor the neuropsychological and neurocognitive effects associated with concussive head injury. Similar to the selection of any diagnostic test in the medical field, the choice of neuropsychological test used to assess the effects of concussion in very important.

Neuropsychological testing is a critical component in the assessment of the resolution of injury and the recognition of the complications before considering return to activity. Current research has reported that in order to maximize the clinical utility of neuropsychological assessment, baseline testing must be performed on all athletes prior to their participation in activity[10]. Without baseline data, the athlete must be compared with a population norm in test interpretation. The importance of baseline assessment is recognized when considering the fact that occasionally athletes may not be normal prior to their injury and may be represented by either low or high levels of cognitive functioning, history of prior head injury, psychiatric problems, test anxiety, attention deficit disorder, varying educational backgrounds or other various issues[10]. Due to these intrinsic factors, it is important to measure the athlete against his or her own baseline score in order to ensure a true return to normal neuropsychological functioning. Regardless of the utilization of baseline assessment prior to concussive injury, no published repors have demonstrated that a return to baseline of neuropsychological or neurocognitive values is a safe criteria to determine and athlete's readiness for return to participation[10].

Methods

Prior to data collection, the study was reviewed by and received approval from the University's Institutional Review Board. Prior to participation in this study, informed consent was obtained from all subjects in accordance with institutional guidelines regarding the protection of human subjects.

Subjects

Prior to the start of the 2004-2005 Fall Athletic Season, all new and returning men's basketball (MBB), men's soccer (MS), women's soccer (WS), and women's volleyball (VB) athletes from a PAC-10, NCAA Division I-A university underwent baseline assessment with both the SAC™ and ImPACT™ version 2.0 neuropsychological testing measures. A total of 74 healthy, non-concussed collegiate athletes (N_{MBB}=12, N_{MS}= 22, N_{WS}= 19 N_{VB}=14) were studied over the course of the 2004-05 competitive intercollegiate athletic season. An additional subset group of 20 non-competitive college age and gender matched (N_{MC}=10, N_{WC}= 10) controls (MC= male control, FC= female control) followed a similar testing pattern during the first month of school.

Baseline testing on all participating athletes was conducted by the specified athletic team's certified athletic trainer (N=4) during preseason fitness and or weight training sessions, or as a portion of a pre-participation physical examination. Each subject was administered ImPACT™ test 1, and SAC™ form A for the initial baseline assessment. All participants then underwent post-season re-evaluation baseline measurements in order to obtain comparative pre-season, post-season measurement data for all subjects. Each subject was administered ImPACT™ test 4, and SAC™ form C for the post-season baseline assessment. All post-season re-evaluations were performed an average of 173.5 days after the initial baseline assessment was conducted. Fluctuations in the test-retest interval can be attributable to the variation in the length of competitive season between each of the athlete groups, the date of pre-season physical examination and the estimated time frame utilized for the control group. Maximum, minimum and average test-retest intervals per group are presented in Table 1a.

Table 1a: Average test-retest interval for follow-up assessments

	N	Average	High	Low
Overall	87	173.5	286	74
Men's Soccer	22	185.6	249	89
Men's Basketball	12	202.9	209	199
Women's Soccer	19	189.4	286	74
Volleyball	14	159.8	124	265
Male Controls	10	137.8	211	97
Women's Control	10	136.7	188	98
Male Athlete	34	191.7	249	89
Female Athlete	33	176.8	286	74
Controls	20	137.2	211	97

Instruments and Procedures

The Standardized Assessment of Concussion (SAC™)

The Standardized Assessment of Concussion test (SAC™) is a mental-status test administered in five to seven minutes[8, 25, 28-30, 32], and was established in accordance with the American Academy of Neurologists[15] and the Colorado Concussion Guidelines [1]. The SAC is scored from 0 to 30, with a score of 30 being representative of a maximum score[8, 22, 23, 25, 28-30, 32]. Three different forms of the testing battery were utilized to minimize practice effects while tracking post-concussive recovery. McCrea, et al., (1997) demonstrated the three forms as being equivalent. The differences in the test forms occurs in words used for memory testing and in selection of digits in the concentration portion of the evaluation[25].

All certified athletic training staff received standardized training on the administration of the assessment battery. A standardized line of questioning was used throughout the administration of the SAC™. To assess Orientation, the subject was asked to provide the day of the week, month, date, year, and the time of day within one hour[28]. Immediate memory was assessed using a five word list in which the list is read to the subject to assess immediate recall, and then the same procedure is repeated for three trials. Concentration was evaluated by having the subject repeat, in reverse order a sequence of numerical digits that increase in length from three to six values[28]. Additionally, reciting of the months of the year in reverse chronological order was also utilized as part of the concentration measure[28]. Delayed recall was measured by reassessing the ability to recall the original five word list that was provided in the immediate memory section of the test[28]. Overall, the total score was calculated as a composite of the subject's performance on the aforementioned evaluation measures[8, 20, 22, 23, 28-30, 32].

Since the focus of this study was not to identify the effects of previous concussion on neurocognitive functioning, only 3 of the 4 SAC™ test subscales (immediate memory, concentration, and delayed recall) were utilized in the analysis. As an alternative to utilizing the maximum composite score of 30, the maximum modified SAC™ test score was 25. Additionally, this score was converted to a percentage to allow for comparisons between both testing batteries.

Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™)

ImPACT™ Version 2.0[17] is a computer based neuropsychological test battery that measures attention, memory, processing speed, and reaction time to 1/100th of a second[31]. The ImPACT™ program operates on any Windows® based computer, and consists of a self-reported symptom questionnaire, as well as a concussion history evaluation[31]. The baseline ImPACT™ evaluation consists of a more detailed and difficult set of neurocognitive tests compared to the SAC™ test. The ImPACT™ evaluation targets to the neurocognitive functions recognized as being most sensitive to impairment during a concussed state[30, 31]. ImPACT™ consists of a detailed inventory of symptoms and a demographic questionnaire which evaluates pertinent athletic, medical, and concussion history.

The main component of the testing battery consists of seven test modules administered to measure specific aspects of neurocognitive functioning, including tests of memory, reaction time, processing speed, and impulse control[6]. General subsets of the assessment include word discrimination, visual working memory, sequencing, visual attention span, symbol matching, and choice reaction time[31]. The Reaction Time Index represents the average time to respond in seconds. Composite scoring in this module includes choice reaction time, color match, and symbol match. The choice reaction time segment requires the athlete to mouse click the left key if a blue square appears on the screen, or right click if a red circle appears. In the color match module, the athlete is presented with three words (red, green, or blue) with the word either presented in the same color or different color of ink, requiring the athlete to respond quickly to inhibit the impulse to respond to the incorrect word[13].

The last component, the average correct reaction time utilizes the symbol match module to have the athlete mouse click on a number when a provided symbol appears on the screen. The visual motor speed index is the average of two scores. The first score is the total number of blue squares and red circles that were accurately selected in the distracter task in the reaction time index. This score is divided by four, while the second portion, the distracter task from the three letter word module is multiplied by three[13]. The three letter words module requires the athlete to perform a verbal working memory test measuring the ability of an athlete to remember a series of three consonants, immediately followed by a distracter task which requires the athlete to select a randomly displayed array of numbers in backward order from 25 to 1. This specific distracter task measures visual search and visual motor speed[13]. ImPACT™ also includes the Post Concussion Symptoms Scale[19] composed of a 22 item scale that measures symptoms commonly associated with concussion. The Post Concussion Symptoms Scale is described by Iverson et.al[13] as a measure of perceived symptoms associated with concussion during the current mental state. The athlete is asked to report their current symptoms, allowing for the tracking of symptoms over a very short interval of time[6, 13, 19].

The memory index is composed of five subset scores that measure aspects of memory such as verbal learning, recognition, visual associative, visual working, and letter memory[13]. In each test area, with the exclusion of the word memory test, all stimuli are varied automatically for each trial to minimize the practice effects. This composite index score represents the average percent correct between these five testing areas, with a percent correct score provided for both learning and delayed recognition areas of the word memory module[6, 13]. The memory scores derived from ImPACT™ have been shown[16] to be sensitive to the effects of sports related concussion, and maintain stability in non-injured controls. For the current study, verbal memory tasks were specifically used to help determine the relationship of the two assessment tests in their ability to measure specific memory constructs.

Data Analysis

Evaluation of Pre and Post Season Data

To determine if group differences existed between the pre and post season baseline scores (time), test type (type) and gender (gender), three separate 2 x 2 x 2 mixed design analysis of variance (ANOVA's) were calculated for three separate dependent variables for both the SAC™ and ImPACT™ tests. For the purposes of this study, the memory components of each testing battery were categorized into one of three dependent variable categories based upon the goal of their measurement. The three categories of dependent variables included 1) Immediate Memory, 2) Delayed Memory, 3) Composite, see Table 2a.

Table 2a: Dependent Variables		
Dependant Variable	Test: ImPACT	Test: SAC
Immediate Memory (IM)	Verbal Memory Learning (VML)	Modified SAC™ Immediate Memory (MSIM)
Delayed Memory (DM)	Verbal Memory Delayed (VMD)	Modified SAC™ Delayed Memory (MSDM)
Composite (C)	Verbal Memory Composite (VMC)	Modified SAC™ Composite (MSC)

To determine the strength of the relationship between the SAC™ and ImPACT™ scores a bivariate Pearson Product Moment Correlation between the two test types was calculated for both the pre-season measurements as well as for the post-season measurements. Significance level ($\alpha = 0.05$) for all assessments was set a priori for all statistical analyses. All data was analyzed using SPSS software (version 10.0, SPSS Inc., Chicago, IL).

Results

Ninety-two subjects (48 male, 44 female) were recruited from the intercollegiate athletic program and from the University's recreational athletic facilities to participate in this study. Of these 92 subjects, 5 subject's data was excluded from the analysis because they sustained a concussion during the course of this study. The remaining 87 (44 male, 43 female) subjects comprised the non-concussed healthy subject group whose data was utilized in this study. The competitive collegiate athlete group consisted of 67 Division I collegiate athletes. The control group consisted of 20 recreational athletes who were matched with competitive athlete subjects for gender and age. Descriptive statistics for the healthy subjects who underwent pre and post season baseline assessment are presented in Table 3a.

Table 3a: Descriptive Statistics

Testing Measure	Gender	Mean	Std. Deviation	N
ImPACT™ Verbal Learning Memory Pre-Season	Male	98.36	3.26	44
	Female	97.65	4.93	43
	Total	98.01	4.16	87
ImPACT™ Verbal Learning Memory Post-Season	Male	96.52	4.91	44
	Female	97.12	3.84	43
	Total	96.82	4.40	87
ImPACT™ Verbal Delayed Memory Pre-Season	Male	89.43	8.35	44
	Female	92.60	7.66	43
	Total	91.00	8.12	87
ImPACT™ Verbal Delayed Memory Post-Season	Male	87.55	9.27	44
	Female	91.23	8.62	43
	Total	89.37	9.09	87
ImPACT™ Memory Composite Pre-Season	Male	85.14	14.80	44
	Female	87.84	10.21	43
	Total	86.47	12.74	87
ImPACT™ Memory Composite Post-Season	Male	84.39	9.92	44
	Female	88.23	7.46	43
	Total	86.79	8.86	87
SAC™ Immediate Memory Pre-season	Male	98.64	2.72	44
	Female	98.14	4.67	43
	Total	98.39	3.80	87
SAC™ Immediate Memory Post-season	Male	98.18	3.83	44
	Female	97.67	5.02	43
	Total	97.93	4.35	87
SAC™ Delayed Memory Pre-season	Male	80.45	18.54	44
	Female	82.79	17.77	43
	Total	81.60	18.10	87
SAC™ Delayed Memory Post-season	Male	85.45	18.98	44
	Female	85.11	20.04	43
	Total	85.28	19.40	87
SAC™ Composite Pre-Season	Male	89.53	5.46	44
	Female	90.86	5.83	43
	Total	90.20	5.63	87
SAC™ Composite Post-Season	Male	90.06	5.93	44
	Female	91.93	5.40	43
	Total	91.26	5.70	87

The results of the Immediate Memory ANOVA analysis indicated no significant three-way or two-way interactions for any of the independent variables (Table 4a). Additionally, the relations among gender and test factors were statistically non-significant measures. However, the main effect for the variable of time was significant (p= 0.04, x IM pres-season = 98.198, x IM post-season = 97.374).

Table 4a: Immediate Memory 2x2x2 ANOVA's							
Source	Type III Sum of Squares	df	Mean Square	F	Sig	Eta Squared	Observed power
TEST	48.227	1	48.227	2.215	0.140	0.25	0.313
Error (Test)	1850.787	85	21.774				
TIME	59.044	1	59.044	4.364	0.040	0.049	0.542
Error (Time)	1150.012	85	13.530				
GENDER	6.858	1	6.858	0.324	0.571	0.004	0.571
Error (Gender)	1799.684	85	21.173				
TEST * GENDER	4.261	1	4.261	0.196	0.659	0.002	0.072
TIME * GENDER	9.124	1	9.124	0.674	0.414	0.008	0.128
TEST * TIME	11.528	1	11.528	0.823	0.367	0.010	0.146
Error (Test * Time)	1190.861	85	14.010				
TEST * TIME * GENDER	9.424	1	9.424	0.673	0.414	0.008	0.128

The analysis of the delayed memory dependent variable showed no significant three way interactions for any of the independent variables. A significant two-way interaction of test x time was found (p=0.031, x DM ImPACT™, pre-season = 91.01, x DM ImPACT™, post-season = 89.38, x DM SAC™, pre-season = 81.62, x DM SAC™, post-season = 85.28) due to the factor of test, Table 5a. A clear interaction effect can be depicted in Figure 1a. The main effect of gender for this category was non-significant, Table 6a.

Figure 1a

Estimated Marginal Means of Test * Time

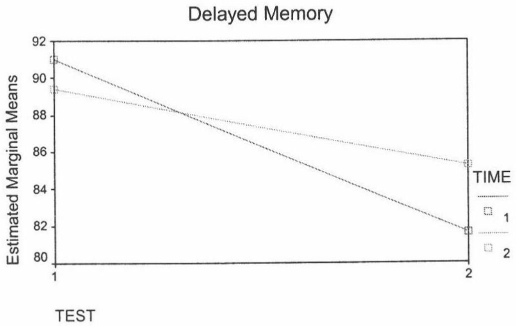

Figure 1a: The graphical depiction of the estimated marginal means of Test * Time, demonstrates an interaction effect between the two levels (test and time).

Table 5a: Delayed Memory 2x2x2 ANOVA's							
Source	Type III Sum of Squares	df	Mean Square	F	Sig	Eta Squared	Observed power
TEST	3962.948	1	3962.948	18.457	0.000	0.178	0.989
Error (Test)	18250.397	85	214.711				
TIME	89.933	1	89.933	0.601	0.440	0.007	0.120
Error (Time)	18250.397	85	214.711				
GENDER	426.575	1	426.575	1.173	0.282	0.014	0.188
Error (Gender)	30911.654	85	363.667				
TEST * GENDER	128.523	1	128.523	0.599	0.441	0.007	0.119
TIME * GENDER	25.369	1	25.369	0.170	0.681	0.002	0.069
TEST * TIME	609.038	1	609.038	4.785	0.031	0.053	0.580
Error (Test * Time)	10819.375	85	127.287				
TEST * TIME * GENDER	55.280	1	55.280	0.434	0.512	0.005	0.100

Table 6a: Estimated Marginal Means of Test * Time					
				95% Confidence Interval	
Test	Time	Mean	Std. Error	Lower Bound	Upper Bound
ImPACT™	Pre-season	91.01	0.859	89.31	92.72
ImPACT™	Post-season	89.38	0.960	87.48	91.28
SAC™	Pre-season	81.62	1.94	77.75	85.49
SAC™	Post-season	85.28	2.09	81.25	89.44

For the dependent variable of composite score, no significant differences were found on the three-way and two-way interactions. Significance was however detected with the main effect of gender (p= 0.096, x gender M= 85.72, x gender F= 87.93), and test (p= 0.00, x ImPACT™= 90.20, x SAC™= 83.45). See Table 7a for statistical presentation.

Table 7a: Memory Composite 2x2x2 ANOVA's							
Source	Type III Sum of Squares	df	Mean Square	F	Sig	Eta Squared	Observed power
TEST	1453.32	1	1453.324	16.27	0.00	0.161	0.979
Error (Test)	7589.56	85	89.289				
TIME	42.358	1	42.358	1.03	0.313	0.012	0.171
Error (Time)	3489.20	85	41.049				
GENDER	364.342	1	364.342	2.82	0.096	0.032	0.383
Error (Gender)	10957.70	85	128.914				
TEST * GENDER	45.971	1	45.971	0.51	0.475	0.515	0.109
TIME * GENDER	0.157	1	0.157	0.00	0.951	0.000	0.050
TEST * TIME	12.241	1	12.241	0.27	0.601	0.003	0.081
Error (Test * Time)	3779.32	85	44.463				
TEST * TIME * GENDER	7.918e-02	1	7.918e-02	0.002	0.966	0.000	0.050

To assess the relationships between the two tests on the various dependent variables over time, Pearson product correlations were used. An intercorrelation matrix was calculated for all pre-season and post-season ImPACT™ and SAC™ variables (Table 8a and Table 9a). Of particular interest are the results of the correlations calculated between the pre and post season scores for all subjects in each test for the Immediate Memory, and Delayed Memory Components. When comparing the ImPACT™ and SAC™ immediate memory components, there was a clinically insignificant correlation (r=0.302, Tables 8a and 9a) between the mean performance during the pre-season assessment. Additionally, another statistically low correlation was demonstrated (r=0.223, Tables 8a and 9a) between the pre-season and post-season measures. Each individual testing battery demonstrated moderate correlation (ImPACT™ r=0.597, SAC™ r=0.307, Tables 8a and 9a) within its own test between assessment 1 and 2 respectively. The correlation between the composite scores for both assessments were low for both pre-season measures (r=0.156, Tables 8a and 9a), and post-season measures (r=0.170, Tables 8a and 9a).

Table 8a: Pre-test Correlation Matrix	Immediate Memory **ImPACT™**	Delayed Memory **ImPACT™**	Memory Composite **ImPACT™**	Immediate Memory **SAC™**	Delayed Memory **SAC™**	Memory Composite **SAC™**
Immediate Memory **ImPACT™**	-	0.405	0.340	0.010	0.231	0.257
Delayed Memory **ImPACT™**	0.405	-	0.308	0.003	0.302	0.269
Memory Composite **ImPACT™**	0.340	0.308	-	-0.080	0.066	0.156
Immediate Memory **SAC™**	0.010	0.003	-0.080	-	-0.030	0.231
Delayed Memory **SAC™**	0.231	0.302	0.066	-0.030	-	0.657
Memory Composite **SAC™**	0.257	0.269	0.156	0.231	0.657	-

Table 9a: Post-test Correlation Matrix	Immediate Memory **ImPACT™**	Delayed Memory **ImPACT™**	Memory Composite **ImPACT™**	Immediate Memory **SAC™**	Delayed Memory **SAC™**	Memory Composite **SAC™**
Immediate Memory **ImPACT™**	-	0.565	0.351	-0.036	0.276	0.105
Delayed Memory **ImPACT™**	0.565	-	0.481	-0.077	0.237	0.264
Memory Composite **ImPACT™**	0.351	0.481	-	-0.186	0.287	0.170
Immediate Memory **SAC™**	-0.036	-0.077	-0.186	-	-0.126	0.211
Delayed Memory **SAC™**	0.069	0.237	0.287	-0.126	-	0.585
Memory Composite **SAC™**	0.105	0.264	0.170	0.211	0.585	-

Discussion

The application of simple validated neuropsychological tests in a clinical assessment of sports induced concussion to measure memory function has gained interest over time[14]. Due to this widespread interest across many levels of athletic competition, the use of neuropsychological testing is gradually becoming standard practice in the management of sport-related concussion[11, 12, 21, 31]. Despite its utilization, discussion continues among researchers and clinicians regarding the best assessment battery and test sequencing[11]. Over the past two decades, there has been an increased awareness of the ability of brief concussion assessment batteries to be utilized for accurate assessments of cognitive function, and to facilitate the management of return to participation decisions.

Assessment tools such as the Standardized Assessment of Concussion and the Immediate Post Concussion Assessment and Cognitive Testing battery have been proposed as tools for athletic trainers' to clinically recognize the effects of concussion within as occurring within their professional setting. These approaches are relatively new and not yet widely adopted, in part because of continuing body of research in this area developing within the sports medicine field. Although the aforementioned testing batteries have definite advantages over conventional neuropsychological testing methods, a number of limitations exist that must be considered before these tests can be applied to identify subtle effects of concussion in athletics.

The results of separate studies in 1995[25] and 1996[28] support the clinical use of the SAC™ in the evaluation of concussion in football players. In these studies, the SAC™ test was administered to 568 non-injured high school and college players before the start of the football season and immediately following concussion of during the 1995 and 1996 football seasons. Research findings revealed that 33 players suspected of having sustained a concussion scored significantly below the group of normal, non-injured players on the SAC™. Further analysis revealed that players with concussion, as a group, also scored significantly below their own normal baseline in terms of the SAC™ total score. The results of this study demonstrated the SAC™ as being a useful assessment in tracking recovery from concussion.

Overall, based on our findings we cannot advocate the use of one neuropsychological test battery over the other for the identification of underlying pathology and deficit in non-concussed athletes during pre-season and post season comparative baseline assessment. Our research findings leave us with additional questions surrounding the efficacy of current neuropsychological testing baseline assessments when using them as a comparative measure during the acute stage of injury in athletes who do sustain relatively mild head injuries. The main questions posed by this study were whether cognitive deficits over time really exist, or are these tests not reliable enough to detect cognitive decline or learning effects over an extended period of time? While the selected tests have demonstrated sensitivity in the assessment of mild head injury over short time periods following injury [12, 17-19, 22-26, 28], they may not be as sensitive in the re-assessment of normal day to day neurocognitive functioning over an extended test- retest interval.

In our study, the true evaluation of similar memory aspects of cognition in the ImPACT™ computerized baseline assessment, and the SAC™ baseline assessment may be questioned in its use given the score performances during the extended testing interval. We propose that the motivation levels of many subjects in the study by the 3 to 4 month may explain the general drop-off in scores over time; however, there is no specific explanation as to why two very similar subcomponents of these testing batteries do not demonstrate a strong relationship with each other.

Potential limitations can be seen with the comparison of these two assessment batteries knowing that each test was developed with some very distinct components integral to concussion assessment. Although both tests are very similar in their assessment of learning and delayed memory, caution must be used in the interpretation of these results as question may be asked whether these two tests are really measuring the same thing. Several factors contributed to the low relation demonstrated between the ImPACT™ and SAC™ tests when measured at the same testing interval. In our study, one factor that may have contributed to this relationship may be that these assessments are measuring similar yet uniquely different aspects of cognition. This may be specifically attributable to the fact that each composite score is comprised of several different components. Data from this interpretation should still be interpreted with caution as most often clinicians look at the composite score as a quick and reliable source for information.

Conclusions

The occurrence of head injury and concussion in athletic activity has recently been the focus of increasing interest for medical experts, researchers, parents, the media and governing bodies of organized sports. Following the recent publication the National Athletic Trainers' Association Position Statement: Management of Sport Related Concussion(2004)[11]; clinicians are beginning to recognize the value of standardized methods of assessment. Due to the increase in recognition and utilization of portable neuropsychological assessment measures, understanding the time interval of when to obtain or re-test baseline measurements is important, and plays a substantial role in the reliability of post-injury comparisons.

Although neuropsychological testing has become popular in recent years for assessing the cognitive domain of neurological functioning, more research is necessary to establish the most sensitive, practical, and useful battery of tests that are consistent in their assessment over extended periods of time as necessary when utilizing baseline assessment measures in the determination of a return to pre-injury baseline. Future researcher should attempt to compare the consistency of neuropsychological assessment in athletes in a more diversified atmosphere, including those at high risk of sustaining a concussion through athletic participation. Clinicians must exercise caution in the interpretation of any concussion assessment battery and how the results play a role in return to play criteria.

As validated in the athletic setting[13, 27], computerized neuropsychological assessment tools such as the Immediate Post Concussion Assessment Test as well as convenient on the field assessment measures such as the Standardized Assessment of Concussion have demonstrated merit as being a useful option for the sports medicine clinician. Based on our findings, athletes whose baseline assessment measures vary significantly during a re-test interval should, at the very least undergo re-assessment of baseline measures every year, a time frame in which they may not have sustained a concussion. Clinicians should seriously consider whether or not they might be placing athletes at risk by utilizing baseline data for comparison that may not be an accurate assessment of pre-injury cognition. Clinicians should also realize that these two neuropsychological testing measures and the two memory components compared are only a few of the pieces of a very large puzzle in the assessment of concussion.

Concussive injury may not necessarily affect the memory system or neurocognitive areas of the brain in every patient. No two concussions are identical in presentation or symptomology, nor are two individuals in base neurocognitive functioning, hence the need for reliability in measurement of an individualized baseline scoring system. Furthermore, the presence of a consistent baseline measure may have little to do with the recovery rate and post-injury assessment, and therefore, these conditions should not be overemphasized in the overall management of concussion. The most comprehensive concussion assessment involve a sound clinical examination with close monitoring of all symptoms while including objective measurements such as neuropsychological testing as an additional resource in the assessment and management of sports related concussion.

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CHAPTER III: MANUSCRIPT II

A Measure of the Reliability of Multiple Components of Two Concussion Assessment Batteries at a Test-Retest Interval

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A Measure of the Reliability of Multiple Components of Two Concussion Assessment Batteries at a Test-Retest Interval

Key words: concussion, neuropsychological assessment, athletes, head injury

Abstract

Background: Support by sports medicine professionals for the use of standardized mental status assessment measures utilizing baseline assessment protocols to assist in the diagnosis and management of concussion in athletes is growing, however question arises at how often should the baseline assessment be reassessed without confounding test-retest reliability. After an athlete has sustained a concussion, the challenge for the clinician lies in the tracking of the recovery and determining whether it is safe for the athlete to return to athletic participation. If the athlete's test-retest assessment is unreliable over the course of one athletic season, the clinical decision process is complicated even further.

Hypothesis: No significant differences will be detected between pre-season baseline assessments and post season reassessment on the memory components of the Standardized Assessment of Concussion (SAC™) and the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™) assessment.

Study Design: Prospective cross-sectional study designed to evaluate neuropsychological functioning in non-concussed athletes during a pre-season post season test-retest time interval.

Methods: Seventy-four healthy non-concussed collegiate athletes and twenty non-competitive college age and gender matched controls completed the Standardized Assessment of Concussion (SAC™) and Immediate Post-Concussion Assessment and Cognitive Functioning (ImPACT™) tests prior to and post their respective competitive athletic season. Data from specific components of each test were utilized in this analysis.

Results: Non-significant interclass correlations were demonstrated for all measures excluding the ImPACT™ 3 Letter Average Counted test (R= 0.69), and the ImPACT™ Delayed Memory component (R= 0.58) which had statistically low significance[25] when comparing each individual component at a baseline assessment 4 month re-test interval.

Conclusions: Clinicians must acknowledge the importance of the reliability of the baseline assessment scores over time as this is the measure in which data most often is compared following concussive injury. The reliability of this measurement is a key factor in tracking the recovery of an athlete who has sustained a concussion and can assist in guiding return-to-play decisions.

Currently there is support among sports medicine professionals for the use of standardized mental status assessment measures that assist in the diagnosis and management of concussion in athletes. After an athlete has sustained a concussion, the challenge for the clinician lies in tracking the athlete's recovery and determining whether the athlete is fit to return to athletic participation. Current findings suggest the use of standardized concussion assessment batteries may be helpful as a quantifiable index in which the resolution of acute and post-concussive cognitive and neuropsychological deficits can be tracked[3, 5, 8, 9, 16, 20-22, 26, 28, 29].

To date many studies have emphasized the use of preseason baseline testing in the assessment of athletes[2, 4, 14, 24, 27, 30]. Baseline assessment has been shown to recognize the individual levels of performance on tests of memory, concentration, processing speed and reaction time[4]. Without knowing how an individual athlete performed prior to suffering a concussion, it is somewhat difficult to determine whether any deficits displayed in testing are the result of unrelated secondary factors. Although some athletes may perform poorly in some assessments due to pre-injury learning disabilities or other factors such as test anxiety, similar patterns of cognitive difficulty should be displayed following concussive head trauma or at a test-retest interval.

When evaluating the neuropsychological and neurocognitive performance of athletes who have experienced a concussion it is important to understand the psychometric properties of the testing battery and the general ability of the individual tests within that battery to accurately measure neurocognitive and neuropsychological processes over varying amounts of time[11]. Throughout the course of participation in athletics, athletes may often undergo concussion assessment measures on multiple occasions following injury or as a baseline assessment. Due to the extensive use of these types of assessments in the clinical setting, it is critical that the testing batteries are stable and capable of presenting consistency in evaluation over multiple testing sessions. The matter of stability plays a key role especially with initial baseline assessments that are used as a "gold standard" measure of each individual's normal cognitive functioning. The purpose of this study was to assess the reliability of selected components of both the ImPACT™ computerized concussion assessment battery and the SAC™ sideline assessment test in the ability to consistently measure neurocognitive and neuropsychological functioning at a season-long test-retest interval in non-concussed athletes.

Methods

Prior to data collection, the study was reviewed by and received approval from the University's Institutional Review Board. Prior to participation in this study, informed consent was obtained from all subjects in accordance with institutional guidelines regarding the protection of human subjects.

Subjects

Prior to the start of the 2004-2005 Fall Athletic Season, all new and returning men's basketball (MBB), men's soccer (MS), women's soccer (WS), and women's volleyball (VB) athletes from a PAC-10, NCAA Division I-A university underwent baseline testing on the SAC™ and ImPACT™ neuropsychological testing assessments. A total of 74 healthy, non-concussed collegiate athletes ($N_{\text{Men's Basketball}}$=12, $N_{\text{Men's Soccer}}$= 22, $N_{\text{Women's Soccer}}$= 19 $N_{\text{Volleyball}}$=14) were studied over the course of the 2004-05 competitive intercollegiate athletic season. An additional subset group of 20 non-competitive college age and gender matched ($N_{\text{Men's Control}}$=10, $N_{\text{Female Control}}$= 10) controls followed a similar testing pattern during the first month of school.

Baseline testing on all participating athletes was conducted by the specified athletic team's certified athletic trainer (N=4) during preseason fitness and or weight training sessions, or as a portion of a pre-participation physical examination. All participants then underwent post-season re-evaluation baseline measurements in order to obtain comparative pre-season, post-season measurement data for all subjects. All post-season re-evaluations were performed an average of 173.5 days after the initial baseline assessment was conducted. Fluctuations in the test-retest interval can be attributable to the variation in the length of competitive season between each of the athlete groups, the date of pre-season physical examination and the estimated time frame utilized for the control group. For a complete time frame of test-retest, intervals per group please refer to Table 1b.

Table 2a: Average test-retest interval for follow-up assessments				
	N	Average	High	Low
Overall	87	173.5	286	74
Men's Soccer	22	185.6	249	89
Men's Basketball	12	202.9	209	199
Women's Soccer	19	189.4	286	74
Volleyball	14	159.8	124	265
Male Controls	10	137.8	211	97
Women's Control	10	136.7	188	98
Male Athlete	34	191.7	249	89
Female Athlete	33	176.8	286	74
Controls	20	137.2	211	97

<u>Instruments and Procedures</u>

The Standardized Assessment of Concussion (SAC™)

The Standardized Assessment of Concussion test (SAC™) is a mental-status test administered in five to seven minutes[7, 20, 23, 24, 26, 29], and was established in accordance with the American Academy of Neurologists[10] and the Colorado Concussion Guidelines[1]. The SAC™ is scored from 0 to 30, with a score of 30 being representative of a maximum score[7, 17, 18, 20, 23, 24, 26, 29]. Three different forms of the testing battery were utilized to minimize practice effects while tracking post-concussive recovery. McCrea, et al., (1997) demonstrated the three forms as being equivalent. The differences in the test forms occurs in words used for memory testing and in selection of digits in the concentration portion of the evaluation[20].

All certified athletic training staff received standardized training on the administration of the assessment battery. A standardized line of questioning was used throughout the administration of the SAC™. To assess Orientation, the subject was asked to provide the day of the week, month, date, year, and the time of day within one hour[23]. Immediate memory was assessed using a five word list in which the list is read to the subject to assess immediate recall, and then the same procedure is repeated for three trials. Concentration was evaluated by having the subject repeat, in reverse order a sequence of numerical digits that increase in length from three to six values[23]. Additionally, reciting of the months of the year in reverse chronological order was also utilized as part of the concentration measure[23]. Delayed recall was measured by reassessing the ability to recall the original five word list that was provided in the immediate memory section of the test[23]. Overall, the total score was calculated as a composite of the subject's performance on the aforementioned evaluation measures[7, 16-18, 23, 24, 26, 29].

Since the focus of this study was not to identify the effects of previous concussion on neurocognitive functioning, only 3 of the 4 SAC™ test subscales (immediate memory, concentration, and delayed recall) were utilized in the analysis. As an alternative to utilizing the maximum composite score of 30, the maximum modified SAC™ test score was 25.

Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™)

ImPACT™ Version 2.0[13] is a computer based neuropsychological test battery that measures attention, memory, processing speed, and reaction time to 1/100th of a second[28]. The ImPACT™ program operates on any Windows® based computer, and consists of a self-reported symptom questionnaire, as well as a concussion history evaluation[28]. The baseline ImPACT™ evaluation consists of a more detailed and difficult set of neurocognitive tests compared to the SAC™ test. The ImPACT™ evaluation targets to the neurocognitive functions recognized as being most sensitive to impairment during a concussed state[26, 28]. ImPACT™ consists of a detailed inventory of symptoms and a demographic questionnaire which evaluates pertinent athletic, medical, and concussion history. The main component of the testing battery consists of seven test modules administered to measure specific aspects of neurocognitive functioning, including tests of memory, reaction time, processing speed, and impulse control[6]. General subsets of the assessment include word discrimination, visual working memory, sequencing, visual attention span, symbol matching, and choice reaction time[28]. The Reaction Time Index represents the average time to respond in seconds. Composite scoring in this module includes choice reaction time, color match, and symbol match. The choice reaction time segment requires the athlete to mouse click the left key if a blue square appears on the screen, or right click if a red circle appears. In the color match module, the athlete is presented with three words (red, green, or blue) with the word either presented in the same color or different color of ink, requiring the athlete to respond quickly to inhibit the impulse to respond to the incorrect word[9].

The last component, the average correct reaction time utilizes the symbol match module to have the athlete mouse click on a number when a provided symbol appears on the screen. The visual motor speed index is the average of two scores. The first score is the total number of blue squares and red circles that were accurately selected in the distracter task in the reaction time index. This score is divided by four, while the second portion, the distracter task from the three letter word module is multiplied by three[9]. The three letter words module requires the athlete to perform a verbal working memory test measuring the ability of an athlete to remember a series of three consonants, immediately followed by a distracter task which requires the athlete to select a randomly displayed array of numbers in backward order from 25 to 1. This specific distracter task measures visual search and visual motor speed[9]. ImPACT™ also includes the Post Concussion Symptoms Scale[14] composed of a 22 item scale that measures symptoms commonly associated with concussion. The Post Concussion Symptoms Scale is described by Iverson, et.al[9] as a measure of perceived symptoms associated with concussion during the current mental state. The athlete is asked to report their current symptoms, allowing for the tracking of symptoms over a very short interval of time[6, 9, 14].

The memory index is composed of five subset scores that measure aspects of memory such as verbal learning, recognition, visual associative, visual working, and letter memory[9]. In each test area, with the exclusion of the word memory test, all stimuli are varied automatically for each trial to minimize the practice effects. This composite index score represents the average percent correct between these five testing areas, with a percent correct score provided for both learning and delayed recognition areas of the word memory module[6, 9]. The memory scores derived from ImPACT™ have been shown[12] to be sensitive to the effects of sports related concussion, and maintain stability in non-injured controls. For the current study, verbal memory tasks were specifically used to help determine the relationship of the two assessment tests in their ability to measure specific memory constructs.

Data Analysis

Evaluation of Pre and Post Season Data

To assess test-retest reliability, interclass correlation coefficients (ICC 2,1) were calculated between each testing measuring from the ImPACT™ and SAC™ assessments at test time 1 and test time 2. Significance level ($\alpha = 0.05$) for all assessments was set a priori for all statistical analyses. All data was analyzed using SPSS software (version 10.0, SPSS Inc., Chicago, IL).

Results

Interclass correlation coefficients were used to test the reliability of components of the ImPACT™ and SAC™ concussion assessment tools. Results from the analysis of the ImPACT™ components revealed statistically low correlations between the pre-test and post-test for most measures (Table 2b). The ImPACT™ 3 Letter Average Counted test (R= 0.6909), and the ImPACT™ Delayed Memory component (R= 0.5828) demonstrated the greatest correlation between these measures when comparing each pre-season baseline value on individual components obtained an average of 4 months earlier.

Table 2b: ImPACT™ Interclass Correlation Coefficients			
Source	**ICC**	**95% Low**	**95% High**
Verbal Learning Memory	0.3499	0.1521	0.5209
Verbal Delayed Memory	0.5828	0.4258	0.7059
Visual Learning Memory	0.3588	0.1621	0.5283
Visual Delayed Memory	0.2669	0.0614	0.4508
X's & O's Memory	0.4223	0.2340	0.5802
X's & O's Choice RT	0.5237	0.3535	0.6605
X's & O's Immediate RT	0.2217	0.0135	0.4118
3 Letters Avg. Counted	0.6909	0.5633	0.7864
3 Letters Counted Correct	0.4393	0.2537	0.5939
Verbal Memory Composite	0.4550	0.2720	0.6064
Visual Memory Composite	0.3674	0.1717	0.5354
RT Composite	0.3181	0.1170	0.4943

Results of the analysis of the SAC™ components demonstrated similar findings as no assessment measure had an interclass correlation value above 0.48 (Table 4b). Specific areas that demonstrated poor reliability over time were the memory components. The immediate memory component presented an alarmingly low coefficient at (r=0.004), while the delayed memory component was slightly better with a value of (r=0.29).

Table 3b: SAC™ Interclass Correlation Coefficients			
Source	**ICC**	**95% Low**	**95% High**
Orientation	0.0218	-0.1879	0.2299
Immediate Memory	0.0484	-0.1622	0.2549
Concentration	0.4820	0.3036	0.6278
Delayed Memory	0.2986	0.0957	0.4779
Composite	0.4188	0.2300	0.5773

Discussion

From this study it is important to emphasize that the use of concussion assessment batteries such as neuropsychological and neurocognitive assessments must be meticulously constructed and researched prior to their utilization in a clinical setting. The property of reliability must be extensively researched ensuring that the testing measures produce uniform results over time in both concussed and non-concussed athletes. Generally, interclass correlation coefficient values below 0.75 are considered to indicate moderate-to-poor reliability[25]. This measurement standard is alarming as no measure on both assessments extended above these values. The current lack of clinical studies addressing the psychometric properties of these assessment tools in an extended test retest interval is a limiting factor in the adoption of one standardized uniform approach to concussion assessment.

Previous investigators[9, 11, 22, 23] have documented the psychometric properties of both the SAC™ and ImPACT™ assessment batteries supporting the sensitivity and clinical validity of these instruments in the detection of sports related concussion, and as a general measure of cognitive recovery following injury. One particularly important aspect of reliability relates to the stability of the test being utilized over multiple administrations of the testing battery. Generally, concussion assessment batteries should be relatively unaffected by the effects of prior exposure and other non-concussion related sources of test variability when designed to be administered over multiple occasions[14]. The memory scores derived from the ImPACT™ testing battery have been shown[12] to be sensitive to the effects of sports related concussion, and as being a stable measure in non-injured controls. In a study comparing the scores of concussed athletes with non-injured controls and their own baseline levels, 64 athletes were shown to have reduced memory functioning at 3 day post intervals. Additionally in this test, the ImPACT™ memory composite scores revealed no significant differences due to practice effects and were stable across the testing sessions[12].

Baseline assessment is the recommended model for use both the ImPACT™[13] and the SAC™ tests[22] in an athletic setting. Accessibility to pre-injury data allows clinicians to compare an injured athlete to his or her own normal performance on a specific measure. The model of utilization allows for greater control of variability across subjects, non-related learning factors, and the possible effects of previous concussion. An evaluation of the psychometric properties of the SAC™[22] was conducted by McCrea, Kelly, and Randolph and they reported no significant differences between scores of high school and college players. Based on the results of this study, the authors suggest that age and education within the population studied have minimal effects on performance. There were no meaningful differences between forms A, B, and C of the SAC™, allowing for the reassessment of mental status and recovery with minimal practice effects. Research data supports the further testing of the SAC™ by medical personnel as an objective and quantifiable measure of the immediate neurocognitive effects of concussion[17-23]. The SAC™ appears to be sensitive in evaluating athletes with concussion immediately after the injury and may be helpful in making decisions as to a player's readiness to return to play, however the reliability of the baseline scores over an extended re-test period remains in question.

A large study of the clinical validity of the SAC™ attempted to clarify the utility of the instrument in the absence of baseline data in concussed athletes. All subjects were administered the SAC™ as a pre-season measure, then were re-assessed 15 minutes, 48 hours, and 90 days post injury. The subjects were divided into a baseline and non-baseline group. Subjects in the no baseline protocol underwent testing immediately following concussion at the same testing interval, however did not have a pre-season measure done. There were no statistically significant differences between SAC™ scores between subjects from the baseline and no-baseline protocols immediately following injury (p=0.70) or at any of the post-injury assessments (15min p=0.29, 48hrs p=0.36, 90 days p=0.09)[20].

Despite the frequent use of the ImPACT™ and SAC™ concussion assessment measures in both the clinical setting and in upper extremity research[12, 14, 15, 17-19, 23], interclass reliability for these techniques has not been clearly reported. The test-retest reliability of the both assessment measures used in this study was moderate to very poor. Care must be undertaken when interpreting findings of clinical measures with moderate-to-poor reliability. Several factors may have been contributing factors in the moderate-to-poor reliability reported with the ImPACT™ and SAC™ tests measured at this testing interval. We propose that the motivation levels of many subjects in the study by the 3 to 4 month mark may explain the general drop-off in scores overtime thus significantly decreasing the test-retest reliability presented in this study.

Reliability is an important foundation of all measures in a clinical assessment tool and directly impacts the confidence that clinicians may have when administering a specified assessment protocol[22]. Several studies have been conducted to assess the reliability of the scores of both of these assessment measures over time in the presence of injury, and in the absence of injury. These studies have indicated that the instrument is reasonably stable over serial administration; however, caution still must be practiced when utilizing these assessment measures as the reliability of these measures has not been significantly demonstrated over an extended test-retest interval.

Conclusions

The occurrence of head injury and concussion in athletic activity has recently been the focus of increasing interest for medical experts, researchers, parents, the media and governing bodies of organized sports. Following the recent publication the National Athletic Trainers' Association Position Statement: Management of Sport Related Concussion (2004)[8]; clinicians are beginning to recognize the value of standardized methods of assessment. Due to the increase in recognition and utilization of baseline assessment measure it is vital there is an understanding regarding stability of these measures over time. These measurements provide key information for which important post-injury comparisons, and return to play decisions can be made. The findings of our study suggest that further study is clearly needed to better describe the test-retest reliability of these important clinical tests.

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CHAPTER IV: GENERAL CONCLUSIONS

Currently there is support across many sports medicine professionals for the use of standardized mental status assessment measures that serve to assist clinicians in the diagnosis and management of concussion in athletes. After it has been determined that an athlete has sustained a concussion, the challenge for the clinician lies in the tracking of the athlete's recovery and determining whether the athlete is fit to return to athletic participation. Current findings suggest that the utilization of standardized concussion assessment batteries may be helpful as a quantifiable index in which the resolution of acute and post-concussive cognitive and neuropsychological deficits can be tracked[1, 2, 4-12].

Taken together, the results of this study call attention to the utility of neuropsychological and neurocognitive testing prior to and following a sports related concussion. The data from these tests do provide sports medicine clinicians with an objective index of cognitive functioning that can signal the return to pre-injury function. The goal for sports medicine professionals assessing and caring for the brain injured athlete is to ensure delivery of appropriate care that the athlete is safely returned to play[3]. In order to be utilized in an athletic setting, concussion assessment batteries should be short in duration, easy to administer, have similar psychometric properties to extensive neuropsychological assessments, and have a history of utilization in an athletic population[3].

Each of the testing measures described within this paper have demonstrated extensive use in an athletic setting and should be continually researched to identify the psychometric properties of each test at various test-retest intervals. Additionally, the relationship of each individual testing measure with similar measures should be evaluated in regard to similar components providing the capacity for sports medicine professionals to conduct the most accurate and effective concussion assessment when necessitated.

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Appendices

Appendix A- IRB Application

OREGON STATE
UNIVERSITY

Institutional Review Board

APPLICATION FOR RESEARCH INVOLVING HUMAN PARTICIPANTS

Please read through the entire application before beginning. All material, including this cover sheet, must be typed and submitted to the Human Protections Administrator, Office of Sponsored Programs and Research Compliance, 312 Kerr Administration Building, with the required number of copies for the type of review (see below). **Incomplete applications will delay the review process.** Send an e-mail to *IRB@oregonstate.edu* or call (541) 737-3437 with any questions.

Protocol No. 2612

Principal Investigator: Mark Hoffman **E-mail:** hoffmanm@onid.orst.edu

Department: Exercise and Sport Science **Telephone:** 541-237-6548

Project Title: A Comparison of Two Neuropsychological Assessment Batteries in Identification of Concussion Symptoms in Division I Soccer and Football athletes

Type of Project: ☐ **OSU Faculty or Staff Research Project** ☒ **Student Project or Thesis**
☐ **Courtesy Faculty Research Project** (see page 4 for additional information)

Student Researcher: Diana Padilla

Type of review requested:

☐ Exempt from Full Board review — see ATTACHMENT A for a complete listing of Exempt categories. *Allow a minimum of one week for the initial review and additional time for required modifications, if requested. Submit one copy of the complete application (with the original signature of the Principal Investigator) and indicate reason(s) for exemption on Attachment A.*

☒ Expedited review — see ATTACHMENT B for a complete listing of Expedited categories. *Allow a minimum of one month for the initial review and additional time for required modifications, if requested. Submit three complete copies of the application (one copy must have the original signature of the Principal Investigator) and indicate reason(s) for expedited review on Attachment B.*

☐ Full Board review — *a schedule of upcoming Full Board meetings and submission deadlines can be found at:* http://osu.orst.edu/research/RegulatoryCompliance/HumanSubjects.html. *Submit sixteen complete copies of the application (one copy must have the original signature of the Principal Investigator) with each page numbered.*

External Funding *(present or proposed)*: ☒ **No** ☐ **Yes**

If yes, Sponsor Name: _____ *(include one complete copy of the grant application for all PHS/DHHS/NIH funding, clearly flag and highlight any pages referencing human participants, indicate whether funding is received directly or through a subaward)*

Project Start Date *(i.e., recruitment of human participants)*: July 01, 2004

All research staff involved in this project must receive training in the ethical use of human participants in research. To document this training, the Certification of Education form (available at: http://osu.orst.edu/research/RegulatoryCompliance/HumanSubjects.html) must be submitted. This form needs to be submitted only once for each researcher.

CERTIFICATION OF EDUCATION – Please indicate if the form has been previously submitted:

Principal Investigator: ☒ **Yes** ☐ **No*** **Student Researcher:** ☒ **Yes** ☐ **No***

Additional Research Staff *(attach additional sheet if necessary)*:

Name:	**Role in project:**	**Previously submitted:**
_____	_____	☐ **Yes** ☐ **No***
_____	_____	☐ **Yes** ☐ **No***
_____	_____	☐ **Yes** ☐ **No***
_____	_____	☐ **Yes** ☐ **No***
_____	_____	☐ **Yes** ☐ **No***

***If not previously submitted, please submit the Certification of Education form immediately. IRB review of the proposed project will not occur until the appropriate Certification of Education form for each research staff member has been received.**

Principal Investigator's assurance and compliance statement:

- I agree to accept responsibility for the scientific and ethical conduct of this project.

- If this project is approved, I agree to submit ***any*** modifications to the approved project to the IRB for review and approval prior to implementation (including changes in research staff, external funding sources, changes in wording to the consent form, etc.).
- I agree to promptly report all adverse events that may occur as a result of this study.
- I agree not to start any part of this study involving human participants (including participant recruitment) until I have received full IRB approval.
- I will submit any requested information in a timely manner.

Conflict of Interest Statement: Could the results of the study provide a potential financial gain to you, a member of your family, or any of the co-investigators that may give the appearance of a potential conflict of interest?

☒ **No** ☐ **Yes** (please describe any potential conflicts of interest in a cover letter and disclose in the informed consent document)

If acting as an advisor for a student project:

- I agree to be the point of contact between the IRB and the student investigator(s) for all communication (students will not receive communications directly).
- I agree to oversee the student research and to ensure the project's methods and the model are sound and ethical.

Signed ______________________________ Date______________

Principal Investigator

Appendix B: IRB Approval letter

OSU
Oregon State
UNIVERSITY

Institutional Review Board • Office of Sponsored Programs and Research Compliance
Oregon State University, 312 Kerr Administration Building, Corvallis, Oregon 97331-2140
Tel 541-737-3437 | Fax 541-737-3093 | http://oregonstate.edu/research/RegulatoryCompliance/HumanSubjects.html
IRB@oregonstate.edu

TO: Mark Hoffman,
Exercise and Sport Science

RE: A Comparison of Two Neuropsychological Concussion Assessment Tests
(Student Researcher: Diana Padilla)

IRB Protocol No. 2612

The referenced project was reviewed under the guidelines of Oregon State University's Institutional Review Board (IRB). The IRB has **approved** the application. This approval will expire on **7/25/2005**. This new request was reviewed at the Expedited level. A copy of this information will be provided to the full IRB committee.

Enclosed with this letter please find the approved informed consent documents for this project, which have received the IRB stamp. This information has been stamped to ensure that only current, approved informed consent forms are used to enroll participants in this study. All participants must receive the appropriate IRB-stamped informed consent document.

- **Any proposed change to the approved protocol, informed consent form(s), or testing instrument(s) must be submitted using the MODIFICATION REQUEST FORM.** Allow sufficient time for review and approval by the committee *before* any changes are implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB.
- In the event that a human participant in this study experiences an outcome that is not expected and routine and that results in bodily injury and/or psychological, emotional, or physical harm or stress, it must be reported to the IRB Human Protections Administrator within three days of the occurrence using the ADVERSE EVENT FORM.
- If a complaint from a participant is received, you will be contacted for further information.
- Please go to the IRB web site at: http://osu.orst.edu/research/RegulatoryCompliance/HumanSubjects.html to access the MODIFICATION REQUEST FORM and the ADVERSE EVENT FORM as needed.

Before the expiration date noted above, a Status Report will be sent to either close or renew this project. It is imperative that the Status Report is completed and submitted by the due date indicated or the project must be suspended to be compliant with federal policies.

If you have any questions, please contact the IRB Human Protections Administrator at IRB@oregonstate.edu or by phone at (541) 737-3437.

for Laura K. Jimeson [signature] Date: 7/26/04

Drs. Courtney Campbell and Wayne Kradjan
Institutional Review Board Co-Chairs

pc: 2612 file

Appendix C- Informed Consent Document

Project Title: **A Comparison of Two Neuropsychological Concussion Assessment Batteries**

Investigators: **Mark Hoffman, and Diana Padilla, Exercise & Sports Science**

PURPOSE

This is a research study. The purpose of this research study is to assess the agreement of the Immediate Post-Concussion Assessment and Cognitive Functioning (ImPACT™) computerized concussion assessment software with the abbreviated on-field Standardized Assessment of Concussion (SAC™) neuropsychological testing batteries in their ability to assess concussion symptoms. Agreement will be determined thru pre and post season measures, as well as post concussion evaluation if subjects sustain a concussion during the course of one complete competitive intercollegiate football or soccer season.

Concussion can be defined as any transient neurological dysfunction resulting from a biomechanical force such as being struck directly or indirectly in the head. The goals of concussion are to 1) assist in the identification of head injury, 2) identify of athletes requiring advanced medical attention, and 3) assist in decision making regarding return to play post concussion.

The purpose of this consent form is to give you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, what you will be asked to do, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not. This process is called "informed consent". You will be given a copy of this form for your records.

We are inviting you to participate in this research study because you are an intercollegiate football or soccer athlete who is at risk of sustaining a concussion while participating in athletics at Oregon State University.

PROCEDURES

If you agree to participate, your involvement will last for the entire duration of you fall season, including post season, and tournament play.
The following procedures are involved in this study. In the summer of 2004, all participating athletes will undergo baseline testing on the Standardized Assessment of Concussion (SAC™) and the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™) version 2.0 neuropsychological testing

assessments before the start of their respective competitive athletic seasons. Baseline testing on all participating athletes will be conducted by certified athletic trainers during preseason fitness and or weight training sessions, or as a portion of a pre-participation physical examination.

Throughout the course of the season, all athletes who are identified by a certified athletic trainer as sustaining a possible concussion or mild traumatic brain injury will be re-evaluated using both testing protocols within 24 hours of sustaining injury, as well as 3, and 10 days post initial concussion symptoms. Lastly, all athletes will also be measured in a post-season re-evaluation in order to obtain comparative measurement data for all subjects.
The assessment protocols performed in this study will involve the collection of data as normally collected by your institution's sports medicine personnel. Additionally, any pre-test baseline measures that have previously been collected within 3 months of initiation of this study will be utilized as part of the analysis. This study will not be collecting any measures that are not already performed during standardized concussion assessment within the sports medicine facility at Oregon State University.

RISKS

There are no foreseeable risks associated with participating in this research project.

BENEFITS

There will not be personal benefit for participating in this study. However, the researchers anticipate that society may benefit from this study by the development of an improved assessment approach for athletes who have sustained a concussion while participating in physical activity. This approach may potentially improve an athlete's quality of life while reducing the risk of long term neurological dysfunction and deficit due to mis-evaluation of concussion symptoms.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. However, federal government regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies involving human subjects) may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies you. In the event of any report or publication from this study, your identity will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified. All data will be viewable at any time by the certified athletic training staff at Oregon State University throughout the course of this study. This information is viewable to the athletic training staff as it is a part of your medical file, allowing for treatment and evaluation of concussion performed as a standard assessment technique by the Oregon State Athletic Training staff.

VOLUNTARY PARTICIPATION

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled. If in the case that you decide to discontinue participation in the study, all previously collected data will be removed from the research database, however will remain as a working medical record within the Oregon State University Athletic Training Room.

QUESTIONS

Questions are encouraged. If you have any questions about this research project, please contact: **Mark Hoffman, PhD, ATC/R, (541) 237- 6548, hoffmanm@orst.edu or Diana Padilla, ATC/EMT, (541) 737-7357, diana.padilla@oregonstate.edu.** If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________________ ______________

(Signature of Participant) (Date)

______________________________ ______________

(Signature of Parent/Guardian or Legally Authorized Representative) (Date)

RESEARCHER STATEMENT

I have discussed the above points with the participant or, where appropriate, with the participant's legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

____________________________________ _______________

(Signature of Researcher) (Date)

Appendix C- Informed Consent Document

INFORMED CONSENT DOCUMENT
Non-Athlete Group

Project Title: **A Comparison of Two Neuropsychological Concussion Assessment Batteries**

Investigators: **Mark Hoffman, and Diana Padilla, Exercise & Sports Science**

PURPOSE

This is a research study. The purpose of this research study is to assess the agreement of the Immediate Post-Concussion Assessment and Cognitive Functioning (ImPACT™) computerized concussion assessment software with the abbreviated on-field Standardized Assessment of Concussion (SAC™) neuropsychological testing batteries in their ability to assess concussion symptoms. This study will utilize pre and post season measures, as well as post-concussion evaluation measures recorded from NCAA Division I Intercollegiate athletes, and a non-athlete control group during the course of one complete competitive football or soccer season.

Concussion can be defined as any neurological dysfunction resulting from a force such as being struck directly or indirectly in the head. The goals of concussion assessment are to 1) assist in the identification of head injury, 2) identify of athletes requiring advanced medical attention, and 3) assist in decision making regarding return to play post concussion.

The purpose of this consent form is to give you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, what you will be asked to do, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not. This process is called "informed consent". You will be given a copy of this form for your records.

We are inviting you to participate in this research study because you meet the inclusion criteria to be a member of the non-athlete control group in this study.

PROCEDURES

If you agree to participate, your involvement will last for the entire duration of an intercollegiate fall athletic season, including post season, and tournament play.

I understand that as a participant in this study the following procedures will occur:

1. **Pre- Season baseline testing-** All participating individuals will undergo baseline evaluations consisting of the administration of a 22-minute computerized Immediate Post Concussion Assessment and Cognitive Functioning (ImPACT™) evaluation, as well as a 5-minute Standardized Assessment of Concussion (SAC™) evaluation.
    a. The ImPACT™ program evaluates and documents many aspects of neurocognitive functioning including memory, brain processing speed, reaction time, and post-concussion symptoms.
    b. ImPACT™ operates through the use of either a desktop personal computer, or laptops with a color screen or monitor, and an external mouse.
    c. ImPACT™ will be administered individually in an athletic training environment that is free of noise and distractions. Participants will be required to input information via a keyboard, and utilize an external mouse to navigate, and select responses on the screen throughout the duration of test administration.
    d. The SAC™ test is a mental status test that is used to measure and document aspects of neurocognitive functioning including orientation, memory, concentration, and delayed recall.
    e. A standardized line of questioning is used throughout the administration of the SAC™ with questions being asked by trained administrators.
        i. The line of questioning will be performed by Oregon State University Certified Athletic Trainers (ATC's).
2. **Post- Season baseline testing-** At the conclusion of a four month period (average fall athletic season), all participants will undergo post-season re-evaluation baseline measurements in order to obtain comparative measurement data for all subjects.
    f. Post-season baseline measurements will consist of the same assessment batteries used in pre-season testing.

RISKS

There are no foreseeable risks associated with participating in this research project.

BENEFITS

There will not be personal benefit for participating in this study. However, the researchers anticipate that society may benefit from this study by the development of an improved assessment approach for athletes who have sustained a concussion while participating in physical activity. This approach may potentially improve an athlete's quality of life while reducing the risk of long term neurological dysfunction and deficit due to mis-evaluation of concussion symptoms.

COSTS AND COMPENSATION

Subjects will not have any costs for participating in this research project, nor will they receive any compensation for their participation.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. However, federal government regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies involving human subjects) may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies you. In the event of any report or publication from this study, your identity will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified. All data will be viewable at any time by the researchers named in this study, and will not be accessible to Oregon State University's athletic training staff.

VOLUNTARY PARTICIPATION

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled. If at any time during the course of the study, you choose to opt out of this study you may do so confidentially by contacting either of the researchers. Prior to discontinuation of participation in this study, you may be asked if your previously recorded baseline assessment data and any post-concussion assessments measured prior to forfeiture of the study could be utilized for data analysis. You may choose not to have your assessment scores utilized in this study; doing so will result in your assessments being permanently removed from the study database.

QUESTIONS

Questions are encouraged. If you have any questions about this research project, please contact: **Diana Padilla, ATC/EMT, (541) 737-7357, diana.padilla@oregonstate.edu or Mark Hoffman, PhD, ATC/R, (541) 237-6548, hoffmanm@orst.edu.**
If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________________ ______________
(Signature of Participant) (Date)

______________________________ ______________
(Signature of Parent/Guardian or
Legally Authorized Representative) (Date)

RESEARCHER STATEMENT

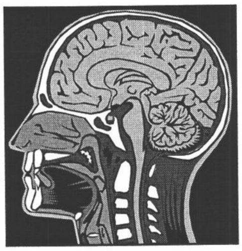
I have discussed the above points with the participant or, where appropriate, with the participant's legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

______________________________ ______________
(Signature of Researcher) (Date)

Appendix D- Subject Recruitment Flyer

VOLUNTEERS NEEDED!!!

A Comparison of Two Neuropsychological Concussion Assessment Batteries



- **Researchers are looking for volunteers with no significant history of concussions in the past three years, who are not currently participating in any contact athletic events.**
  - We are looking for individuals who are between the ages of 18 and 25.
  - Both Males and Females are encouraged to participate.

- **Researchers are interested in comparing the level of agreement between the neuropsychological sports concussion assessment testing batteries of the Immediate Post Concussion Assessment and Neurocognitive Functioning Test (ImPACT), and the Standardized Assessment of Concussion (SAC).**
  - The ImPACT assessment is a 22 minute computerized assessment test that measures various aspects of neurocognitive functioning such as memory, speed, and reaction time.
  - The SAC assessment is a brief five minute verbal question test that assesses aspects of neurocognitive functioning such as memory, concentration, and delayed recall.

Enrollment requires a two session commitment that spans the course of five months. As a participant you will be part of a control group compared against collegiate athletes.

If you are interested in this study, meet the above criteria and have time for a meeting with the study investigator for two 30 to 40 minute sessions, then please contact:

Diana Padilla, ATC, EMT
Email: diana.padilla@oregonstate.edu
Phone: 541-829-9913

Concussion Assessment Study
Diana Padilla

Concussion Assessment Study
Diana Padilla

Concussion Assessment Study
Diana Padilla

Concussion Assessment Study
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Concussion Assessment Study
Diana Padilla

Concussion Assessment Study
Diana Padilla

Appendix E- Approval to Use Copyrighted Material

OREGON STATE University

Request for Approval to Use Copyrighted ImPACT Software Graphics

June 22, 2005

Diana Padilla, ATC
114 Gill Coliseum
Corvallis, OR 97331
Ph: (541)230-0663
Fax: (541) 737-3570

Michael McCrea, Ph.D.
Head of Neuropsychology Service
Waukesha Memorial Hospital
Phone: 262-928-2156
e-mail: michael.mccrea@phci.org

Dear Mr. McCrea:

I am currently an assistant athletic trainer at Oregon State University where I recently completed my course work for a Master's degree in Sports Medicine. In order to complete my degree requirements I am in the process of completing my thesis entitled "A comparison of two neuropsychological test batteries". This project involves the comparison of the Immediate Post Concussion Assessment and Cognitive testing (ImPACT) program with the Standardized Assessment of Concussion (SAC) in their ability to measure neurocognitive functioning in non-concussed individuals over time utilizing repeated baseline assessments. I would like your permission to reprint the Standardized Assessment of Concussion test form A in the final bound copy of my thesis. This reprint will exclude specific word and numbering patterns as included in several other publications.

The requested permission extends to any future revisions and editions of my thesis, and to the prospective publication of my dissertation. These rights will in no way restrict republication of the material in any other form by you or by others authorized by you. Your signing of this letter will also confirm that your company owns the copyright to the above-described material.

Please indicate your approval of this permission by signing this letter where indicated below and returning it to me as soon as possible.

Thank you very much.

Sincerely,

Diana Padilla, ATC, EMT
Assistant Athletic Trainer
Oregon State University

FAX: 541-737-3570

Name: Michael McCrea
Title: Director, Neuroscience Ctr
Organization: ProHealth
Date: 7-5-05
Signed: _Redacted for privacy

Appendix F- Approval to Use Copyrighted Material

OREGON STATE
University

Request for Approval to Use Copyrighted ImPACT Software Graphics

June 22, 2005

Diana Padilla, ATC
114 Gill Coliseum
Corvallis, OR 97331
Ph: (541)230-0663
Fax: (541) 737-3570

Labiba Russo
Director of Sales and Marketing
Email: lrusso@impacttest.com
Tel: (877) 646-7991

Dear Ms. Russo:

This letter is to confirm our conversation at the recent National Athletic Trainers' Association convention. I am an assistant athletic trainer at Oregon State University where I recently completed my course work for a Master's degree in Sports Medicine. In order to complete my degree requirements I am in the process of completing my thesis entitled "A comparison of two neuropsychological test batteries". This project involves the comparison of the Immediate Post Concussion Assessment and Cognitive testing (ImPACT) program with the Standardized Assessment of Concussion (SAC) in their ability to measure neurocognitive functioning in non-concussed individuals over time utilizing repeated baseline assessments. I would like your permission to reprint the Post Concussion Symptoms test, as well as selected images from the Power Point presentation detailing the operation of the testing battery in the Appendix of the final bound copy of my thesis.

The requested permission extends to any future revisions and editions of my thesis, and to the prospective publication of my dissertation. These rights will in no way restrict republication of the material in any other form by you or by others authorized by you. Your signing of this letter will also confirm that your company owns the copyright to the above-described material.

Please indicate your approval of this permission by signing this letter where indicated below and returning it to me as soon as possible.

Thank you very much.

Sincerely,

Diana Padilla, ATC, EMT
Assistant Athletic Trainer
Oregon State University

Name:	Labiba Russo
Title:	Director of Sales and Marketing
Organization:	ImPACT Applications, Inc
Date:	6/22/05
Signed:	Redacted for privacy

Appendix G- Standardized Assessment of Concussion (SAC)

(1) ORIENTATION

Month	______	0	1
Date	______	0	1
Day of Week	______	0	1
Year	______	0	1
Time (within 1 hour)	______	0	1
Orientation Total Score	______	/	5

(2) IMMEDIATE MEMORY (All 3 trials are completed regardless of score on trial 1 & 2: Total score equals the sum across all 3 trials.

List	Trial 1		Trial 2		Trial 3	
Word 1	0	1	0	1	0	1
Word 2	0	1	0	1	0	1
Word 3	0	1	0	1	0	1
Word 4	0	1	0	1	0	1
Word 5	0	1	0	1	0	1
TOTAL						

Immediate Memory Total Score		/ 15

(Note: Subject is not informed of delayed recall testing of memory.)

(3) NEUROLOGICAL SCREENING

Loss of Consciousness: (Occurrence, duration)

Retrograde & Post Traumatic Amnesia: (recollection of events pre- and post injury)

Strength:

Sensation:

Coordination:

(3) CONCENTRATION

Digits Backward (If correct, go to next string length, if incorrect, read trial 2. Stop after incorrect on both trials.)

4-9-3	6-2-9	______	0	1
3-8-1-4	3-2-7-9	______	0	1
6-2-9-7-1	1-5-2-8-6	______	0	1
7-1-8-4-6-2	5-3-9-1-4-8	______	0	1

Months in Reverse Order: (Entire sequence correct for 1 point)

Dec-Nov-Oct-Sep-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	______	0	1
Concentration Total Score	______	/	5

EXERTIONAL MANUEVERS

(when appropriate):

5 jumping jacks	5 push-ups
5 sit-ups	5 knee bends

(4) DELAYED RECALL:

Word 1	______	0	1
Word 2	______	0	1
Word 3	______	0	1
Word 4	______	0	1
Word 5	______	0	1

Delayed Recall Total Score		/ 5

SUMMARY OF TOTAL SCORES:

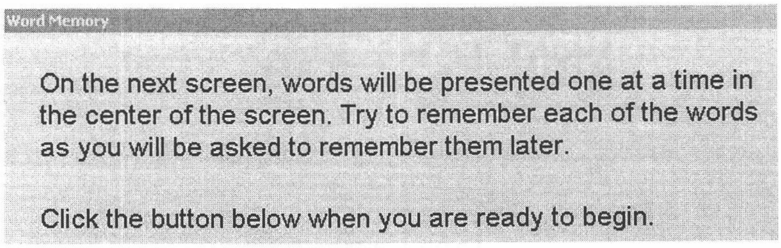
ORIENTATION		/	5
IMMEDIATE MEMORY		/	15
CONCENTRATION		/	5
DELAYED RECALL		/	5
OVERALL TOTAL SCORE		/	30

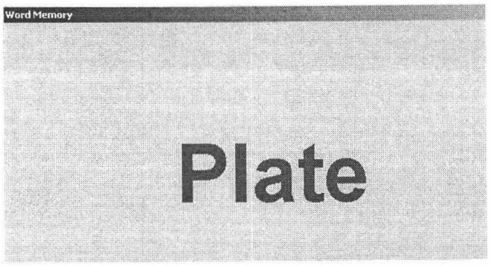
Appendix H: ImPACT Display information

ImPACT: Test Description

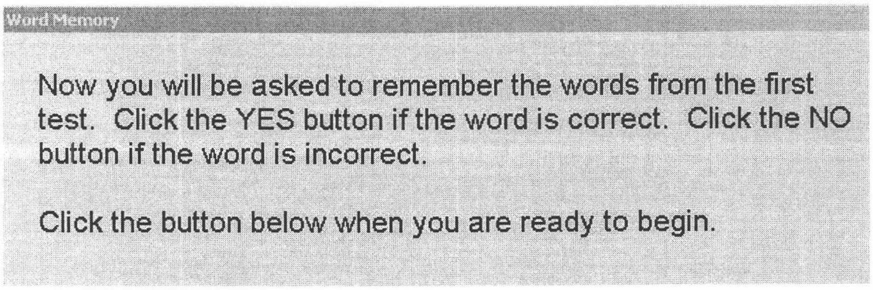
Module 1: Word Discrimination

- Evaluates attentional processes and verbal recognition memory through the utilization of a word discrimination paradigm.
- Each subject is presented with 12 target words for 750 milliseconds two consecutive times in order to facilitate learning of the list.

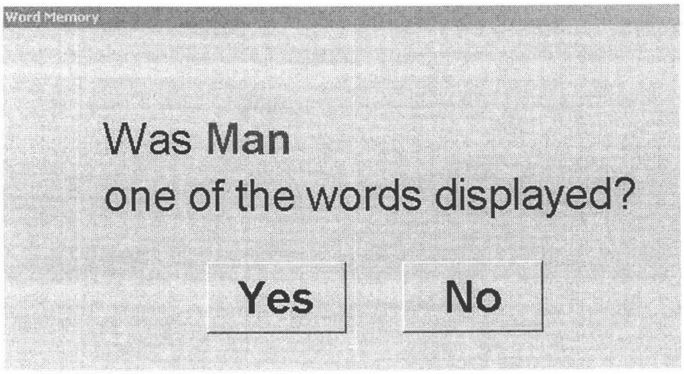




- Each subject is then tested for word recall via the presentation of a 24 word list that is comprised of the following factors:
    - The list is comprised of 12 target and 12 non-target words
    - Each non-target word is chosen from the same semantic category as the target word.
    - Individual scores are provided for yes and no responses, as well as a total percent correct.
    - Overall, there are five different forms of word lists.

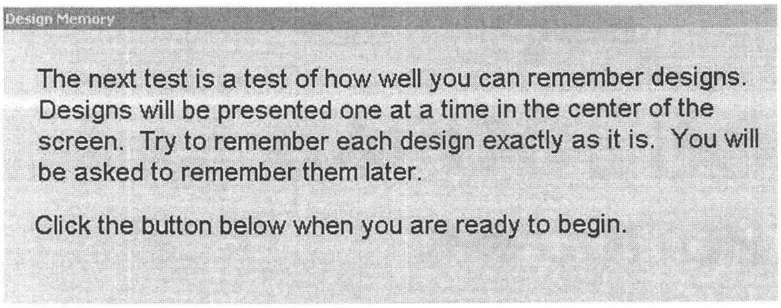


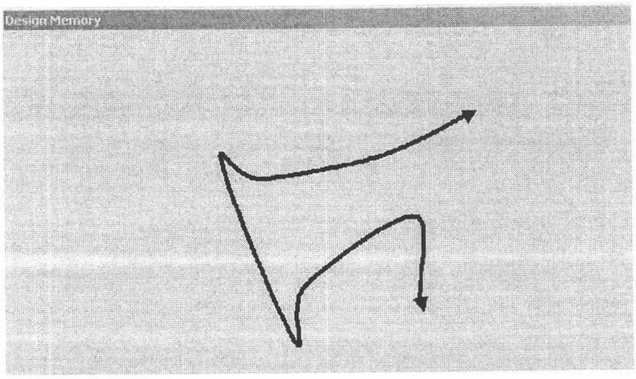
- Each subject is then tested under a delay condition following the administration of all other modules utilizing the same methodology as described above.



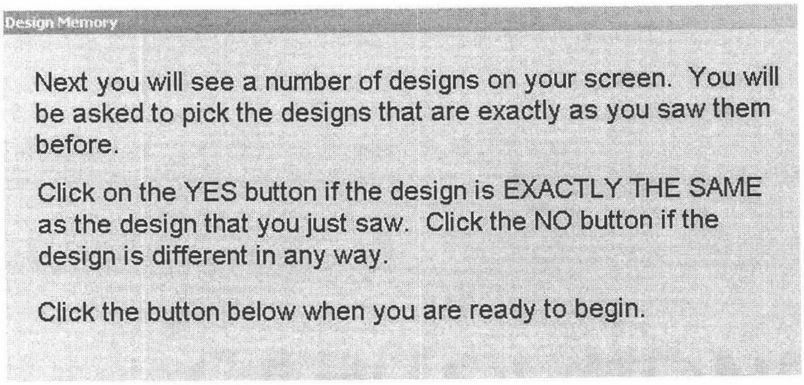
Module 2: Design Memory

- Evaluates attentional processes and visual recognition memory through the utilization of a design discrimination paradigm.
- Each subject is presented with 12 target designs for 750 milliseconds two consecutive times in order to facilitate learning of the list.

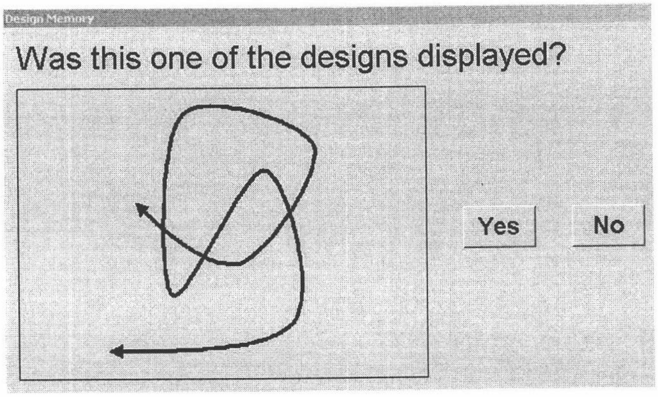




- Each subject is then tested for word recall via the presentation of 24 designs that are comprised of the following factors:
    - The list is comprised of 12 target and 12 non-target designs
    - Each non-target design is similar to the target design only rotated in space.
    - Individual scores are provided for yes and no responses, as well as a total percent correct.
    - Overall, there are five different forms of word lists.

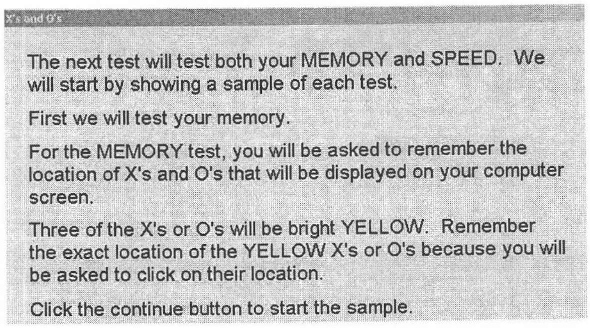


- Each subject is then tested under a delay condition following the administration of all other modules utilizing the same methodology as described above.

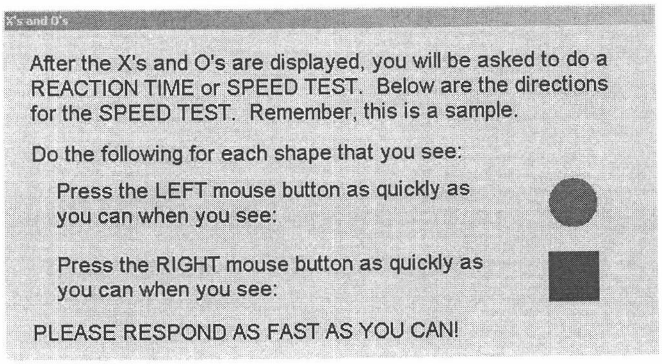


Module 3: X's and O's

- Measures visual working memory, visual processing speed, and visual memory through the incorporation of a distractor task following presentation of stimuli.

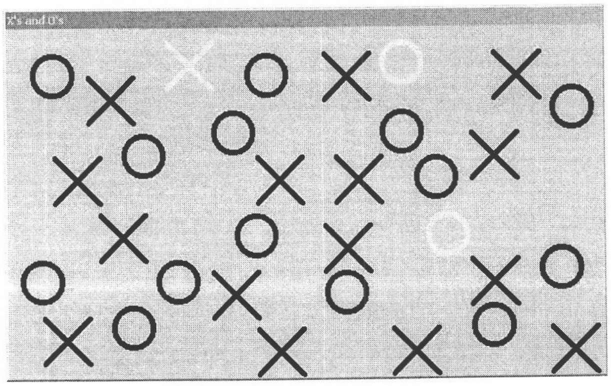


- Each subject is instructed to click either the left mouse button if a blue square is presented, and the right mouse button if a red circle is presented.



- Upon completion of the primary task, each subject will undergo a memory task which consists of:
    - During each trial three X's or O's will be illuminated in yellow and placed in a random assortment that is displayed for 1.5 seconds.

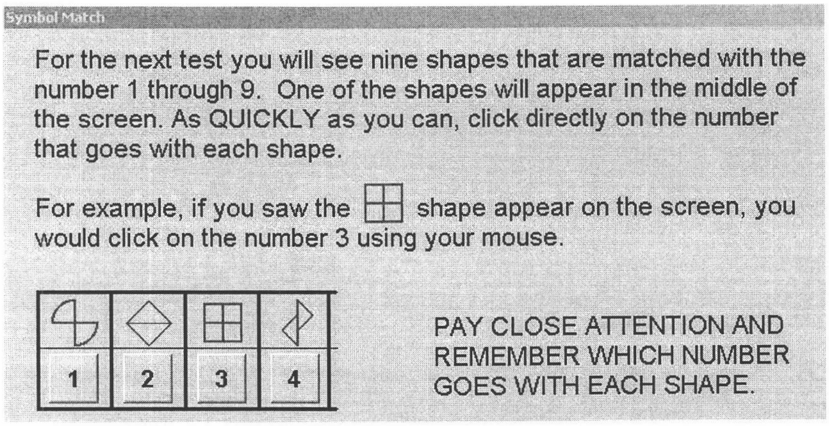
  - Each subject is instructed to memorize the position of each illuminated letter.



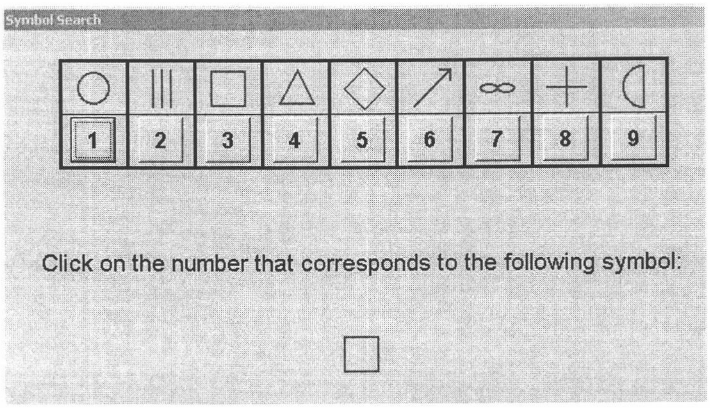
  - Immediately upon presentation of the X's and O's, the distractor task reappears on the screen.
  - Following the distractor task, the memory X and O screen will reappear requiring the athlete to click on the previously illuminated X's and O's.
  - Scores are provided for correct identification of the X's and O's under the memory task, the reaction time for the distractor task, as well as the number of errors incurred during the distractor task.
- During each testing administration, each subject will undergo four consecutive trials of the X's and O's module.

Module 4: Symbol Matching

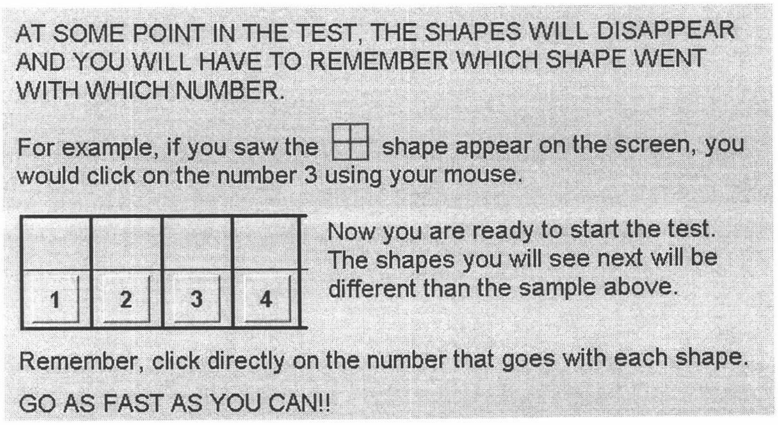
- Measures visual processing speed, learning, and memory through symbol matching and recall.
- Each subject is presented with a screen that displays 9 common symbols such as triangles, squares, crosses, etc. with each symbol having a corresponding number between 1-9.



- Below the grid, a symbol is presented requiring the subject to select the matching number from the grid as quickly as possible while remembering the symbol/number pairings.



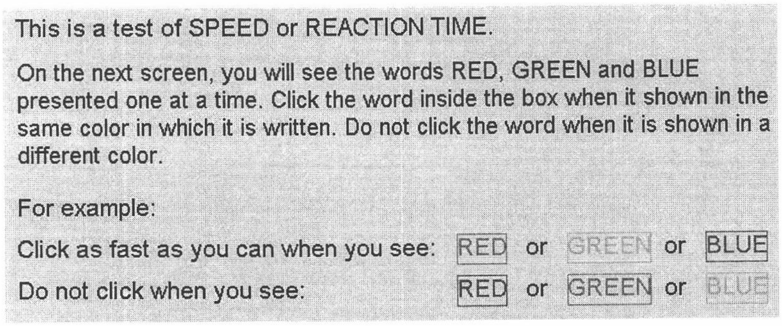
  - Correct performance is presented by the number being illuminated in green, while incorrect performance illuminates the number in red.
  - Following the completion of 27 trials, the symbols disappear from the top grid instructing the subject to recall the correct symbol/number pairing by selecting the appropriate number button.

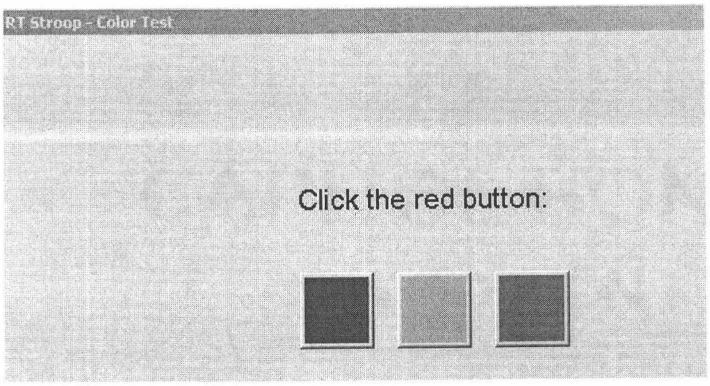


- This module presents an average reaction time score as well as a score for the memory condition.

Module 5: Color Matching

- Measures reaction time, impulse control and response inhibition.
- Each subject is required to respond by selecting a red, blue, or green button as they are presented on the screen in order to assure that subsequent trials are not affected by color blindness.

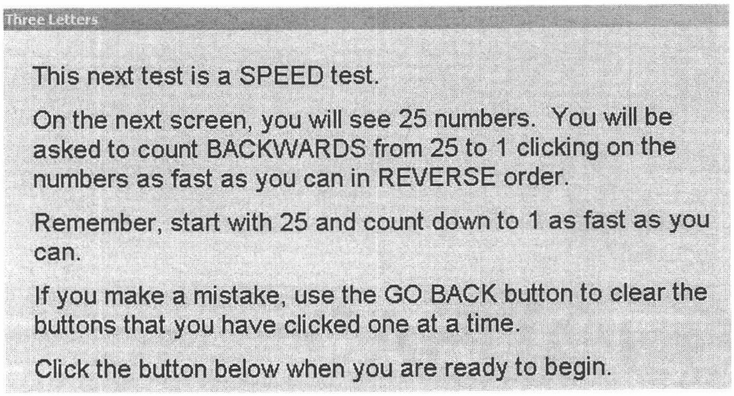




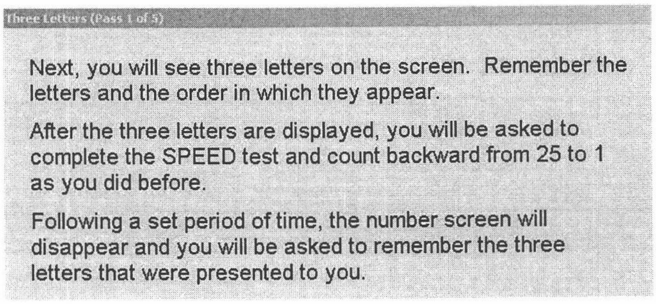
- Following the trial, a word is displayed on the screen in the same colored ink as the word, or in a different colored ink.
  - Each subject is instructed to click the box as quickly as possible only if the word was presented in the matching ink.
- This module presents a reaction time score, as well as an error score.

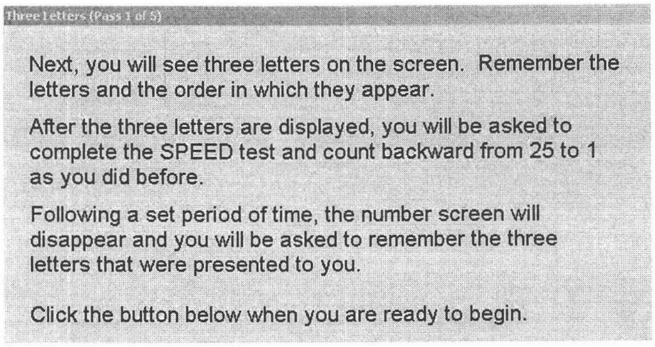
Module 6: Three Letters

- Measures working memory and visual motor response speed.
- Each subject is instructed to click as quickly as possible counting down numbers from 1 to 25 on a distractor task that consists of 25 randomly placed numbered buttons in a 5 x 5 grid.



  - Following an initial practice task the subject is instructed to remember three consonant letters that appear on the screen.
  - Immediately following the display of the three letters, the number grid reappears and the subject is instructed to perform the number countdown again.





- Following a period of 18 seconds, the number grid disappears and the subject is immediately asked to recall the three previously displayed letters by typing them in with the keyboard.
- This module presents a memory score as well as a score for the average number of correctly selected numbers for each trial of the distracter task.
- Each subject completes five trials of the three letters task.

Injury Description

- Upon completion of the computerized assessment, the test administrator has the opportunity to describe the characteristics of the injury and treatment undertaken.

Appendix I- Post-Concussion Symptoms Scale

		Rating					
Symptoms	**None**	**Moderate**			**Severe**		
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping more than usual	0	1	2	3	4	5	6
Sleeping less than usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light	0	1	2	3	4	5	6
Sensitivity to Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Feeling more emotional	0	1	2	3	4	5	6
Numbness or tingling	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling mentally "foggy"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Visual Problems	0	1	2	3	4	5	6

TOTAL SCORE ______________________

Iverson, G., Lovell, M., Podell, K., & Collins., M. (2003, February 2003). *Reliability and Validity of ImPACT.* Paper presented at the Annual Conference of the International Neuropsychological Society, Honolulu, Hawaii.

Appendix J- Sample ImPACT™ Data Report

ImPACT© Clinical Report

ImPACT Applications

Organization:	Oregon State University		
Subject ID#:			
Date of birth:		Age:	
Gender:		Height:	65 inches
Handedness:	Left	Weight:	135 lbs
Native country / region:	United States of America	Second language:	(None)
Native language:	English	Years speaking:	0
Years of education completed excluding kindergarten:	12	Received speech therapy:	No
Diagnosed learning disability:	No	Problems with ADD/Hyperactivity:	No
Attended special education classes:	No	Repeated one or more years of school:	No
Current sport:		Primary position/event/class:	
Current level of participation:	Collegiate	Years experience at this level:	0

Number of times diagnosed with a concussion (excluding current injury):	0
Concussions that resulted in loss of conciousness:	0
Concussions that resulted in confusion:	0
Concussions that resulted in difficulty remembering events that occured immediately after injury:	0
Concussions that resulted in difficulty remembering events that occured immediately before injury:	0
Total games missed as a result of all concussions combined:	0

Concussion history:

Treatment for headaches by physician:	No		
Treatment for migraine headaches by physician:	No	Treatment for psychiatric condition (depression, anxiety):	No
Treatment for epilepsy / seizures:	No	History of meningitis:	No
History of brain surgery:	No	Treatment for substance/alcohol abuse:	No

ImPACT© Clinical Report

ImPACT Applications

	Baseline	Post-concussion
Exam Type:		
Date Tested:	08/02/2004	12/07/2004
Last Concussion:		
Exam Language:	English	English
Test Version:	2.3.401	2.3.401

Word Memory	*WG = 1*	*WG = 4*
Hits (immediate)	12	12
Correct distractors (immediate)	12	12
Learning percent correct	100%	100%
Hits (delay)	10	11
Correct distractors (delay)	12	11
Delayed memory percent correct	92%	92%
Total percent correct	96%	96%

Design Memory		
Hits (immediate)	10	9
Correct distractors (immediate)	8	10
Learning percent correct	75%	79%
Hits (delay)	9	8
Correct distractors (delay)	8	8
Delayed memory percent correct	71%	67%
Total percent correct	73%	73%

X's and O's		
Total correct (memory)	6	8
Total correct (interference)	117	122
Avg. correct RT (interference)	0.40	0.39
Total incorrect (interference)	21	13
Avg. incorrect RT (interference)	0.24	0.27

Symbol Match		
Total correct (symbols)	27	26
Avg. correct RT (symbols)	1.28	1.26
Total correct (symbols hidden)	6	9
Avg. correct RT (symbols hidden)	2.11	1.59

Color Match		
Total correct	9	9
Avg. correct RT	0.84	0.80
Total commissions	0	0
Avg. commissions RT	0.00	0.00

Three Letters		
Total sequence correct	2	3
Total letters correct	11	11
Percent of total letters correct	73%	73%
Avg. time to first click	3.25	2.10
Avg. counted	14.6	13.4
Avg. counted correctly	14.6	0.0

ImPACT© Clinical Report

ImPACT Applications

	Baseline	Post-concussion
Exam Type:	**Baseline**	**Post-concussion**
Date Tested:	08/02/2004	12/07/2004
Last Concussion:		

Composite Scores

	Baseline	Post-concussion
Memory composite (verbal)	79%	90%
Memory composite (visual)*	61%	70%
Visual motor speed composite	36.53	15.25
Reaction time composite	0.56	0.54
Impulse control composite	21	13

* *New clinical/research composite score for ImPACT version 2.0. All other composite scores are identical to ImPACT version 1.1.*

Concussion Details

Loss of consciousness
Retrograde amnesia
Anterograde amnesia
Confusion / disorientation
Returned to play
Taken to hospital
CT/MRI scan of head
Mouthguard type
Mouthguard condition
Symptoms

Description of injury and additional information

The information provided by this report should be viewed as only one source of information regarding the athlete's level of functioning. Diagnostic or return to play decisions should not be based solely on the data generated by ImPACT but should be based on an evaluation by medical personnel in accordance with usual and standard medical practice. If an athlete is suspected of suffering a mild traumatic brain injury or concussion, this individual should be evaluated by medical personnel and should be followed carefully for the emergence of symptoms.

Consultation is recommended to help facilitate proper interpretation of the outlined test scores. For consultation please feel free to contact Dr. Mark Lovell or Dr. Micky Collins at the University of Pittsburgh Center for Sports Medicine. To reinforce proper interpretation of the test data, there will be no charge for the intial post-injury consultation.

Dr. Mark Lovell can be reached at:
412-432-3670 (Office)
412-958-5075 (Pager)
lovellmr@msx.upmc.edu

Dr. Micky Collins can be reached at:
412-432-3668 (Office)
412-958-6714 (Pager)
collinsmw@msx.upmc.edu

ImPACT© Clinical Report

ImPACT Applications

Exam Type:	**Baseline**	**Post-concussion**
Date Tested:	08/02/2004	12/07/2004
Last Concussion:		

Symptoms		
Headache	3	0
Nausea	0	0
Vomiting	0	0
Balance Problems	0	0
Dizziness	2	0
Fatigue	5	3
Trouble falling asleep	5	1
Sleeping more than usual	0	0
Sleeping less than usual	6	2
Drowsiness	3	0
Sensitivity to light	0	0
Sensitivity to noise	0	0
Irritability	0	0
Sadness	6	0
Nervousness	5	3
Feeling more emotional	5	0
Numbness or tingling	0	0
Feeling slowed down	3	0
Feeling mentally foggy	0	0
Difficulty concentrating	2	1
Difficulty remembering	0	0
Visual problems	0	0
Total Symptom Score	**45**	**10**

ImPACT© Clinical Report

ImPACT Applications

Baseline	Hours slept last night:	2.0
	Medications:	
	Subject comments:	
	Supervisor comments:	
Post-concussion	Hours slept last night:	8.0
	Medications:	
	Subject comments:	
	Supervisor comments:	

The information provided by this report should be viewed as only one source of information regarding the athlete's level of functioning. Diagnostic or return to play decisions should not be based solely on the data generated by ImPACT but should be based on an evaluation by medical personnel in accordance with usual and standard medical practice. If an athlete is suspected of suffering a mild traumatic brain injury or concussion, this individual should be evaluated by medical personnel and should be followed carefully for the emergence of symptoms.

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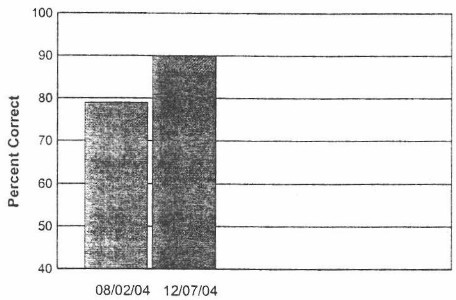
412-958-6714 (Pager)
collinsmw@msx.upmc.edu

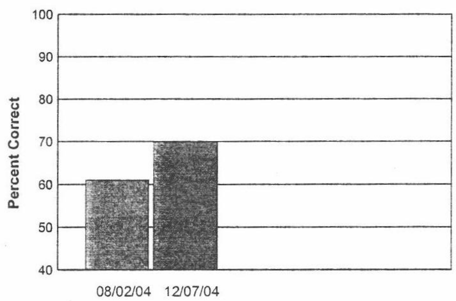
ImPACT© Clinical Report

ImPACT Applications

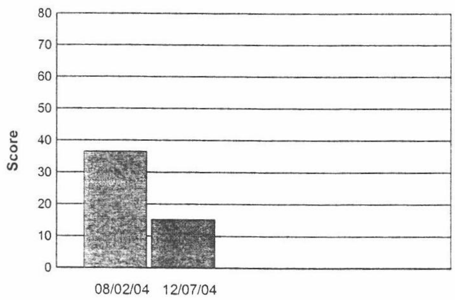
Memory Composite (Verbal)



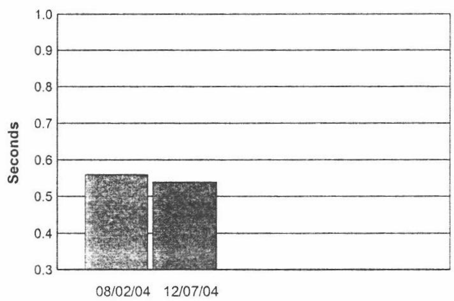
Memory Composite (Visual)



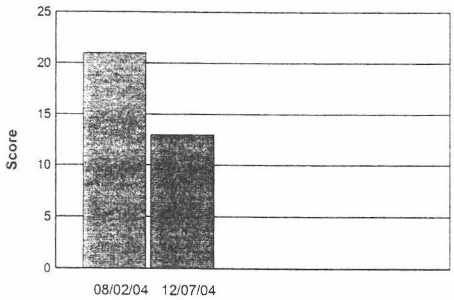
Visual Motor Speed Composite



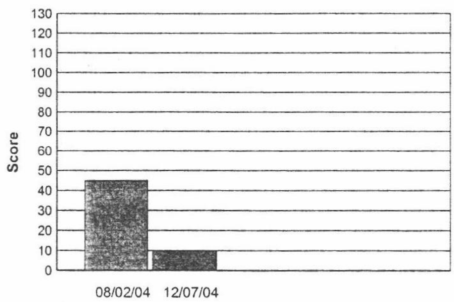
Reaction Time Composite



Impulse Control Composite



Symptom Score



Appendix K- Comparison of Grading Scales

Concussion Grade	Cantu Grading System (2001 Revision)[1]	1991 Colorado Medical Society Guidelines [2]	1997 American Academy of Neurology (AAN) Guidelines[3]
Grade 1 (mild)	No (LOC) Either PTA or post-concussion signs and symptoms that clear in less than 30 minutes	Transient mental confusion No PTA No LOC	No LOC Transient confusion Symptoms or abnormalities clear in less than 15 minutes
Grade 2 (moderate)	LOC lasting less than 1 minute and PTA *or* Post-concussion signs or symptoms lasting longer than 30 minutes but less than 24 hours	No LOC Confusion with PTA	No LOC Symptoms or abnormalities last more than 15 minutes
Grade 3 (severe)	LOC lasting more than 1 minute *or* PTA lasting longer than 24 hours *or* Post-concussion signs or symptoms lasting longer than 7 days	Any LOC, however brief	Any LOC, either brief (seconds) or prolonged (minutes)

1. Cantu, R. (2001). Posttraumatic Retrograde and Anterograde Amnesia: Pathophysiology and Implications in Grading and Safe Return to Play. *Journal of Athletic Training, 36*(3), 244-247.

This grading system modifies the original Cantu grading system proposed in Cantu, R. (1986). Guidelines for return to contact sports after a cerebral concussion. *The Physician and Sportsmedicine, 14*(10), 75-83.

2. *Report of the Sports Medicine Committee: Guidelines for the Management of Concussion in Sports (revised).* (1991). Denver, CO: Colorado Medical Society.

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

Appendix L: Comparison of Return to Play Guidelines

Concussion Grade	Number of Concussion Suffered	Cantu Guidelines (Revised)[4]	Colorado Medical Society Guidelines[5]	American Academy of Neurology (AAN) Guidelines[6]
Grade 1 (mild)	First	Return to play after 1 symptom-free week End season if CT or MRI abnormal	Remove from contest May return to same contest or practice if symptom free for at least 20 minutes	Remove from contest May return to play if symptom free within 15 minutes
Grade 1 (mild)	Second	Return to play in 2 weeks after 1 symptom free week	May not return to contest or practice May return after 1 symptom-free week	May not return to contest or practice May return to play after 1 symptom-free week
Grade 1 (mild)	Third	End season May return to play next season if no symptoms	End season May return to play in 3 months if without symptoms	
Grade 2 (moderate)	First	Return to play after 1 symptom-free week	May not return to contest or practice May return to play after 1 symptom-free week	May not return to contest or practice May return to play after 1 full symptom-free week CT or MRI recommended if symptoms or signs persist
Grade 2 (moderate)	Second	May not return for minimum of 1 month May return to play then if symptom-free for 1 week Consider ending season	Consider ending season May return in 1 month if symptom-free	May not return to contest or practice May return to play after at least 2 symptom-free weeks End season if any CT or MRI abnormality
Grade 2 (moderate)	Third	End season May return to play next season if without symptoms	End season May return to play next season if without symptoms	
Grade 3 (severe)	First	May not return to play for	May not return to contest or	May not return to contest or

		minimum of 1 month May then return to play then after 1 symptom-free week	practice Transport to hospital for evaluation May return to play in 1 month, after 2 symptom-free weeks	practice Transport to hospital if unconscious or neurological abnormality CT or MRI recommended if post-traumatic symptoms or signs persist If LOC brief (seconds) may return to play in 1 week if no symptoms or signs If LOC is prolonged (minutes), return after 2 symptom-free weeks
Grade 3 (severe)	Second	End season May return to play next season if no symptoms	End season May return to play next season if no symptoms	May not return to contest or practice May return to play after minimum of 1 symptom-free month End season if any CT or MRI abnormality
Grade 3 (severe)	Third		End season Strongly discourage any return to contact or collision sports	

1. Cantu, R. (2001). Posttraumatic Retrograde and Anterograde Amnesia: Pathophysiology and Implications in Grading and Safe Return to Play. *Journal of Athletic Training, 36*(3), 244-247.
This grading system modifies the original Cantu grading system proposed in Cantu, R. (1986). Guidelines for return to contact sports after a cerebral concussion. *The Physician and Sportsmedicine, 14*(10), 75-83.
2. *Report of the Sports Medicine Committee: Guidelines for the Management of Concussion in Sports (revised).* (1991). Denver, CO: Colorado Medical Society.
3. Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. (1997). *Neurology, 48*(3), 581-585.

Appendix M: Review of Literature

One of the most challenging issues currently facing sports medicine professionals focuses on the accurate identification of cerebral concussion. Once identified, the proper care and management of the athlete and their return to athletic competition is of utmost concern. With the incidence of sports related concussion reaching over 300,000 cases per year,[1, 9, 84] a consensus regarding the assessment and guidelines for managing this potentially life threatening injury are necessary. According to the National Collegiate Athletic Association Injury Surveillance System, the incidence of head injury is 0.06-0.55 per every 1,000 athletic exposures per year[4]. Although the majority of athletes who experience a concussion are likely to recover, an unknown number of these individuals experience chronic cognitive and neurobehavioral difficulties related to recurrent injury. In addition to the risk of post-concussion type syndromes, suffering a second blow to the head while recovering from an initial concussion can have catastrophic consequences as in the case of Second Impact Syndrome which has led to approximately 30-40 deaths over the past decade[59].

Overall, athletes that do not completely recover from an initial concussion are significantly more vulnerable to sustaining recurrent, cumulative, and even catastrophic consequences of a second concussive injury. Such problems are preventable if each athlete is allowed adequate time to recover from concussive symptoms allowing for consistent and clinically sound return to play decisions to be made. Over the past decade, in response to the increased concern regarding the incidence of concussion and the many difficulties associated with concussion management, several new comprehensive assessment techniques have been presented. These assessments include non-traditional computer based and paper and pencil neurocognitive assessment tools. The goal of neuropsychological assessments are to provide objective clinical data to assist clinicians in making safe and appropriate return to play decisions following concussion[87].

The decision process for returning an athlete to competition following concussion is complex and dynamic[59]. Recent evidence suggests that a history of concussion increases the risk of sustaining a more severe concussion and decreases the threshold for sustaining a concussion of any severity in the furture[24, 59]. The primary reason why head injured athletes must meet the aforementioned return to play criteria prior to returning to competition is due to the increasingly vulnerability of subsequent head trauma. One rare but potentially devastating effect of successive mild concussion is termed Second Impact Syndrome (SIS). This syndrome was first described by Schneider in 1973[59], and has been reported to occur when a second concussion is sustained before the signs and symptoms of the initial incident have completely resolved[59, 71]. The specific pathophysiology of SIS is still not completely understood, however the available evidence to date suggests that initial head trauma results in increased intracranial pressure and sub-clinical edema that make the brain more susceptible to secondary injury[71]. The possibility of an athlete developing secondary head trauma such as that involved with second impact syndrome accentuates the importance of developing reliable return to play criteria and accurate neuropsychological assessment methods.

The purpose of the present study was to assess the agreement of the Immediate Post-Concussion Assessment and Cognitive Functioning (ImPACT™) computerized concussion assessment software with the abbreviated on-field Standardized Assessment of Concussion (SAC™) neurocognitive test in their ability to consistently assess neuropsychological functioning during an extended time interval. This review of literature will describe in detail the effects of athletic induced concussion including its pathophysiology, and will touch on some of the integral components of concussion management including cognitive assessment, and return to play guidelines. Upon completion of this presentation, the utility of the Standardized Assessment of Concussion™ and the Immediate Post-Concussion Assessment and Cognitive Functioning™ tests with be critically examined as applied in an athletic setting. Research and review articles were considered for discussion in this review if they had been published in international peer reviewed scientific journals in sports medicine, neurology, or neuropsychology, or met one or more of the following criteria: (*a*) the article reported the results of computerized cognitive or conventional neuropsychological assessment of athletes with a athletic related brain trauma; (*b*) the article made an inference regarding the neurological and/or cognitive consequences of athletic related brain injury; (*c*) the article provided an in-depth description of a computerized cognitive test or on the field test battery; or (*d*) the article discussed the limitations of on-the-field neuropsychological or computerized cognitive tests.

Recognition of Concussion

Brain injuries that occur due to athletic activity vary in severity from mild injuries with minor sequelae to more severe injuries with potentially life threatening effects[31]. Traumatic brain injury has long been recognized as a serious hazard since early in the 20th century. In 1904, President Theodore Roosevelt's concern for 19 athletes who were permanently paralyzed or killed due to injuries sustained while playing football lead to the formation of the National Collegiate Athletic Association. This committee was formed to establish and enforce standards and rules for safer competition[62, 80]. In order enhance safety of the athletic participants, the type, severity and incidence of injury had to be monitored and examined through clinical evaluation within an athletic setting. In response to the defined necessity, the committee created the National Collegiate Athletic Association Injury Surveillance System which initiated action as a tracking device for head and neck injuries in football[53]. Early studies of this system tracked catastrophic head and neck injuries occurring solely in the sport of football. The ISS has since expanded to include examination and tracking of a wide variety of injuries occurring in all NCAA sponsored sports. Collectively, the information gathered through the studies tracking mild concussive head injury have enabled researchers to identify common causes of injury related to concussion, and have resulted in the development of several substantial changes to athletic competition that have helped to make athletic participation safer for all participants. Despite the longevity of the recognition and investigation of athletic induced concussion, researchers and clinicians have consistently struggled to recognize and identify a clear and universally accepted definition of concussion.

To date there are many different definitions of concussion that vary in specificity and complexity. In order to understand the basis of these definitions it is important to identify the root meaning behind the condition. The word concussion originates from the Latin term *concutere* which means to shake violently[15], while the term commotion *cerebi* was introduced by Pare in the 16th century demonstrating similar meaning[62]. The condition of cerebral concussion was first defined in 1966 by the Committee on Head Injury Nomenclature of the Congress of Neurological Surgeons as a clinical syndrome characterized by an "immediate and transient impairment of neural functions, such as an alteration of consciousness, disturbances of vision and equilibrium due to brain stem involvement"[2, 40, 55, 74]. Although this definition was widely accepted in 1966, further evaluation of the definition over the past two decades has recognized a number of limitations. As concluded at the First International Conference on Concussion in Sport, this definition is deficient in its account of the symptoms associated with concussion such as nausea and headache. In response to the criticism of this and other definitions, several alternative definitions have been developed.

One of the more recent well-known definitions is that proposed in 1997 by the American Academy of Neurology. This definition recognizes concussion as a "trauma-induced alteration in mental status that may or may not involve a loss of consciousness"[52, 82]. In contrast to this brief, consolidated definition is that created by the Concussion in Sport Group, a group formulated during the First International Conference on Concussion and Sport[7]. This group developed a multi-faceted definition of concussion emphasizing the several clinical, pathological and biomechanical features associated with head injury:

> Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathological, and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:
>
> 1. Concussion may be caused either by a direct blow to the head, face, neck, or elsewhere on the body with an "impulsive force transmitted to the head.
> 2. Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously.
> 3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
> 4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.
> 5. Concussion is typically associated with grossly normal neuro-imaging studies[7, 40].

Developing analogous to the term "concussion" has been the term "mild traumatic brain injury"[47]. The term mild Traumatic Brain Injury (mTBI) was introduced into federal law by the Traumatic Brain Injury Act of 1996, making the term cerebral concussion and mTBI interchangeable amongst most medical professionals[62]. Other definitions that have been utilized have included those proposed by Ommaya and Gennarelli[75], Cantu[17], Torg[19], and the Sports Medicine Committee of the Colorado Medical Society[5]. It is evident from the broad definitions and symptomology displayed above that impact of any kind may result in cerebral concussion or mild traumatic brain injury. Due to the complexity in the identification of these factors, there is still a lack of a universally agreement on the standard definition concussion[82]. As reported by the 2004 National Athletic Trainers' Association Position Statement: Management of Sport-related Concussion, although there is a lack of universal agreement on the standard definition or nature of concussion; agreement has been met in regard to the pathological, biomechanical and clinical constructs associated with athletic head injury[40].

Pathologic Causes of Concussion

Brain trauma is in large part caused by an exchange of energy between an external mechanical event and a soft tissue structure with limited elasticity[34]. When the capacity of the brain and the soma to be displaced internally has been met in terms of its ability to return to its normal undamaged location, temporary or permanent brain tissue damage can occur[77]. From a pathological standpoint, the symptoms related to concussion are primarily related to acute metabolic dysfunction[36]. Subsequent to sustaining a concussion, a significant efflux of potassium from the affected neurons takes place resulting in a depolarization of the brain cells, and the release of glutamate exacerbating the efflux of potassium into the brain[8]. This process develops into a continual process until an increased energy demand is recognized within the brain resulting in hyperglycolysis within the affected cells[8]. In addition to these effects, it has also been reported that there is a local reduction in cerebral blood flow that has been speculated to be caused by an increase in extra cellular calcium levels, and resultant vasoconstriction[36]. Collectively, these responses along with many other reactions lead to a general energy crisis that may be sustained from days to weeks following initial injury.

Biomechanical Causes of Concussion

The brain is contained within the bony cranium and is surrounded by cerebrospinal fluid. Within this structural capacity, the brain is free to move about; potentially coming in contact with many bony protuberances within the cranium. As a result of this rigid high contact surface area, concussion may occur as the result of any mechanical force that accelerates the head or brain, and may occur with or without direct contact to the head[35, 82]. Generally speaking, concussive injuries have been described as involving an acceleration-deceleration or rotational mechanism that is capable of resulting in the widespread or global disruption of neurological function[35]. Acceleration-deceleration forces can occur when an object traveling at a high velocity comes in contact with the head. Conversely, rotational forces occur when the cranium is rotated along is axis in an angular motion while the brain remains in a fixated position[8]. Occasionally, concussions have been demonstrated to be the result of a combination of both acceleration-deceleration and rotational forces[8]

The primary mechanisms of concussive injury have been identified by Genneralli[34] as the velocity of the head prior to impact, the time in which the force is applied, and the magnitude of applied force. Collectively, it has been demonstrated that two types of injuries may occur following head injury: diffuse injury and focal injury[34, 35]. Diffuse brain injury is the resultant of a direct blow to the head or is a result of a whiplash type force. In this type of injury, it is not specifically the blow to the head that is significant; rather the acceleration-deceleration mechanism of the head has the greatest effect. In diffuse head injury, there is believed to be a reduction in the overall speed, efficiency, execution and integration of mental processes [38]. Conversely, focal injuries are the result of the soft brain colliding with the rough, bony inside surface of the skull. Primarily, the most common region for focal cerebral contusions to occur is over the frontal and temporal lobes [6]. Regardless of the type of injury, acceleration-deceleration strains and distortions within the brain can result in a shearing or stretching of nerve fibers throughout the brain [34, 35]. Gennarelli[34] stated that:

> Concussive brain injuries can be viewed as caused by strains induced by head motion. They can occur without impact to the cranium and have little to do with the direct effects of an object that strikes the head, except to the degree that the head impact results in head acceleration or deceleration. Thus, concussions are acceleration-deceleration injuries, and they result from the direction, magnitude, and speed with which the head moves,

either from rest or to rest, during the injury sequence. The violent head motions are themselves sufficient to produce strains and distortions within the brain; these result in shearing or stretching of nerve fibers and the consequent axonal damage that now appears to be the substrate of concussive brain injuries[34].

Collectively, researchers have clearly demonstrated that whiplash type, mechanical acceleration-deceleration injuries are capable of producing observable brain damage[35, 75]. As demonstrated by the aforementioned study, rotational acceleration appears to be the primary mechanism responsible for the production of diffuse brain injuries in primates[35], with similar brain damage being observed in humans[76]. Oppenheimer[76] examined the brains of individuals who sustained minor to severe head injuries who consequently died within several days of causes unrelated to the head injury. In this study, evidence of microscopic brain damage in clinically insignificant cerebral injury displayed array of concussive symptoms lasting a few minutes in duration was found. Following this investigation, Oppenheimer concluded that subsequent to head injury, diffuse microscopic lesions are present in a large sample of human brains, with clinical effects being observed not only after severe trauma, but also in cases of concussion or mild head injury[76]. Overall, these results have lead to the belief that the mechanical damage created onto the brain can be attributed to surface shearing and contusion, stretching and tearing of blood vessels, stretching and tearing of nerve fiber groups, and or by tearing of nerve fibers via a crossing vessel[76]. These conclusions are equivocal to those found by Dixon, Taft, and Hayes[29] whose clinical studies suggested that a continuum of diffuse axonal injury exists where the created lesions are mechanical in origin and are caused by the stretching and tearing of nerve fibers and small blood vessels[29].

In addition to the velocity believed to cause the injury, the area of impact is important in regard to the biomechanical forces involved in concussive conditions. A forceful blow to the resting moveable head typically produces brain injury below the point of cranial impact and is termed a coup injury, while an injury where a moving head collides with a non-moving object commonly produces brain injury opposite of the site of impact and is termed a contra-coup injury[8, 12, 13, 20, 40, 51]. Depending upon the location of these types of the injuries, specific deficits can be produced creating problems with functional areas such as language, perception, sensation, motor control, sensory-motor integration, and sensory-motor sequencing[6]. It is evident that the severity of these deficits increases with repeated brain trauma[38, 70, 71]. This may provide explanation as to why some individuals who have seemed to recover from an initial mTBI, subsequently develop permanent sequelae following a successive mTBI. To this date there is no scientific evidence suggesting that one mechanism of injury coup versus contrecoup is more serious than the other, nor that the symptomology of either presents any differently[40].

Clinical Effects of Concussion

Athletes present a unique and complex array of issues relating to the management, diagnosis, and treatment of concussion[8, 17, 86]. The main challenge in the assessment of concussion is the differentiation between the quantification of symptoms versus signs, an assessment that is not so common in the evaluation of athletic injuries. This type of assessment becomes especially problematic as the assessment of symptoms relies heavily on the athlete providing an accurate and honest report of their current symptomatic presence and severity[39]. This inherent difficulty is present for the reason that the symptoms of concussion must be self-reported by the athlete.

The initial symptom presentation of a concussed athlete is highly dependant upon the aforementioned biomechanical aspects of injury, as well as the specifically affected brain structures[25]. The acute symptoms of concussion have been described in detail in many published studies[37, 39, 61, 72]. By definition, the symptoms associated with concussion are immediate. Symptoms of brain injury may or may not persist for varying lengths of time following such a neurological event. It should be recognized that patients with mild traumatic brain injury can exhibit persistent emotional, cognitive, behavioral, and physical symptoms, alone or in combination, which may produce a functional disability. The most commonly validated symptoms include amnesia, loss of consciousness, headache, dizziness, blurred vision, attention deficit, and nausea[39, 47, 61]. These as well as other symptoms generally fall into one of the following categories:

1. Physical symptoms: Include nausea, vomiting, dizziness, headache, blurred vision, sleep disturbance, quickness to fatigue, lethargy, and sensory loss that cannot be accounted for by peripheral injury or other causes;

2. Cognitive deficits: Involving deficits in attention, concentration, perception, memory, speech/language that cannot be completely accounted for by emotional state or other causes; and
3. Behavioral changes: Variations and/or alterations in degree of emotional responses such as irritability, quickness to anger, and dis-inhibition that cannot be accounted for by a psychological reaction to physical or emotional stress or other causes.

In addition to these symptoms, there is also a wide variety of subjective findings that may be reported as being associated with concussion. These include, but are not limited to lethargy, vacant staring, irritability, impaired coordination, sleep disturbances, noise and or light intolerances, behavioral disturbances, and an altered sense of taste/smell[47]. The presence of clinical symptoms alone does not single-handedly determine the presence of concussion.

One of the primary cognitive deficits demonstrated post concussion affects the memory system. The creation and storage of memories is a complex process that involves many regions of including the frontal, temporal and parietal lobes[49]. Damage to these areas can result in varying degrees of memory loss. In order for short-term memory to become long-term memory, it must go through a process known as consolidation. During the consolidation process, short-term memory is repeatedly activated so that certain chemical and physical changes can occur in the brain permanently embedding the memory for long term access. If during this repeated activation and an injury such as a concussion or brain trauma interrupts the process short-term memory cannot be consolidated[49]. This has been presented[49] as being the process occurring in individuals with anterograde amnesia.

Consolidation occurs in the hippocampus, which is located in the temporal lobe regions of the brain. Past research has indicated that the frontal and temporal lobes are the regions of the brain most often damaged during head injury[76, 78]. This may explain why many individuals who sustain severe head trauma or brain injury experience anterograde amnesia. Any athlete who receives a direct blow to the head or any significant acceleration-deceleration type force to the head should be presumed to have possibly sustained a head injury and should be thoroughly evaluated utilizing specific concussion evaluation assessment tools.

Neuropsychological Testing

Traditionally, athletes who have sustained a head injury caused by athletically related incidents are deemed fit to resume participation based on clinical judgment. Such judgments have often been made with reference to the athlete's subjective rating of their current symptomology or by other non-standardized assessments of recovery[28]. In athlete's who have sustained a head injury, early return to activity may lead to potentially serious neurological and cognitive consequences, a factor that judgments made solely based upon clinical judgment fails to adequately consider. The concern for a more accurate, efficient and standardized measure has lead to the development of several neuropsychological tests aimed at the measurement of an athlete's cognitive ability following concussion.

Neuropsychological testing is not a tool intended to be utilized to diagnose injury; rather it is a useful assessment measure that allows clinicians to quantify the severity of injury, and measure injury progression throughout the course of cognitive recovery[10]. Performance on neuropsychological tests has since been used to guide decisions about recovery from concussion and return to activity. To date a number of studies have utilized neuropsychological testing measures to investigate cognitive function in head injured athletes[14, 28, 37, 42, 43, 61]. These studies have generally compared the individual athlete's neuropsychological test scores following concussion with those prior to concussion through the utilization of baseline measurements.

Neuropsychological testing is one of the most sensitive techniques for detecting abnormal brain functioning post concussion[80], and plays a vital role in the medical management of sports-related concussion. Neuropsychological assessment tests offer a method of observing symptoms in a controlled manner, while being standardized in nature[10] and providing an objective measure for documentation and tracking of brain dysfunction[8]. The basic premise behind neuropsychological testing is that a decrease from baseline test scores at a test-retest event may signify the presence of cognitive impairment secondary to concussion[10]. Conversely, an increase in scores in subsequent testing is demonstrative of improvement in cognitive functioning or ability[10]. The development and standardization of neuropsychological testing has involved many steps including the decision of the psychological construct or symptom to be evaluated, as well as ensuring validity and reliability of the specific measure.

Accurate detection of changes to baseline evaluation scores is a highly critical component in detecting the subtle changes that occur post concussion[10].

Neuropsychologists are aware that no single test can be effective in the diagnosis of the presence or absence of concussion. Tests that are used in this manner are not as effective when assessed in isolation, and are thus primarily administered in groups called testing batteries[10]. The purpose of administering neuropsychological testing batteries is to examine the consistency in symptoms presentation as exhibited in each of the various tests. Typically, a clinical assessment of an individual with a concussion requires an extended testing battery that measures the individuals motivational and emotional state in addition to the severity and patterning of cognitive functioning[10].

The discipline of neuropsychology originally developed in the 1940's due to the general insensitivity of standard neurological examinations in diagnosing many cases of brain damage[28]. While advances are currently being made in the development of more sensitive and reliable neurodiagnostic tests, neuropsychological assessment is considered to be the most sensitive measure of brain damage[47]. Neuropsychological testing provides an assessment and quantification of brain functioning by examining brain behavior relationships[32], and is a means to quantify the effects of head trauma on cognitive functioning[48].

The use of neuropsychological testing in the assessment of concussion in athletes is not a new concept, as Rimel et al.[81] were amongst the first to emphasize the importance of neuropsychological testing in individuals suspected of sustaining a mild traumatic brain injury[62, 81]. In 1989, Barth et al.[12] reported the first large scale neuropsychological evaluation of the effects of cerebral concussion. This study evaluated the effects experienced by 2350 collegiate football athletes, who had baseline neuropsychological data collected. Two hundred of these athletes were reassessed at a 24-hour, 5-day, and 10-day interval post concussion[12, 62, 73]. Results from this study have demonstrated that a majority of the athletes who sustained concussion returned to their non-injury baseline within 10 days of onset, confirming that the effects of mild head injury can be accurately assessed utilizing neuropsychological testing[12, 62].

Baseline Testing

In order to maximize the clinical utilization of all neuropsychological assessments, baseline testing is a necessity. Baseline data provides clinicians with data to make informed decisions about the presence or absence of changes in cognitive functioning over time[10, 80]. Without baseline data, the athlete is compared to normative data in order to interpret test results. This can be potentially problematic as each individuals "normal" may vary substantially due to various factors including cognitive functioning, previous head injury, psychiatric problems, test anxiety, attentional disorders, educational backgrounds, sleep deprivation, medication, alcohol or drugs, primary languages other than English, and experience or familiarity with prior neuropsychological testing procedures[37]. Therefore, without the benefit of knowing how the athlete performed prior to sustaining a concussion, it is very difficult to determine whether any deficits evident during testing are due to the effects of concussion or other unrelated factors[60].

Previous reports[11, 22, 23, 44-46, 63-65, 67-69] have demonstrated the utility of baseline testing in the assessment of the neuropsychological effects of concussion. Access to pre-injury baseline data has allowed athletic training clinicians, and physicians to compare an athlete who has sustained a head injury with their own normal performance on any given measure of the assessment[63]. Additionally, baseline measures allows for greater control of variability among subjects, extraneous variables such as learning disability and level of education, and associated long term effects of deficits caused by previous concussions[63]. In a 2001 study, Barr and McCrea demonstrated that the comparison of a subject's pre-injury and post-injury data is the most accurate indicator of recovery in athletes, while providing the ability to track cumulative effects of recurrent concussions, and monitor post-concussion symptoms[11].

Although conventional neuropsychological assessments have been demonstrated as being an accurate measure of neuropsychological deficit following concussion, this approach also presents a number of methodological and practical problems that are difficult to overcome in an athletic setting[10]. Standard neuropsychological assessment batteries may require two to three hours to administer and requires a neuropsychologist or trained technician be present in order to supervise the athlete[10]. The requirements of this form of testing makes the baseline assessment of an entire athletic team or squad unreasonably time consuming and expensive to conduct. In an attempt to overcome this problem, recent studies have utilized condensed test batteries comprising five to six neuropsychological tests that typically require about 20–30 minutes to administer[61]. These "screening" batteries provide an adequate guide to the athlete's baseline cognitive status, while still allowing comparisons with the status after concussion in a number of cognitive domains[10, 14].

Computerized Assessment Batteries

Computerized testing offers a solution to many of the methodological and practical problems associated with traditional neuropsychological testing batteries. Computerized tests were designed initially to detect severe impairments in patients with neurological and psychiatric illness, brain lesions, and in individuals exposed to neurotoxic substances[21]. Current computerized batteries have utilized the unique properties of computing hardware to develop tests that are sensitive to very mild changes in cognition, such as those expected to occur in sports related concussion.

Currently research suggests that computer based neuropsychological tests may be more sensitive to cognitive impairment following athletic related head injury in comparison to other conventional neuropsychological tests[14, 21, 58, 60]. Computerized testing offers the many theoretical advantages of randomization of testing forms, standardized self administration, rapid testing, internet based delivery, and centralized data storage, analysis, and reporting[32, 40, 60, 83]. Computerized testing has also been shown to be sensitive enough to detect neurological defects even after the athlete feels “normal”[25, 83]. Although computerized testing has been proved to have definite advantages over conventional neuropsychological testing, there are a number of limitations that must be considered before they can be applied to identify subtle cognitive dysfunction in athletes.

At least three major limitations exist for most computerized cognitive assessment tools. The first is in hardware required to administer the tests. Many current computerized testing batteries require not only a PC and keyboard, but also a touch sensitive screen[10]. This means that the tests are not as portable as conventional neuropsychological tests, and may be difficult to administer during an optimal time frame while traveling for competition. The second limitation is the cost involved in setting up a computerized assessment system, which may include purchasing expensive software and hardware, as well as training Neuropsychologists and technicians in administration protocols, data storage, and analysis[10]. Furthermore, many computerized tests do not have sufficient normative and test-retest reliability data, and have not been validated against conventional neuropsychological measures or for use in different disorders and settings[10]. These limitations may all be overcome by further test development and validation of the testing batteries. Over the past few years, many neuropsychological testing batteries have been validated and standardized for use in many settings thus overcoming the third limitation.

Recently, a number of computerized neuropsychological testing programs have been designed for the assessment of concussion in athletes. One such computerized assessment measure is the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT™) testing battery. The ImPACT™ computerized software was designed to provide information in the form of cognitive data and symptom reporting to sports medicine professionals interested in determining recovery from injury as well as a safe timeline for return to participation for athletes[57]. The ImPACT™ neuropsychological testing battery allows for assessment of cognitive speed, memory and reaction time across seven different testing modules[24, 58, 62]. Each module has the opportunity to consist of a near infinite number of forms through the randomized variation of stimuli during each administration[57]. This testing battery currently consists of three forms, which can expanded into an infinite number of variations by randomly varying the order of stimuli, as the modules utilized in this testing battery can be administered as a portion of a single testing battery, or individually[44, 46]. The program measures the components of attention span, verbal and visual memory, working memory, response variability, reaction time, and non-verbal problem solving throughout each of the seven modules[24, 44-46, 57]. For a complete explanation of each of the modules, refer to Appendix H. In addition, the ImPACT™ battery also includes the Post-Concussion Symptoms Scale (Appendix I) which is a 22-item scale that is designed to measure the severity of symptoms in the acute phase of recovery post-concussion[44-46, 60]. The post-concussion scale has been reported[44-46, 60] as a "state" measure of perceived symptoms associated with concussion as reported by each individual subject.

In 2003, the reliability of the ImPACT™ testing battery version 1.0 was assessed by Iverson, Lovell, Powell, and Collins[45, 57]. Test-retest reliability and reliable change scores were examined in 49 non-concussed amateur athletes who completed the testing battery at least three times. The second evaluation was performed an average of 14 days post-baseline assessment, and the third evaluation an average of 4.5 days after that. Results of this study demonstrated that there were no significant differences within subjects for level of performance and test-retest correlation coefficients for multiple time intervals indicating that there are no demonstrated practice effects utilizing the neurological composite scores[45, 57]. This study did however have limitations in that the sample size was relatively small; and the sample heterogeneity of the test re-test coefficients for each group was unknown. Similarly, the reliability of the post-concussion symptoms scale was also evaluated. A sample of 2,304 amateur athletes (2,189 healthy and 894 concussed) was assessed utilizing the 22 item scale. The internal consistency reliability ranged from 0.88 to 0.94 in healthy subjects and 0.93 in concussed subjects[45, 57].

Similar investigations have been done measuring the validity of ImPACT™ version 1.0[45, 57] in measuring the effects of sports related concussion was assessed. A sample of 120 amateur athletes completed pre-season testing and was evaluated within three days of sustaining a concussion. Concurrent criterion validity was examined by determining whether the four composite scores were sensitive to the acute effects of concussion. The athletes in the study reported more concussion symptoms ($p<0.001$, $d=1.0$), performed worse on the memory composite ($p<0.001$, $d=0.66$), and on reaction time ($p<0.014$, $d=0.27$), while not performing significantly worse on the processing speed composite ($p<0.07$, $d=0.19$) post-concussion in comparison to preseason baseline testing[45, 57]. Divergent validity was examined by an interclass correlation matrix of the four composite scores at two levels; preseason, and post concussion. During the preseason measurement a statistically significant correlation was presented between the reaction time and processing speed components (r=-0.35). Conversely, during the post concussion assessment there was a significant correlation between symptoms and memory composites (r=-0.38), memory and reaction time composites (r=-0.27), memory and processing speed composites (r=0.35), and reaction time and processing speed composites (r=-0.32). Overall the relatively small correlations amongst composites demonstrate that the composite scores do not have a lot of shared variance, meaning that they are truly measuring different things[45, 57]. In the same study, convergent validity was examined by correlating the composite scores with specific items within the post-concussion symptoms scale. A subset of physical, cognitive, and emotional symptoms were selected for the analyses and were correlated for composite scores derived from post concussion assessments only. There was a very small correlation demonstrated between reaction time and any of the symptoms, as well as processing speed and the symptom of vomiting (r=-0.19). Medium to high correlations were demonstrated between the total symptoms score and the items of vomiting, balance, concentration, memory, sensitivity, and emotionality (r= between 0.53 to 0.83). The highest correlations were demonstrated between the memory composite score and poor memory (r=-0.40), concentration (r=-0.40), light sensitivity (r=-0.32), balance problems (r=-0.27), and was uncorrelated to the remainder of the variables[45, 57]. From these results it is clear that ImPACT™ is sensitive to the acute effects of concussion as measured in young athletes, however future investigation is needed to further define what each composite score is measuring and how it is correlated with factors associated with acute effects of concussion.

Other studies have examined other properties of the testing battery including the stability of scores and reliable change intervals for test-retest difference scores. In a study of psychometric properties of ImPACT™ version 2.0, test-retest reliability, practice effects and reliable change parameters were estimated in a sample of 46 healthy amateur athletes[45, 57]. Each subject completed the test battery as a baseline measure then underwent a second testing session at a brief retest interval of 5 days. A second group of 41 amateur athletes who underwent baseline assessment, and sustained a concussion during their competitive season were retested within 72 hours of their concussion in order to determine reliable change parameters. The results of the first subject group demonstrated that the there were no within group differences for the verbal memory, visual memory, reaction time, or total symptoms scale, while there was a significant difference demonstrated between baseline and retest measures on the processing speed composite ($p<0.003$, $d=0.27$). Furthermore, the percentages of subjects demonstrating a decline across the five composite scores were: no decline= 63.0%, one decline= 30.4%, two declines= 4.3%, and 3 declines= 2.2% when evaluating the reliable change scores. Comparatively the second group demonstrated a decline in verbal memory ($p<0.002$, $d=0.69$), visual memory ($p<0.002$, $d=0.69$), processing speed ($p< 0.005$, $d=0.95$), reaction time ($p< 0.005$, $d=0.95$), and an increase in symptom reporting (p, 0.001, $d=0.99$). Additionally, the percentages of athletes in the group that demonstrated a decline across the five composite scores was: no decline= 24%, one decline= 12.2%, two declines= 19.5%, three declines= 12.2%, four declines= 19.5%, and five declines= 12.2%[45, 57]. The results of this study demonstrated that athletes with concussions are much more likely to demonstrate two or more declines across the five composites in comparison to healthy subjects.

Despite the many advantages of computerized cognitive assessment, the results from such assessments should not be considered in isolation. Computerized testing should be used primarily to inform decisions on resuming participation when the team physician or athletic trainer is uncertain of the athlete's status after a conventional neurological and physical examination has been conducted. In some cases, it still may be appropriate to conduct a more detailed neuropsychological examination of the athlete after a concussive episode, in order to gain a greater understanding of the domains of cognition persistently affected by the brain injury.

<u>On-Field Neuropsychological Testing Batteries</u>

The purpose of on-the-field neuropsychological evaluations is to ascertain whether a life threatening injury caused by trauma to the head has occurred. Prior to 1997, no previous studies had utilized a standardized technique for immediately administering a sideline neuropsychological examination to detect and characterize concussive symptoms in athletes[66]. Recent efforts have focused on the development of a brief, standardized method of concussion assessment available for use on athletic sidelines which include measures of post-concussion symptoms, postural stability, and neurocognitive status[64]. Currently the most widely used and best validated on-field testing instrument is the Standardized Assessment of

Concussion test (SAC™). The SAC™ (Appendix G) was developed to help provide sports medicine clinicians with an objective and standardized method of immediately assessing an injured athlete's mental status on the sideline within minutes of initial trauma[64, 67, 69]. The intention of the SAC™ neurocognitive testing battery is not meant to be a stand-alone measure to determine the severity of injury or an athlete's readiness to return to activity; rather the instrument was designed to supplement other methods of concussion assessment such as complete neuropsychological evaluations, or computerized neuropsychological assessments[63-69].

The sideline evaluation was designed in accordance to the American Academy of Neurology[54], and the Colorado Medical Society[5] guidelines for management of concussion in sport. The SAC™ consists of a 30-point scale that includes measures of orientation, attention, immediate memory, and delayed recall[69]. For a complete description of the SAC™ test please refer to Appendix G. There are two potential scoring methods available for examination of athletes who have sustained a concussion. The first is to compare an injured athlete's scores to their own pre-injury baseline performance in order to compare changes that are indicative of concussion. The second method is to use population-based normative data to establish cutoff scores with a score below which is considered significant and indicative of concussion[68, 69]. Data to this point has demonstrated that comparing an individual's scores to their own pre-injury baseline is the most reliable method of comparison[63-65, 67, 68]. Access to pre-injury baseline data allows sports medicine professionals to compared an injured athlete with their own normal performance for a measure, allowing for control of variability across subjects, extraneous influential variables such as learning disabilities, as well as the effects of previous concussion[63]. Sufficient data is not available at this point to determine if the SAC™ can be used clinically if baseline data is not available.

Three equivalent alternative forms (A, B, and C) are available in order to minimize any practice effects caused by repetitive administration[11, 26, 63-65, 67-69, 85]. Each form differs only in the selection of digits in the concentration section, and the words used in the memory testing. Additionally, the SAC™ includes a standard neurological screening that assesses deficits in strength, sensation, and coordination[63-67, 69]. The occurrence and duration of loss of consciousness, retrograde and anterograde amnesia is recorded as part of the SAC™[63-67, 69]. The examination requires approximately 5 minutes for administration, and was specifically designed for administration by a non-Neuropsychologists with limited to no experience in psychometric testing[63].

Studies[66, 69] have supported the utilization of the SAC™ as a valid and reliable measure of mental status and neurological abnormality within minutes after concussion in athletes. In the original study (1997) involving preliminary clinical evaluation of the practicality and validity of the SAC™ test, 141 non-concussed high school football athletes were administered the SAC™ test. Of the total sample, 76 were test controls in games, while 65 were test controlled in practice. Throughout the course of the season, a total of six athletes sustained a concussion during the season, and were re-tested by an athletic trainer immediately following injury[66]. Results of this study demonstrated that there was no significant difference between the total scores on examinations collected during either practices or games; additionally there was insignificant differences detected between the scores attained from three different athletic trainer evaluators. Results from this study also demonstrated that the total score obtained from concussed athletes immediately following injury was significantly lower than that of the non-concussed control athletes[66]. Collectively the data reported in this study laid the foreground for future evaluation of the validity, reliability and utility of this testing battery.

In a later study, 353 high school, and 215 college (N=568) non-concussed athletes underwent baseline testing on the SAC™ test. One variation in this study, from the previous study was that baseline testing on all controls was conducted during off-season fitness training, or pre-participation physical examinations prior to the start of contact drills[69]. Of the total 568 athletes, 33 athletes sustained a concussion throughout the duration of the study, all of which were re-tested by an athletic trainer immediately following injury. Follow-up testing was also completed 48 hours following injury on 28 of the concussed athletes. The experimental design of this study incorporated the element of test re-test reliability, however did not measure practice or repeated measure effects. Results of this study demonstrated that the SAC™ is a useful testing battery in tracking recovery from concussion, as follow-up testing on all of the 28 concussed athletes who were re-evaluated returned to baseline on all SAC™ measures within 48 hours of re-evaluation. Additional results of this study also support the utilization of the SAC™ in detection of concussion in football athletes, as all athletes who sustained a concussion during the testing period scored significantly lower than the non-concussed athlete controls[69].

In 2000, original normative data for the SAC™ test was published[68] presenting data that evaluated a testing group of 2,500 male and female junior high, high school, college and professional athletes. Results from the data collection demonstrated a scores significantly below their own pre-injury baseline performance, the baseline mean score for a non-injured population, and the control group who was administered the SAC™ at the same testing intervals[63]. Collectively these results demonstrated that the testing battery is appropriate for use at all athletic competition levels, reliable over repeated testing, as well as free from any significant gender effects[63, 68].

In a later study, Barr and McCrea[11] evaluated a total of 1,313 male football players from 15 high schools and four universities between 1997 and 1999. In this study 68 non-injured athletes were re-tested at 60 and 120 days following baseline measures, timeframes that correspond to the length of time between baseline testing and the middle of the respective football seasons[11]. The purpose of this study was to distinguish between real neuropsychological change and performance variability due to psychometric or extraneous factors by using a reliable change index (RCI) to identify and characterize change in neurocognitive performance over time[11]. Computation of reliable change indices in this study demonstrated that a decrease in total score by 3 points is representative to a significant change when a conservative 90% CI is used. Further examination of the distribution of total score between injured and non-injured subjects demonstrated that a decrease ranging from 1 to 3 demonstrate comparable levels of classification of injured and non-injured subjects. Similarly, a decline of 1 point or more from a subject's individual baseline SAC™ score is a marker of injury immediately following concussion was demonstrated in 94% of the injured population[11, 63]. With a decrease of 1 point on the SAC™ identifying the largest number of injured athletes[11], it also may misclassify a significant number of athletes who have not sustained a concussion. This brings up the dispute regarding which cutoff score should be utilized in order to classify injured and non-injured subjects. The most sensitive score may be accepted best by sports medicine professionals, and family members of injured individuals, while the high risk for misclassification may be unacceptable to subjects, coaches and teammates who are concerned with returning to play as soon as possible may lead to the selection of the psychometrically based cutoff score[11]. Currently no distinct regulation exist that indicates which cutoff method should be utilized, however Barr and McCrea (2001) have suggested that the criteria for significance should be set by the examiner based on the population and question at hand prior to administration of baseline assessments[11].

One area still lacking in regard to the clinical utilization of the SAC testing battery in assessment of concussion in athletes is a comparison with varying measures of neuropsychological testing. To date, there has been one study found that had any comparison to other testing protocols. Valovich, Perrin and Gansneder[85] conducted a study to evaluate practice effects during repeated administration of the SAC™ test and the Balance Error Scoring System evaluation which is a measure of postural stability. The Balance Error Scoring System (BESS™) is a clinical testing battery that utilizes modified Rhomberg stances on various testing surfaces[85]. This study included the assessment of 32 uninjured high school male and female athletes who participated in a variety of athletic events. All subjects were administered the SAC™ and the BESS™ as a baseline measure, then were re-tested at day 30. Subjects (N=16) who were assigned to the practice effects group were also administered both tests at day 3, 5, and 7 after baseline measure. Results of this study demonstrated that there was no significant practice effect with repeated administration of the SAC™ test. Comparatively, repeated administration of the BESS™ presented significantly fewer errors on day 5 and 7 in the repeated measure group. Overall this study provides comparison between two methods of evaluating factors related to concussion, however does not fill the void in comparison of methods with other multi-faceted testing batteries such as computerized neuropsychological testing batteries.

RETURN TO PLAY GUIDELINES & GRADING SCALES

All of the aforementioned definitions were constructed with return to play guidelines, none of which were specifically designed on the basis of scientific knowledge, rather they are formulated based on anecdotal or clinical experience[39, 62]. With the exception of Cantu's[18] grading system, all current sports concussion grading scales published in scholarly literature base an injury with a positive loss of consciousness as a more than a concussive injury with positive confusion or amnesia with an absence of loss of consciousness[23, 24, 47]. These recommendations have been attributed to much of the early research on head trauma defining loss of consciousness as the hallmark of concussive injury[24]. As reported by Collins, et.al, Symonds describes concussion as "the patient is completely unconscious, and in a state of flaccid paralysis"[24]. In addition to loss of consciousness, the assessment of injury severity consider the nature and duration of key injury symptoms[33]. Guskiewicz reports that the primary purpose of grading scales is to (1) provide a tool for triaging an injury, and projecting the management based on the injury severity, (2) assist in the prediction of injury outcome, and (3) prevent potential catastrophic outcomes of acute injury, second impact syndrome, or cumulative brain injury that is caused by repetitive trauma[39].

Approximately 16-25 different published concussion grading systems exist that may be used in the classification of severity of concussive injury[39, 47, 55]. To date, none of the scales or guidelines have emerged as a gold standard or been followed with an extreme amount of consistency in the assessment of cerebral concussion[39]. Each varies in the aspects of definition, medical treatment and return to play recommendations. Part of the difficulty in developing accurate guidelines has been a lack scientific data on which to base these protocols. As reported by Johnston et al.[1, 47], and Bailes & Hudson[9] there have been no prospective validated randomized clinical studies of any of the current grading systems in sports-related concussion. In addition, rigid procedures do not account for individual differences in symptom resolution. Despite this disagreement, studies agree that at no time should an athlete be returned to play while still experiencing symptoms of a head injury[88].

Current guidelines for grading sports-related concussion are based on the parameters of the severity of injury and the patient's history of concussion[56]. With the exception of the revised Cantu grading scale[18], all current sports-related concussion grading scales base an injury with a positive loss of concussion as more severe than one with no loss of consciousness[18, 25, 47]. The focus of loss of consciousness in current grading scales had been related[24] to early animal model work by Denny Brown and Russell in 1941[24, 27], and later by Ommaya and Gennarelli[24, 50, 75], and Gennarelli et al.[35] in 1974. The previously mentioned studies induced various degrees of whiplash and rotational injury in squirrel monkeys, then extrapolated brain tissue to perform a histological analysis[24]. From this data, the researchers proposed 6 grades of traumatic brain injury, basing severity on the level of consciousness, with 3 of the 6 grades not involving a loss of consciousness[24, 50]. This animal model research is currently referenced as evidence based support of the Colorado and American Academy of Neurology concussion management and assessment guidelines[24, 50, 53].

The three most widely used guidelines are those proposed by the American Academy of Neurologists[54], the Colorado guidelines[5], and those proposed by Cantu[17, 18]. In the assessment of injury severity, all three grading systems take into account the nature and duration of the key injury characteristics of concussion. The AAN practice parameters[54] classify a grade I concussion as having no loss of consciousness, and mental status abnormalities that last less than 15 minutes in duration[5, 9, 18, 33, 50, 54]. The Colorado guidelines classify a grade I concussion as having no loss of consciousness, with a state of confusion being the hallmark sign[5, [9, 18, 33, 50]. Cantu[17] defines a mild concussion as having no loss of consciousness, with confusion, and possible a brief period of amnesia[9, 17, 18, 33, 50]. This "mild" or grade I concussion is the type most commonly seen in sports-related concussion[9]. This type of concussion is not infrequent in contact sports, and may commonly be referred as a "ding" or a "ringing of the bell"[3]. The athlete in this case is awake, alert, and slightly dis-orientated, and may be able to function unnoticed during the course of activity[9]. As represented in all three scales however, if significant disorientation, confusion, memory disturbance, dizziness, headache, or if any neurological abnormality beyond the 15-30 minute observation period, the athlete may have sustained more than a "mild" concussion[9].

Classification of a "moderate" or grade 2 concussion presents some disagreement between the three scales regarding the presence of loss of consciousness. The AAN parameters[54] classify a "moderate" or grade 2 concussion as having transient confusion with no loss of consciousness, and the duration of symptoms lasting less than 30 minutes, while the Colorado guidelines[5] specify that there is a presence of confusion with amnesia, and no loss of consciousness[5, 9, 17, 18, 33, 52, 54]. Comparatively, the original Cantu scale defines a moderate concussion a being on with a short loss of consciousness less than 5 minutes in duration, with associated post-traumatic amnesia lasting between 30 minutes and 24 hours post-impact[9, 17, 18, 33, 52].

A "severe" or grade 3 concussion is defined by all three classification systems ads being associated with a loss of consciousness. Athletes sustaining this severity of concussion may require emergent transport to an advanced care facility to undergo CT scanning an a complete neuropsychological evaluation[9]. The AAN guidelines[54], and the Colorado guidelines[5] agree upon the defining characteristic of a grade 3 concussion as being one associated with any loss of consciousness irregardless of longevity[9, 18, 30, 50]. Cantu's original grading system [17, 18] recognizes a grade 3 concussion as experiencing a loss of consciousness greater than 5 minutes in duration, or having a state of post-traumatic amnesia that last longer than 24 hours in duration[9, 17, 18, 30, 52]. Appendix J presents a comparison of the AAN parameters, Colorado Guidelines, and Cantu Grading System.

There has been a lot of criticism on the various grading systems since the beginning of their utilization[18, 39]. The major criticisms of the AAN parameters[54] and the Colorado guidelines[5] involves their emphasis on loss of consciousness, while the symptoms of amnesia, and mental confusion are not relevant until evaluation of a severe concussion[39]. Conversely, the Cantu grading system[17] is often criticized due to the lengthy window of time placed on loss of consciousness in order to classify a grade 2 concussion[18, 39]. It is highly uncommon to see a period of unconsciousness lasting more than 5 minutes in duration in the athletic setting; most periods of unconsciousness last less than a minute[18]. Criticism regarding the system prompted Cantu to re-evaluate the current scale, leading to the presentation of an evidence-based modified version of the original Cantu grading system[17]. The evidence based Cantu grading system[18] suggests that a grade 2 or moderate concussion is associated with a loss of consciousness less than 1 minute in duration, or post-traumatic amnesia, or post-concussive signs and symptoms lasting longer than 30 minutes, but less than 24 hours[18]. Additionally, the modified system defines a grade 3 concussion as one being associated with a loss of consciousness longer than 1 minute in duration, or the presence of post-traumatic amnesia lasting longer than 24 hours; post-concussion signs or symptoms lasting longer than 7 days[18].

Each respective grading scale is associated with recommended return to play guidelines suggesting the amount of time that should elapse before an athlete is allowed to return to contact activity. In these scales, more severe grades of concussion require longer periods of time to elapse before return to play is allowed. Appendix J presents a comparison of return to play guidelines utilizing the aforementioned grading scales. In addition to the grade of concussion sustained, each return to play guideline includes consideration of the athletes overall concussion history, with special emphasis on the current season in determinacy of the athlete's readiness to return to activity. Although research has suggested that those individuals with a concussion history sustain a greater neurocognitive impairment following new incidence of head injury[41, 79], once an athlete has sustained an initial concussion the chances of them incurring a subsequent one is significantly greater than an athlete who has never sustained a concussion[18, 33, 41].

While there is no universal agreement on the definition and grading of concussion, or when the athlete returns to play, there is unanimous agreement among these grading scales that if an athlete is still suffering from post-concussive signs or symptoms at rest, or with physical exertion, they should not be allowed to return to contact athletic activity[18, 33, 39]. Currently, the National Athletic Trainers'

Association (Dallas, TX), or the National Collegiate Athletic Association (Indianapolis, IN) endorse any specific grading scale or system due to lack of consensus by the medical community regarding the management and assessment of concussion[3, 16]. Despite the utilization of concussion classification guidelines and return-to-play criteria, there will always be the likelihood that future head impact can occur, along with the potential for additional head trauma. While neuropsychological testing provides important diagnostic information, it is highly emphasized that neuropsychological testing provides only a small piece of the diagnostic assessment with many other factors being of integral importance.

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Appendix N- Statistics

Descriptive Statistics

Descriptive Statistics				
Testing Measure	Gender	Mean	Std. Deviation	N
ImPACT™ Verbal Learning Memory Pre-Season	Male	98.36	3.26	44
	Female	97.65	4.93	43
	Total	98.01	4.16	87
ImPACT™ Verbal Learning Memory Post-Season	Male	96.52	4.91	44
	Female	97.12	3.84	43
	Total	96.82	4.40	87
ImPACT™ Verbal Delayed Memory Pre-Season	Male	89.43	8.35	44
	Female	92.60	7.66	43
	Total	91.00	8.12	87
ImPACT™ Verbal Delayed Memory Post-Season	Male	87.55	9.27	44
	Female	91.23	8.62	43
	Total	89.37	9.09	87
ImPACT™ Memory Composite Pre-Season	Male	85.14	14.80	44
	Female	87.84	10.21	43
	Total	86.47	12.74	87
ImPACT™ Memory Composite Post-Season	Male	84.39	9.92	44
	Female	88.23	7.46	43
	Total	86.79	8.86	87
SAC™ Immediate Memory Pre-season	Male	98.64	2.72	44
	Female	98.14	4.67	43
	Total	98.39	3.80	87
SAC™ Immediate Memory Post-season	Male	98.18	3.83	44
	Female	97.67	5.02	43
	Total	97.93	4.35	87
SAC™ Delayed Memory Pre-season	Male	80.45	18.54	44
	Female	82.79	17.77	43
	Total	81.60	18.10	87
SAC™ Delayed Memory Post-season	Male	85.45	18.98	44
	Female	85.11	20.04	43
	Total	85.28	19.40	87
SAC™ Composite Pre-Season	Male	89.53	5.46	44
	Female	90.86	5.83	43
	Total	90.20	5.63	87
SAC™ Composite Post-Season	Male	90.06	5.93	44
	Female	91.93	5.40	43
	Total	91.26	5.70	87

Immediate Memory 2x2x2 ANOVA's							
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**	**Eta Squared**	**Observed power**
TEST	48.227	1	48.227	2.215	0.140	0.25	0.313
Error (Test)	1850.787	85	21.774				
TIME	59.044	1	59.044	4.364	0.040	0.049	0.542
Error (Time)	1150.012	85	13.530				
GENDER	6.858	1	6.858	0.324	0.571	0.004	0.571
Error (Gender)	1799.684	85	21.173				
TEST * GENDER	4.261	1	4.261	0.196	0.659	0.002	0.072
TIME * GENDER	9.124	1	9.124	0.674	0.414	0.008	0.128
TEST * TIME	11.528	1	11.528	0.823	0.367	0.010	0.146
Error (Test * Time)	1190.861	85	14.010				
TEST * TIME * GENDER	9.424	1	9.424	0.673	0.414	0.008	0.128

Delayed Memory 2x2x2 ANOVA's							
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**	**Eta Squared**	**Observed power**
TEST	3962.948	1	3962.948	18.45	0.00	0.17	0.989
Error (Test)	18250.397	85	214.711				
TIME	89.933	1	89.933	0.601	0.44	0.007	0.120
Error (Time)	18250.397	85	214.711				
GENDER	426.575	1	426.575	1.17	0.28	0.014	0.188
Error (Gender)	30911.654	85	363.667				
TEST * GENDER	128.523	1	128.523	0.59	0.44	0.007	0.119
TIME * GENDER	25.369	1	25.369	0.17	0.68	0.002	0.069
TEST * TIME	609.038	1	609.038	4.78	0.03	0.053	0.580
Error (Test * Time)	10819.375	85	127.287				
TEST * TIME * GENDER	55.280	1	55.280	0.43	0.51	0.005	0.100

Memory Composite 2x2x2 ANOVA's							
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**	**Eta Squared**	**Observed power**
TEST	1453.324	1	1453.324	16.27	0.00	0.161	0.979
Error (Test)	7589.564	85	89.289				
TIME	42.358	1	42.358	1.03	0.313	0.012	0.171
Error (Time)	3489.206	85	41.049				
GENDER	364.342	1	364.342	2.82	0.096	0.032	0.383
Error (Gender)	10957.707	85	128.914				
TEST * GENDER	45.971	1	45.971	0.51	0.475	0.515	0.109
TIME * GENDER	0.157	1	0.157	0.00	0.951	0.000	0.050
TEST * TIME	12.241	1	12.241	0.27	0.601	0.003	0.081
Error (Test * Time)	3779.322	85	44.463				
TEST * TIME * GENDER	7.918e-02	1	7.918e-02	0.00	0.966	0.000	0.050

Estimated Marginal Means of Test * Time					
				95% Confidence Interval	
Test	Time	Mean	Std. Error	Lower Bound	Upper Bound
ImPACT™	Pre-season	91.01	0.859	89.31	92.72
ImPACT™	Post-season	89.38	0.960	87.48	91.28
SAC™	Pre-season	81.62	1.94	77.75	85.49
SAC™	Post-season	85.28	2.09	81.25	89.44

Pre-test Correlation Matrix	Immediate Memory **ImPACT™**	Delayed Memory **ImPACT™**	Memory Composite **ImPACT™**	Immediate Memory **SAC™**	Delayed Memory **SAC™**	Memory Composite **SAC™**
Immediate Memory **ImPACT™**	-	0.405	0.340	0.010	0.231	0.257
Delayed Memory **ImPACT™**	0.405	-	0.308	0.003	0.302	0.269
Memory Composite **ImPACT™**	0.340	0.308	-	-0.080	0.066	0.156
Immediate Memory **SAC™**	0.010	0.003	-0.080	-	-0.030	0.231
Delayed Memory **SAC™**	0.231	0.302	0.066	-0.030	-	0.657
Memory Composite **SAC™**	0.257	0.269	0.156	0.231	0.657	-

Post-test Correlation Matrix	Immediate Memory **ImPACT™**	Delayed Memory **ImPACT™**	Memory Composite **ImPACT™**	Immediate Memory **SAC™**	Delayed Memory **SAC™**	Memory Composite **SAC™**
Immediate Memory **ImPACT™**	-	0.565	0.351	-0.036	0.276	0.105
Delayed Memory **ImPACT™**	0.565	-	0.481	-0.077	0.237	0.264
Memory Composite **ImPACT™**	0.351	0.481	-	-0.186	0.287	0.170
Immediate Memory **SAC™**	-0.036	-0.077	-0.186	-	-0.126	0.211
Delayed Memory **SAC™**	0.069	0.237	0.287	-0.126	-	0.585
Memory Composite **SAC™**	0.105	0.264	0.170	0.211	0.585	

Correlation Matrix	Immediate Memory **ImPACT™**	Delayed Memory **ImPACT™**	Memory Composite **ImPACT™**	Immediate Memory **SAC™**	Delayed Memory **SAC™**	Memory Composite **SAC™**
			Pre-test Correlations			
Immediate Memory **ImPACT™**	-	0.565	0.351	-0.036	0.276	0.105
Delayed Memory **ImPACT™**	0.405	-	0.481	-0.077	0.237	0.264
Memory Composite **ImPACT™**	0.340	0.308	-	-0.186	0.287	0.170
Immediate Memory **SAC™**	0.010	0.003	-0.080	-	-0.126	0.211
Delayed Memory **SAC™**	0.231	0.302	0.066	-0.030	-	0.585
Memory Composite **SAC™**	0.257	0.269	0.156	0.231	0.657	-
			Post-test Correlations			

ImPACT™ Interclass Correlation Coefficients				
Source	**ICC**	**Alpha**	**95% Low**	**95% High**
Verbal Learning Memory	0.3499	0.5415	0.1521	0.5209
Verbal Delayed Memory	0.5828	0.7447	0.4258	0.7059
Visual Learning Memory	0.3588	0.5500	0.1621	0.5283
Visual Delayed Memory	0.2669	0.5022	0.0614	0.4508
X's & O's Memory	0.4223	0.5930	0.2340	0.5802
X's & O's Choice RT	0.5237	0.6843	0.3535	0.6605
X's & O's Immediate RT	0.2217	0.3562	0.0135	0.4118
3 Letters Avg. Counted	0.6909	0.8151	0.5633	0.7864
3 Letters Counted Correct	0.4393	0.6102	0.2537	0.5939
Verbal Memory Composite	0.4550	0.6214	0.2720	0.6064
Visual Memory Composite	0.3674	0.5345	0.1717	0.5354
RT Composite	0.3181	0.4794	0.1170	0.4943

SAC™ Interclass Correlation Coefficients				
Source	**ICC**	**Alpha**	**95% Low**	**95% High**
Orientation	0.0218	0.0356	-0.1879	0.2299
Immediate Memory	0.0484	0.0878	-0.1622	0.2549
Concentration	0.4820	0.6559	0.3036	0.6278
Delayed Memory	0.2986	0.4685	0.0957	0.4779
Composite	0.4188	0.5983	0.2300	0.5773

Appendix O- Raw Data

Data Analysis Codes

Testing Intervals	
	Pre-Season Measurement
	Post-Season Measurement

Group Codes		
Code	Number	Complete Group Name
MA	1	Male Athlete
FA	2	Female Athlete
MC	3	Male Control
FC	4	Female Control
MS	1	Men's Soccer Athlete
MBB	2	Men's Basketball Athlete
WS	3	Women's Soccer Athlete
VB	4	Volleyball Athlete
C	5	Control subject
NC	1	Not Concussed
C	2	Concussed

Dependant Variable Codes

ImPACT™ MEASURES		
Component	**Data Analysis Code**	
	Pre-Test	**Post-Test**
Word Memory: Learning percent correct	VML1	VML2
Word Memory: Delayed percent correct	VMD1	VMD2
Design Memory: Learning percent correct	OML1	OML2
Design Memory: Delayed percent correct	OMD1	OMD2
X's & O's: Total correct memory	XOM1	XOM2
X's & O's: Avg. Correct RT	XOCRT1	XOCRT2
X's & O's Avg. Incorrect RT	XOIRT1	XOIRT2
3 Letters: Avg. Counted	3LF1	3LF2
3 Letters: Avg. Counted correct	3LC1	3LC2
Composite: Verbal Memory	VMC1	VMC2
Composite: Visual Memory	OMC1	OMC2
Composite: RT	RTC1	RTC2

SAC™ MEASURES		
Component	**Data Analysis Code**	
	Pre-Test	**Post-Test**
Immediate Memory	SIM1	SIM2
Concentration	SCO1	SCO2
Delayed Recall: Memory	SDM1	SDM2
Composite	SC1	SC2
Modified Immediate Memory	MSIM1	MSIM2
Modified Concentration	MSCO1	MSCO2
Modified Delayed Recall: Memory	MSDM1	MSDM2
Modified Composite	MSC1	MSC2

RAW DATA: ImPACT™ Verbal and Design Memory Modules

Subject	Sport	Gender	Head Contact	Group	Team	VML1	VML2	VMD1	VMD2	OML1	OML2	OMD1	OMD2
1	1	1	1	1	MA1	100	100	100	92	79	92	88	79
2	1	1	1	1	MA2	100	96	83	88	92	83	96	75
3	1	1	1	2	MA3	96	92	79	88	83	83	75	83
4	1	1	1	1	MA4	100	100	96	92	92	96	83	88
5	1	1	1	1	MA5	100	100	88	88	75	67	75	75
6	1	1	1	1	MA6	100	100	100	100	100	75	88	75
7	1	1	1	1	MA7	100	100	88	88	50	67	42	75
8	1	1	1	1	MA8	100	100	83	96	92	88	88	92
9	1	1	1	2	MA9	100	100	96	83	96	79	92	71
10	1	1	1	1	MA10	100	88	92	83	88	58	88	63
11	1	1	1	1	MA11	96	96	83	75	75	79	67	54
12	1	1	1	2	MA12	100	100	79	83	88	54	79	75
13	1	1	1	1	MA13	100	96	92	79	96	96	88	83
14	1	1	1	1	MA14	100	100	100	96	75	79	75	71
15	1	1	1	1	MA15	100	100	100	100	96	96	96	100
16	1	1	1	1	MA16	88	88	83	83	75	75	75	75
17	1	1	1	1	MA17	96	100	96	96	96	83	92	83
18	1	1	1	1	MA18	88	88	79	75	83	79	75	71
19	1	1	1	1	MA19	100	96	100	96	96	83	92	83
20	1	1	1	2	MA20	100	96	100	96	96	88	67	83
21	1	1	1	1	MA21	100	100	96	100	96	83	96	75
22	1	1	1	1	MA22	96	100	88	75	92	67	79	50
23	2	1	2	1	MA23	100	100	92	88	96	83	88	83
24	2	1	2	1	MA24	96	88	79	75	67	79	75	71
25	2	1	2	1	MA25	100	96	88	83	88	79	92	71
26	2	1	2	1	MA26	100	100	96	96	75	96	42	75
27	2	1	2	1	MA27	100	88	88	79	83	79	79	58
28	2	1	2	1	MA28	100	92	83	92	92	79	83	75
29	2	1	2	1	MA29	100	100	88	96	100	88	92	75
30	2	1	2	1	MA30	100	100	96	88	50	54	54	63
31	2	1	2	1	MA31	88	96	83	88	67	83	63	75
32	2	1	2	1	MA32	96	83	71	71	96	63	71	67
33	2	1	2	1	MA33	100	100	67	67	54	54	50	50
34	2	1	2	1	MA34	100	100	100	100	96	92	88	88
35	3	2	1	1	FA1	96	92	88	75	96	56	88	38
36	3	2	1	1	FA2	96	96	92	79	75	79	58	75
37	3	2	1	1	FA3	100	100	96	100	96	71	88	67

Subject	Sport	Gender	Head Contact	Group	Team	VML1	VML2	VMD1	VMD2	OML1	OML2	OMD1	OMD2
38	3	2	1	1	FA4	100	100	92	100	88	79	79	71
39	3	2	1	1	FA5	100	100	100	100	96	100	92	96
40	3	2	1	1	FA6	100	96	92	79	83	88	75	71
41	3	2	1	1	FA7	71	88	75	79	38	79	67	71
42	3	2	1	1	FA8	96	96	100	100	88	92	83	92
43	3	2	1	1	FA9	96	100	75	92	92	96	92	75
44	3	2	1	1	FA10	96	92	96	92	88	88	83	83
45	3	2	1	1	FA11	100	100	100	100	96	88	96	92
46	3	2	1	1	FA12	100	100	100	92	100	100	92	100
47	3	2	1	1	FA13	100	100	100	92	71	67	58	46
48	3	2	1	1	FA14	96	96	100	92	96	96	83	83
49	3	2	1	1	FA15	92	100	88	92	83	92	92	79
50	3	2	1	1	FA16	100	96	92	88	92	71	83	67
51	3	2	1	1	FA17	100	100	96	100	92	92	83	83
52	3	2	1	1	FA18	96	100	100	96	67	63	50	63
53	3	2	1	1	FA19	100	100	100	100	96	75	79	63
54	4	2	2	1	FA20	100	100	92	92	75	79	71	67
55	4	2	2	1	FA21	100	92	96	88	92	71	92	54
56	4	2	2	1	FA22	100	96	100	92	75	71	79	88
57	4	2	2	1	FA23	96	100	92	96	92	100	92	96
58	4	2	2	1	FA24	100	100	83	100	92	96	92	88
59	4	2	2	1	FA25	100	100	92	96	75	88	75	67
60	4	2	2	1	FA26	100	100	96	100	71	79	67	83
61	4	2	2	1	FA27	92	96	96	79	79	79	83	75
62	4	2	2	1	FA28	100	100	100	100	71	96	67	79
63	4	2	2	1	FA29	100	100	100	100	100	79	100	71
64	4	2	2	1	FA30	100	100	92	96	96	88	88	67
65	4	2	2	1	FA31	100	92	71	75	75	63	58	54
66	4	2	2	1	FA32	92	96	88	92	96	79	88	63
67	4	2	2	1	FA33	96	92	79	88	63	71	50	54
68	5	1	2	1	MC1	100	100	100	100	96	88	88	83
69	5	1	2	1	MC2	96	96	75	75	71	71	71	71
70	5	1	2	1	MC3	96	100	88	88	75	75	54	79
71	5	1	2	1	MC4	100	88	92	92	88	79	96	71
72	5	1	2	1	MC5	100	88	88	67	83	71	79	46
73	5	1	2	1	MC6	100	100	92	96	92	79	83	71
74	5	1	2	1	MC7	100	96	96	83	92	92	92	63

Subject	Sport	Gender	Head Contact	Group	Team	VML1	VML2	VMD1	VMD2	OML1	OML2	OMD1	OMD2
75	5	1	2	1	MC8	100	100	92	88	92	96	83	92
76	5	1	2	1	MC9	96	100	88	92	88	83	88	83
77	5	1	2	1	MC10	100	100	92	96	71	88	71	71
78	5	2	2	1	FC1	100	100	88	71	92	58	88	63
79	5	2	2	1	FC2	100	100	100	92	96	88	100	71
80	5	2	2	1	FC3	100	96	92	100	96	88	92	83
81	5	2	2	1	FC4	100	100	100	88	92	96	92	75
82	5	2	2	1	FC5	100	88	92	83	88	88	96	83
83	5	2	2	1	FC6	96	92	92	92	75	88	75	83
84	5	2	2	1	FC7	100	100	96	96	100	100	88	96
85	5	2	2	1	FC8	92	96	79	96	50	79	71	67
86	5	2	2	2	FC9	100	100	96	92	92	96	92	75
87	5	2	2	1	FC10	100	88	88	71	71	67	83	50

RAW DATA ImPACT™ X's and O's ModuleS

Subject	Sport	Gender	Head Contact	Group	Team	XOM1	XOM2	XOCRT1	XOCRT2	XOIRT1	XOIRT2	XOM1	XOM2
1	1	1	1	1	MA1	6	12	0.4	0.3	0.3	0.2	6	12
2	1	1	1	1	MA2	11	12	0.3	0.3	0.3	0.3	11	12
3	1	1	1	2	MA3	10	11	0.4	0.3	0.3	0.2	10	11
4	1	1	1	1	MA4	6	10	0.4	0.3	0.5	0.3	6	10
5	1	1	1	1	MA5	10	4	0.4	0.4	0.3	0.3	10	4
6	1	1	1	1	MA6	9	12	0.4	0.5	0	0	9	12
7	1	1	1	1	MA7	3	4	0.4	0.4	0.3	0.3	3	4
8	1	1	1	1	MA8	11	11	0.3	0.3	0.3	0.3	11	11
9	1	1	1	2	MA9	11	10	0.4	0.4	0.3	0.3	11	10
10	1	1	1	1	MA10	11	11	0.4	0.4	0.3	0.4	11	11
11	1	1	1	1	MA11	9	11	0.4	0.5	0.3	0.3	9	11
12	1	1	1	2	MA12	10	6	0.4	0.4	0.3	0.4	10	6
13	1	1	1	1	MA13	10	12	0.3	0.3	0.3	0.3	10	12
14	1	1	1	1	MA14	9	5	0.3	0.3	0.3	0.2	9	5
15	1	1	1	1	MA15	11	12	0.4	0.4	0.4	0.3	11	12
16	1	1	1	1	MA16	9	9	0.3	0.3	0.3	0.3	9	9
17	1	1	1	1	MA17	11	10	0.4	0.4	0.3	0.5	11	10
18	1	1	1	1	MA18	6	10	0.4	0.4	0.4	0.3	6	10
19	1	1	1	1	MA19	9	10	0.5	0.4	0.5	0.4	9	10
20	1	1	1	2	MA20	8	5	0.4	0.4	0.3	0.2	8	5
21	1	1	1	1	MA21	11	11	0.4	0.4	0	0.3	11	11
22	1	1	1	1	MA22	7	0	0.5	0.2	1	0.2	7	0
23	2	1	2	1	MA23	10	10	0.4	0.5	0	0.4	10	10
24	2	1	2	1	MA24	11	10	0.4	0.4	0.3	0.3	11	10
25	2	1	2	1	MA25	7	9	0.4	0.4	0.3	0.3	7	9
26	2	1	2	1	MA26	7	8	0.4	0.4	0.2	0.3	7	8
27	2	1	2	1	MA27	7	9	0.3	0.3	0.4	0.3	7	9
28	2	1	2	1	MA28	8	12	0.4	0.6	0.5	1.6	8	12
29	2	1	2	1	MA29	11	10	0.4	0.4	0.3	0.2	11	10
30	2	1	2	1	MA30	9	10	0.4	0.4	0.2	0.3	9	10
31	2	1	2	1	MA31	7	8	0.2	0.4	0.4	0.3	7	8
32	2	1	2	1	MA32	10	7	0.4	0.5	0.3	0.5	10	7
33	2	1	2	1	MA33	8	8	0.2	0.3	0.5	0.5	8	8
34	2	1	2	1	MA34	12	12	0.3	0.3	0.3	0.3	12	12
35	3	2	1	1	FA1	5	4	0.4	0.3	0.3	0.3	5	4
36	3	2	1	1	FA2	10	9	0.4	0.3	0.3	0.3	10	9
37	3	2	1	1	FA3	10	8	0.4	0.4	0.3	0.3	10	8

Subject	Sport	Gender	Head Contact	Group	Team	XOM1	XOM2	XOCRT1	XOCRT2	XOIRT1	XOIRT2	XOM1	XOM2
38	3	2	1	1	FA4	10	10	0.3	0.4	0.3	0.3	10	10
39	3	2	1	1	FA5	12	10	0.3	0.3	0.3	0.2	12	10
40	3	2	1	1	FA6	12	11	0.4	0.4	0.3	0.3	12	11
41	3	2	1	1	FA7	2	4	0.7	0.5	0.7	0.6	2	4
42	3	2	1	1	FA8	11	10	0.4	0.4	0.2	0.3	11	10
43	3	2	1	1	FA9	8	11	0.4	0.4	0.3	0.3	8	11
44	3	2	1	1	FA10	6	9	0.4	0.4	0.4	0.2	6	9
45	3	2	1	1	FA11	9	10	0.3	0.4	0.3	0.4	9	10
46	3	2	1	1	FA12	11	11	0.4	0.4	0.3	0.3	11	11
47	3	2	1	1	FA13	5	11	0.4	0.4	0.3	0.3	5	11
48	3	2	1	1	FA14	10	10	0.3	0.3	0.4	0.4	10	10
49	3	2	1	1	FA15	11	9	0.3	0.3	0.2	0.2	11	9
50	3	2	1	1	FA16	9	11	0.3	0.3	0.2	0.2	9	11
51	3	2	1	1	FA17	8	6	0.3	0.3	0.4	0.2	8	6
52	3	2	1	1	FA18	7	3	0.5	0.4	0.3	0.3	7	3
53	3	2	1	1	FA19	7	9	0.5	0.5	0.3	0	7	9
54	4	2	2	1	FA20	6	8	0.4	0.4	0.2	0.3	6	8
55	4	2	2	1	FA21	11	10	0.4	0.4	0.2	0.5	11	10
56	4	2	2	1	FA22	8	12	0.3	0.4	0.2	0.2	8	12
57	4	2	2	1	FA23	3	7	0.4	0.4	0.3	0.3	3	7
58	4	2	2	1	FA24	8	9	0.4	0.3	0.3	0.3	8	9
59	4	2	2	1	FA25	8	8	0.3	0.4	0.2	0.3	8	8
60	4	2	2	1	FA26	8	9	0.4	0.4	0.6	0	8	9
61	4	2	2	1	FA27	7	7	0.5	0.5	0.5	0.5	7	7
62	4	2	2	1	FA28	5	7	0.4	0.5	0.3	0.3	5	7
63	4	2	2	1	FA29	12	11	0.4	0.4	0.2	0.3	12	11
64	4	2	2	1	FA30	10	9	0.3	0.3	0.4	0.3	10	9
65	4	2	2	1	FA31	9	11	0.4	0.3	0.3	0.3	9	11
66	4	2	2	1	FA32	11	9	0.3	0.3	0.3	0.3	11	9
67	4	2	2	1	FA33	6	10	0.4	0.4	0.4	0.5	6	10
68	5	1	2	1	MC1	10	11	0.3	0.4	0.4	0.3	10	11
69	5	1	2	1	MC2	8	8	0.4	0.4	0.3	0.3	8	8
70	5	1	2	1	MC3	11	12	0.3	0.4	0.3	0.2	11	12
71	5	1	2	1	MC4	10	11	0.4	0.4	0.3	0.3	10	11
72	5	1	2	1	MC5	9	2	0.4	0.4	0.3	0.3	9	2
73	5	1	2	1	MC6	7	9	0.4	0.3	0.3	0.2	7	9
74	5	1	2	1	MC7	12	12	0.4	0.4	0	0.2	12	12

Subject	Sport	Gender	Head Contact	Group	Team	XOM1	XOM2	XOCRT1	XOCRT2	XOIRT1	XOIRT2	XOM1	XOM2
75	5	1	2	1	MC8	12	10	0.3	0.3	0.2	0.2	12	10
76	5	1	2	1	MC9	8	8	0.4	0.3	0.3	0.2	8	8
77	5	1	2	1	MC10	8	8	0.5	0.4	0.4	0.3	8	8
78	5	2	2	1	FC1	9	6	0.4	0.4	0.3	0.3	9	6
79	5	2	2	1	FC2	11	6	0.4	0.5	0.3	0	11	6
80	5	2	2	1	FC3	9	11	0.4	0.4	0.2	0.2	9	11
81	5	2	2	1	FC4	11	12	0.4	0.3	0.3	0.2	11	12
82	5	2	2	1	FC5	3	9	0.5	0.4	0.5	0.4	3	9
83	5	2	2	1	FC6	6	8	0.4	0.4	0.3	0.3	6	8
84	5	2	2	1	FC7	9	11	0.4	0.4	0.4	0.3	9	11
85	5	2	2	1	FC8	10	8	0.4	0.4	0.3	0.3	10	8
86	5	2	2	2	FC9	11	9	0.4	0.3	0.3	0.3	11	9
87	5	2	2	1	FC10	8	9	0.3	0.4	0.3	0.3	8	9

RAW DATA: ImPACT™ Three Letters Module

Subject	Sport	Gender	Head Contact	Group	Team	3LF1	3LF2	3LC1	3LC2	3LF1	3LF2	3LC1	3LC2
1	1	1	1	1	MA1	25	23	25	23	25	23	25	23
2	1	1	1	1	MA2	24	25	24	25	24	25	24	25
3	1	1	1	2	MA3	22	23	20	22	22	23	20	22
4	1	1	1	1	MA4	17	20	17	20	17	20	17	20
5	1	1	1	1	MA5	15	12	15	9	15	12	15	9
6	1	1	1	1	MA6	16	13	16	13	16	13	16	13
7	1	1	1	1	MA7	20	18	19	17	20	18	19	17
8	1	1	1	1	MA8	22	25	22	25	22	25	22	25
9	1	1	1	2	MA9	18	18	18	17	18	18	18	17
10	1	1	1	1	MA10	9.2	11	9.2	10	9.2	11	9.2	10
11	1	1	1	1	MA11	21	22	21	19	21	22	21	19
12	1	1	1	2	MA12	16	18	16	0	16	18	16	0
13	1	1	1	1	MA13	20	24	20	24	20	24	20	24
14	1	1	1	1	MA14	17	15	17	15	17	15	17	15
15	1	1	1	1	MA15	14	13	14	13	14	13	14	13
16	1	1	1	1	MA16	13	13	11	11	13	13	11	11
17	1	1	1	1	MA17	14	15	14	15	14	15	14	15
18	1	1	1	1	MA18	8.6	11	8.6	11	8.6	11	8.6	11
19	1	1	1	1	MA19	18	17	17	17	18	17	17	17
20	1	1	1	2	MA20	13	15	13	15	13	15	13	15
21	1	1	1	1	MA21	20	18	20	15	20	18	20	15
22	1	1	1	1	MA22	18	3.6	18	0.8	18	3.6	18	0.8
23	2	1	2	1	MA23	17	16	17	16	17	16	17	16
24	2	1	2	1	MA24	16	11	14	11	16	11	14	11
25	2	1	2	1	MA25	13	11	13	11	13	11	13	11
26	2	1	2	1	MA26	10	13	10	13	10	13	10	13
27	2	1	2	1	MA27	21	24	21	24	21	24	21	24
28	2	1	2	1	MA28	16	16	16	15	16	16	16	15
29	2	1	2	1	MA29	20	13	20	12	20	13	20	12
30	2	1	2	1	MA30	18	19	15	14	18	19	15	14
31	2	1	2	1	MA31	12	12	12	12	12	12	12	12
32	2	1	2	1	MA32	16	13	16	9	16	13	16	9
33	2	1	2	1	MA33	8.8	8.8	3.6	3.6	8.8	8.8	3.6	3.6
34	2	1	2	1	MA34	18	18	18	18	18	18	18	18
35	3	2	1	1	FA1	17	19	17	17	17	19	17	17
36	3	2	1	1	FA2	18	19	18	19	18	19	18	19
37	3	2	1	1	FA3	16	17	13	14	16	17	13	14

Subject	Sport	Gender	Head Contact	Group	Team	3LF1	3LF2	3LC1	3LC2	3LF1	3LF2	3LC1	3LC2
38	3	2	1	1	FA4	23	20	23	19	23	20	23	19
39	3	2	1	1	FA5	23	20	23	20	23	20	23	20
40	3	2	1	1	FA6	19	21	19	19	19	21	19	19
41	3	2	1	1	FA7	9.2	10	9.2	8.4	9.2	10	9.2	8.4
42	3	2	1	1	FA8	20	20	20	19	20	20	20	19
43	3	2	1	1	FA9	16	17	16	17	16	17	16	17
44	3	2	1	1	FA10	23	17	23	17	23	17	23	17
45	3	2	1	1	FA11	15	17	15	17	15	17	15	17
46	3	2	1	1	FA12	14	14	14	14	14	14	14	14
47	3	2	1	1	FA13	11	13	11	13	11	13	11	13
48	3	2	1	1	FA14	18	18	18	18	18	18	18	18
49	3	2	1	1	FA15	21	23	21	23	21	23	21	23
50	3	2	1	1	FA16	21	23	17	23	21	23	17	23
51	3	2	1	1	FA17	19	23	20	22	19	23	20	22
52	3	2	1	1	FA18	9	12	9	12	9	12	9	12
53	3	2	1	1	FA19	14	9.8	14	9.8	14	9.8	14	9.8
54	4	2	2	1	FA20	15	13	15	0	15	13	15	0
55	4	2	2	1	FA21	13	17	13	15	13	17	13	15
56	4	2	2	1	FA22	19	20	19	20	19	20	19	20
57	4	2	2	1	FA23	17	15	17	12	17	15	17	12
58	4	2	2	1	FA24	18	18	18	19	18	18	18	19
59	4	2	2	1	FA25	18	18	18	18	18	18	18	18
60	4	2	2	1	FA26	19	21	15	21	19	21	15	21
61	4	2	2	1	FA27	21	21	21	21	21	21	21	21
62	4	2	2	1	FA28	12	14	7.2	14	12	14	7.2	14
63	4	2	2	1	FA29	18	18	18	18	18	18	18	18
64	4	2	2	1	FA30	25	24	25	24	25	24	25	24
65	4	2	2	1	FA31	20	24	16	24	20	24	16	24
66	4	2	2	1	FA32	12	18	9	16	12	18	9	16
67	4	2	2	1	FA33	15	17	15	15	15	17	15	15
68	5	1	2	1	MC1	25	11	25	11	25	11	25	11
69	5	1	2	1	MC2	23	23	21	21	23	23	21	21
70	5	1	2	1	MC3	21	21	21	20	21	21	21	20
71	5	1	2	1	MC4	21	21	21	21	21	21	21	21
72	5	1	2	1	MC5	19	17	19	0	19	17	19	0
73	5	1	2	1	MC6	16	20	16	19	16	20	16	19
74	5	1	2	1	MC7	22	21	22	21	22	21	22	21

Subject	Sport	Gender	Head Contact	Group	Team	3LF1	3LF2	3LC1	3LC2	3LF1	3LF2	3LC1	3LC2
75	5	1	2	1	MC8	19	23	19	23	19	23	19	23
76	5	1	2	1	MC9	19	20	10	19	19	20	10	19
77	5	1	2	1	MC10	12	12	11	11	12	12	11	11
78	5	2	2	1	FC1	21	23	21	23	21	23	21	23
79	5	2	2	1	FC2	15	20	15	20	15	20	15	20
80	5	2	2	1	FC3	16	20	15	20	16	20	15	20
81	5	2	2	1	FC4	23	24	23	24	23	24	23	24
82	5	2	2	1	FC5	24	19	24	11	24	19	24	11
83	5	2	2	1	FC6	15	13	15	13	15	13	15	13
84	5	2	2	1	FC7	22	14	22	5	22	14	22	5
85	5	2	2	1	FC8	15	16	15	16	15	16	15	16
86	5	2	2	2	FC9	22	24	22	24	22	24	22	24
87	5	2	2	1	FC10	19	16	0	16	19	16	0	16

RAW DATA: ImPACT™ Composite Scores

Subject	Sport	Gender	Head Contact	Group	Team	VMC1	VMC2	OMC1	OMC2	RTC1	RTC2	VMC1	VMC2
1	1	1	1	1	MA1	81	88	67	93	0.5	0.4	81	88
2	1	1	1	1	MA2	94	90	93	90	0.5	0.4	94	90
3	1	1	1	2	MA3	92	89	81	88	0.6	0.5	92	89
4	1	1	1	1	MA4	70	85	69	88	0.6	0.5	70	85
5	1	1	1	1	MA5	96	83	79	52	0.7	0.7	96	83
6	1	1	1	1	MA6	96	89	84	88	0.6	0.7	96	89
7	1	1	1	1	MA7	79	89	35	88	0.6	0.5	79	89
8	1	1	1	1	MA8	94	96	91	91	0.4	0.5	94	96
9	1	1	1	2	MA9	90	97	93	79	0.5	0.6	90	97
10	1	1	1	1	MA10	95	89	90	76	0.6	0.7	95	89
11	1	1	1	1	MA11	85	89	73	79	0.6	0.5	85	89
12	1	1	1	2	MA12	89	94	83	57	0.5	0.5	89	94
13	1	1	1	1	MA13	85	96	88	95	0.5	0.5	85	96
14	1	1	1	1	MA14	84	91	75	58	0.6	0.5	84	91
15	1	1	1	1	MA15	100	85	94	99	0.5	0.6	100	85
16	1	1	1	1	MA16	75	75	75	75	0.6	0.6	75	75
17	1	1	1	1	MA17	88	92	93	83	0.5	0.5	88	92
18	1	1	1	1	MA18	62	75	65	79	0.7	0.6	62	75
19	1	1	1	1	MA19	94	99	84	83	0.6	0.6	94	99
20	1	1	1	2	MA20	89	99	74	64	0.5	0.6	89	99
21	1	1	1	1	MA21	99	94	94	85	0.5	0.5	99	94
22	1	1	1	1	MA22	95	61	72	29	0.5	0.9	95	61
23	2	1	2	1	MA23	82	96	89	83	0.5	0.7	82	96
24	2	1	2	1	MA24	83	75	81	79	0.5	0.6	83	75
25	2	1	2	1	MA25	83	67	74	75	0.5	0.7	83	67
26	2	1	2	1	MA26	79	76	58	76	0.5	0.6	79	76
27	2	1	2	1	MA27	91	89	70	72	0.5	0.5	91	89
28	2	1	2	1	MA28	97	86	77	89	0.6	0.6	97	86
29	2	1	2	1	MA29	94	85	94	82	0.5	0.6	94	85
30	2	1	2	1	MA30	8	70	64	71	0.6	0.5	8	70
31	2	1	2	1	MA31	77	78	61	73	0.5	0.6	77	78
32	2	1	2	1	MA32	89	79	83	81	0.6	0.7	89	79
33	2	1	2	1	MA33	61	61	59	59	0.6	0.6	61	61
34	2	1	2	1	MA34	94	94	95	95	0.5	0.5	94	94
35	3	2	1	1	FA1	90	83	55	41	0.5	0.5	90	83
36	3	2	1	1	FA2	94	94	75	76	0.5	0.5	94	94
37	3	2	1	1	FA3	99	100	88	68	0.6	0.6	99	100

Subject	Sport	Gender	Head Contact	Group	Team	VMC1	VMC2	OMC1	OMC2	RTC1	RTC2	VMC1	VMC2
38	3	2	1	1	FA4	84	92	83	79	0.5	0.5	84	92
39	3	2	1	1	FA5	100	93	97	91	0.5	0.5	100	93
40	3	2	1	1	FA6	88	90	90	85	0.5	0.5	88	90
41	3	2	1	1	FA7	62	66	34	54	0.7	0.6	62	66
42	3	2	1	1	FA8	97	99	89	88	0.6	0.5	97	99
43	3	2	1	1	FA9	88	85	79	89	0.6	0.6	88	85
44	3	2	1	1	FA10	82	78	68	80	0.5	0.5	82	78
45	3	2	1	1	FA11	93	93	85	86	0.5	0.5	93	93
46	3	2	1	1	FA12	88	88	94	94	0.6	0.6	88	88
47	3	2	1	1	FA13	81	85	57	74	0.6	0.5	81	85
48	3	2	1	1	FA14	94	94	86	86	0.5	0.5	94	94
49	3	2	1	1	FA15	66	89	90	80	0.5	0.5	66	89
50	3	2	1	1	FA16	91	90	81	80	0.5	0.5	91	90
51	3	2	1	1	FA17	86	93	77	69	0.5	0.4	86	93
52	3	2	1	1	FA18	79	84	58	44	0.7	0.6	79	84
53	3	2	1	1	FA19	93	85	73	72	0.6	0.5	93	85
54	4	2	2	1	FA20	79	90	61	70	0.6	0.5	79	90
55	4	2	2	1	FA21	79	77	92	73	0.6	0.6	79	77
56	4	2	2	1	FA22	96	98	72	90	0.5	0.5	96	98
57	4	2	2	1	FA23	91	86	58	75	0.6	0.5	91	86
58	4	2	2	1	FA24	90	84	79	83	0.5	0.4	90	84
59	4	2	2	1	FA25	99	93	71	72	0.5	0.6	99	93
60	4	2	2	1	FA26	99	83	68	78	0.5	0.5	99	83
61	4	2	2	1	FA27	91	77	70	68	0.6	0.5	91	77
62	4	2	2	1	FA28	89	93	55	73	0.6	0.6	89	93
63	4	2	2	1	FA29	100	96	100	83	0.5	0.5	100	96
64	4	2	2	1	FA30	91	96	88	76	0.4	0.5	91	96
65	4	2	2	1	FA31	71	87	71	75	0.7	0.6	71	87
66	4	2	2	1	FA32	72	76	92	73	0.6	0.5	72	76
67	4	2	2	1	FA33	65	77	53	73	0.6	0.6	65	77
68	5	1	2	1	MC1	91	93	88	89	0.4	0.6	91	93
69	5	1	2	1	MC2	85	85	69	69	0.5	0.5	85	85
70	5	1	2	1	MC3	91	79	78	89	0.5	0.7	91	79
71	5	1	2	1	MC4	91	79	88	86	0.5	0.5	91	79
72	5	1	2	1	MC5	91	67	78	38	0.5	0.6	91	67
73	5	1	2	1	MC6	78	92	73	75	0.5	0.5	78	92
74	5	1	2	1	MC7	93	89	96	50	0.5	1	93	89

Subject	Sport	Gender	Head Contact	Group	Team	VMC1	VMC2	OMC1	OMC2	RTC1	RTC2	VMC1	VMC2
75	5	1	2	1	MC8	91	94	94	89	0.5	0.5	91	94
76	5	1	2	1	MC9	82	95	77	75	0.6	0.5	82	95
77	5	1	2	1	MC10	83	83	69	69	0.6	0.6	83	83
78	5	2	2	1	FC1	92	88	82	55	0.6	0.6	92	88
79	5	2	2	1	FC2	100	93	95	65	0.8	0.8	100	93
80	5	2	2	1	FC3	95	97	84	89	0.5	0.6	95	97
81	5	2	2	1	FC4	93	98	92	93	0.5	0.4	93	98
82	5	2	2	1	FC5	78	95	58	80	0.5	0.5	78	95
83	5	2	2	1	FC6	87	79	63	76	0.6	0.6	87	79
84	5	2	2	1	FC7	99	92	84	95	0.5	0.5	99	92
85	5	2	2	1	FC8	73	83	72	70	0.6	0.5	73	83
86	5	2	2	2	FC9	99	92	84	75	0.5	0.5	99	92
87	5	2	2	1	FC10	94	83	72	67	0.5	0.5	94	83

RAW DATA: SAC™ Scores

Subject	Sport	Gender	Head Contact	Group	Team	SO1	SIM1	SCO1	SDM1	SC1	SO2	SIM2	SCO2
1	1	1	1	1	MA1	5	15	4	4	28	5	15	5
2	1	1	1	1	MA2	5	15	4	4	28	5	14	3
3	1	1	1	2	MA3	5	15	4	4	28	5	15	3
4	1	1	1	1	MA4	5	15	2	5	27	5	15	4
5	1	1	1	1	MA5	5	15	3	4	27	5	15	4
6	1	1	1	1	MA6	5	15	2	4	26	5	15	1
7	1	1	1	1	MA7	5	15	3	3	26	5	15	2
8	1	1	1	1	MA8	5	14	5	5	29	5	15	5
9	1	1	1	2	MA9	5	15	5	5	30	5	15	5
10	1	1	1	1	MA10	3	15	3	2	23	5	15	3
11	1	1	1	1	MA11	5	15	2	4	26	5	15	2
12	1	1	1	2	MA12	5	15	4	3	27	5	15	3
13	1	1	1	1	MA13	5	14	3	5	27	5	14	2
14	1	1	1	1	MA14	5	15	4	5	29	5	15	5
15	1	1	1	1	MA15	5	15	2	4	26	4	13	3
16	1	1	1	1	MA16	5	15	1	3	24	5	15	4
17	1	1	1	1	MA17	5	15	4	4	28	5	15	4
18	1	1	1	1	MA18	3	14	2	4	23	4	15	1
19	1	1	1	1	MA19	5	14	4	4	27	5	15	4
20	1	1	1	2	MA20	5	15	3	5	28	5	15	2
21	1	1	1	1	MA21	5	14	4	5	28	5	14	3
22	1	1	1	1	MA22	5	15	4	1	25	5	14	5
23	2	1	2	1	MA23	5	15	2	3	25	5	15	2
24	2	1	2	1	MA24	5	15	4	5	29	5	15	4
25	2	1	2	1	MA25	5	15	3	3	26	4	15	2
26	2	1	2	1	MA26	4	15	5	3	27	5	15	4
27	2	1	2	1	MA27	5	15	5	5	30	5	15	4
28	2	1	2	1	MA28	5	14	2	3	24	5	15	2
29	2	1	2	1	MA29	5	14	5	5	29	5	15	5
30	2	1	2	1	MA30	5	15	2	4	26	5	15	3
31	2	1	2	1	MA31	5	15	2	4	26	5	15	2
32	2	1	2	1	MA32	5	15	3	4	27	5	14	5
33	2	1	2	1	MA33	5	15	4	4	28	4	15	5
34	2	1	2	1	MA34	5	14	3	5	27	5	14	3
35	3	2	1	1	FA1	5	15	4	4	28	4	15	3
36	3	2	1	1	FA2	5	15	2	3	25	5	15	5
37	3	2	1	1	FA3	5	15	4	5	29	5	12	4

Subject	Sport	Gender	Head Contact	Group	Team	SO1	SIM1	SCO1	SDM1	SC1	SO2	SIM2	SCO2
38	3	2	1	1	FA4	5	15	4	4	28	5	15	4
39	3	2	1	1	FA5	5	15	4	5	29	5	15	5
40	3	2	1	1	FA6	5	15	2	3	25	5	15	2
41	3	2	1	1	FA7	5	15	4	5	29	5	15	4
42	3	2	1	1	FA8	5	15	3	3	26	4	15	2
43	3	2	1	1	FA9	4	15	4	5	28	5	15	4
44	3	2	1	1	FA10	5	15	4	3	27	5	15	4
45	3	2	1	1	FA11	5	15	4	5	29	5	15	2
46	3	2	1	1	FA12	5	15	3	5	28	5	15	1
47	3	2	1	1	FA13	5	15	5	5	30	5	12	5
48	3	2	1	1	FA14	5	15	2	5	27	5	15	3
49	3	2	1	1	FA15	4	15	2	4	26	5	14	2
50	3	2	1	1	FA16	5	15	3	5	28	5	15	4
51	3	2	1	1	FA17	5	15	3	5	28	5	15	5
52	3	2	1	1	FA18	5	15	2	3	25	5	15	2
53	3	2	1	1	FA19	5	15	4	5	29	5	15	4
54	4	2	2	1	FA20	5	15	5	5	30	5	15	5
55	4	2	2	1	FA21	5	13	4	4	26	5	14	4
56	4	2	2	1	FA22	5	15	4	3	27	5	15	5
57	4	2	2	1	FA23	5	15	3	4	27	5	14	5
58	4	2	2	1	FA24	5	15	4	4	28	4	15	5
59	4	2	2	1	FA25	4	15	2	5	26	5	14	5
60	4	2	2	1	FA26	5	15	5	4	29	4	15	3
61	4	2	2	1	FA27	5	14	3	5	27	5	13	4
62	4	2	2	1	FA28	5	15	1	5	26	5	15	1
63	4	2	2	1	FA29	4	15	2	4	25	5	14	5
64	4	2	2	1	FA30	5	15	1	3	24	5	14	4
65	4	2	2	1	FA31	5	15	5	2	27	5	15	5
66	4	2	2	1	FA32	5	15	5	5	30	4	15	4
67	4	2	2	1	FA33	5	15	4	5	29	5	15	3
68	5	1	2	1	MC1	5	15	2	4	26	4	13	3
69	5	1	2	1	MC2	5	15	4	4	28	5	15	4
70	5	1	2	1	MC3	5	15	3	4	27	5	15	4
71	5	1	2	1	MC4	4	15	2	5	26	5	15	2
72	5	1	2	1	MC5	4	15	2	5	26	5	14	5
73	5	1	2	1	MC6	5	14	3	5	27	5	14	3
74	5	1	2	1	MC7	5	15	4	3	26	5	15	5

Subject	Sport	Gender	Head Contact	Group	Team	SO1	SIM1	SCO1	SDM1	SC1	SO2	SIM2	SCO2
75	5	1	2	1	MC8	5	15	2	4	26	5	15	2
76	5	1	2	1	MC9	5	15	4	3	27	5	15	4
77	5	1	2	1	MC10	5	15	4	4	28	5	15	3
78	5	2	2	1	FC1	5	15	3	3	26	5	15	3
79	5	2	2	1	FC2	5	15	5	5	30	5	15	4
80	5	2	2	1	FC3	5	14	5	5	29	5	15	5
81	5	2	2	1	FC4	5	15	4	4	28	4	14	5
82	5	2	2	1	FC5	4	13	5	3	25	5	15	4
83	5	2	2	1	FC6	5	14	5	5	29	5	15	5
84	5	2	2	1	FC7	4	12	4	3	23	5	15	4
85	5	2	2	1	FC8	5	15	2	4	26	5	15	3
86	5	2	2	2	FC9	4	13	5	4	26	5	15	3
87	5	2	2	1	FC10	5	15	3	3	26	5	15	3

RAW DATA: Modified SAC™ Scores

Subject	Sport	Gender	Head Contact	Group	Team	MSIM1	MSCO1	MSDM1	MSC1	MSIM2	MSCO2	MSDM2	MSC2
1	1	1	1	1	MA1	100%	80%	80%	93%	100%	100%	80%	97%
2	1	1	1	1	MA2	100%	80%	80%	93%	93%	60%	100%	90%
3	1	1	1	2	MA3	100%	80%	80%	93%	100%	60%	100%	93%
4	1	1	1	1	MA4	100%	40%	100%	90%	100%	80%	100%	97%
5	1	1	1	1	MA5	100%	60%	80%	90%	100%	80%	100%	97%
6	1	1	1	1	MA6	100%	40%	80%	87%	100%	20%	80%	83%
7	1	1	1	1	MA7	100%	60%	60%	87%	100%	40%	80%	87%
8	1	1	1	1	MA8	93%	100%	100%	97%	100%	100%	100%	100%
9	1	1	1	2	MA9	100%	100%	100%	100%	100%	100%	100%	100%
10	1	1	1	1	MA10	100%	60%	40%	77%	100%	60%	80%	90%
11	1	1	1	1	MA11	100%	40%	80%	87%	100%	40%	60%	83%
12	1	1	1	2	MA12	100%	80%	60%	90%	100%	60%	80%	90%
13	1	1	1	1	MA13	93%	60%	100%	90%	93%	40%	100%	83%
14	1	1	1	1	MA14	100%	80%	100%	97%	100%	100%	80%	97%
15	1	1	1	1	MA15	100%	40%	80%	87%	87%	60%	100%	83%
16	1	1	1	1	MA16	100%	20%	60%	80%	100%	80%	60%	90%
17	1	1	1	1	MA17	100%	80%	80%	93%	100%	80%	100%	97%
18	1	1	1	1	MA18	93%	40%	80%	77%	100%	20%	40%	73%
19	1	1	1	1	MA19	93%	80%	80%	90%	100%	80%	80%	93%
20	1	1	1	2	MA20	100%	60%	100%	93%	100%	40%	100%	90%
21	1	1	1	1	MA21	93%	80%	100%	93%	93%	60%	80%	87%
22	1	1	1	1	MA22	100%	80%	20%	83%	93%	100%	40%	87%
23	2	1	2	1	MA23	100%	40%	60%	83%	100%	40%	40%	80%
24	2	1	2	1	MA24	100%	80%	100%	97%	100%	80%	100%	97%
25	2	1	2	1	MA25	100%	60%	60%	87%	100%	40%	100%	87%
26	2	1	2	1	MA26	100%	100%	60%	90%	100%	80%	80%	93%
27	2	1	2	1	MA27	100%	100%	100%	100%	100%	80%	100%	97%
28	2	1	2	1	MA28	93%	40%	60%	80%	100%	40%	80%	87%
29	2	1	2	1	MA29	93%	100%	100%	97%	100%	100%	100%	100%
30	2	1	2	1	MA30	100%	40%	80%	87%	100%	60%	60%	87%
31	2	1	2	1	MA31	100%	40%	80%	87%	100%	40%	100%	90%
32	2	1	2	1	MA32	100%	60%	80%	90%	93%	100%	80%	93%
33	2	1	2	1	MA33	100%	80%	80%	93%	100%	100%	40%	87%
34	2	1	2	1	MA34	93%	60%	100%	90%	93%	60%	80%	87%
35	3	2	1	1	FA1	100%	80%	80%	93%	100%	60%	80%	87%
36	3	2	1	1	FA2	100%	40%	60%	83%	100%	100%	100%	100%
37	3	2	1	1	FA3	100%	80%	100%	97%	80%	80%	100%	87%

Subject	Sport	Gender	Head Contact	Group	Team	MSIM1	MSCO1	MSDM1	MSC1	MSIM2	MSCO2	MSDM2	MSC2
38	3	2	1	1	FA4	100%	80%	60%	87%	100%	100%	100%	100%
39	3	2	1	1	FA5	100%	80%	80%	93%	100%	80%	60%	90%
40	3	2	1	1	FA6	100%	80%	100%	97%	100%	100%	60%	90%
41	3	2	1	1	FA7	100%	40%	60%	83%	100%	40%	40%	80%
42	3	2	1	1	FA8	100%	80%	100%	97%	100%	80%	100%	97%
43	3	2	1	1	FA9	100%	60%	60%	87%	100%	40%	100%	87%
44	3	2	1	1	FA10	100%	80%	100%	93%	100%	80%	100%	97%
45	3	2	1	1	FA11	100%	80%	60%	90%	100%	80%	100%	97%
46	3	2	1	1	FA12	100%	80%	100%	97%	100%	40%	100%	90%
47	3	2	1	1	FA13	100%	60%	100%	93%	100%	20%	80%	83%
48	3	2	1	1	FA14	100%	100%	100%	100%	80%	100%	100%	93%
49	3	2	1	1	FA15	100%	40%	100%	90%	100%	60%	40%	83%
50	3	2	1	1	FA16	100%	40%	80%	87%	93%	40%	100%	87%
51	3	2	1	1	FA17	100%	60%	100%	93%	100%	80%	100%	97%
52	3	2	1	1	FA18	100%	60%	100%	93%	100%	100%	100%	100%
53	3	2	1	1	FA19	100%	40%	60%	83%	100%	40%	40%	80%
54	4	2	2	1	FA20	100%	80%	100%	97%	100%	80%	100%	97%
55	4	2	2	1	FA21	100%	100%	100%	100%	100%	100%	100%	100%
56	4	2	2	1	FA22	87%	80%	80%	87%	93%	80%	80%	90%
57	4	2	2	1	FA23	100%	80%	60%	90%	100%	100%	60%	93%
58	4	2	2	1	FA24	100%	60%	80%	90%	93%	100%	80%	93%
59	4	2	2	1	FA25	100%	80%	80%	93%	100%	100%	40%	87%
60	4	2	2	1	FA26	100%	40%	100%	87%	93%	100%	100%	97%
61	4	2	2	1	FA27	100%	100%	80%	97%	100%	60%	80%	87%
62	4	2	2	1	FA28	93%	60%	100%	90%	87%	80%	100%	90%
63	4	2	2	1	FA29	100%	20%	100%	87%	100%	20%	100%	87%
64	4	2	2	1	FA30	100%	40%	80%	83%	93%	100%	80%	93%
65	4	2	2	1	FA31	100%	20%	60%	80%	93%	80%	60%	87%
66	4	2	2	1	FA32	100%	100%	40%	90%	100%	100%	80%	97%
67	4	2	2	1	FA33	100%	100%	100%	100%	100%	80%	100%	93%
68	5	1	2	1	MC1	100%	80%	100%	97%	100%	60%	100%	93%
69	5	1	2	1	MC2	100%	40%	80%	87%	87%	60%	100%	83%
70	5	1	2	1	MC3	100%	80%	80%	93%	100%	80%	100%	97%
71	5	1	2	1	MC4	100%	60%	80%	90%	100%	80%	100%	97%
72	5	1	2	1	MC5	100%	40%	100%	87%	100%	40%	80%	87%
73	5	1	2	1	MC6	100%	40%	100%	87%	93%	100%	80%	93%
74	5	1	2	1	MC7	93%	60%	100%	90%	93%	60%	100%	87%

Subject	Sport	Gender	Head Contact	Group	Team	MSIM1	MSCO1	MSDM1	MSC1	MSIM2	MSCO2	MSDM2	MSC2
75	5	1	2	1	MC8	100%	60%	60%	87%	100%	60%	100%	93%
76	5	1	2	1	MC9	100%	40%	80%	87%	100%	40%	100%	90%
77	5	1	2	1	MC10	100%	80%	60%	90%	100%	80%	100%	97%
78	5	2	2	1	FC1	100%	80%	80%	93%	100%	60%	100%	93%
79	5	2	2	1	FC2	100%	60%	60%	87%	100%	60%	100%	93%
80	5	2	2	1	FC3	100%	100%	100%	100%	100%	80%	80%	93%
81	5	2	2	1	FC4	93%	100%	100%	97%	100%	100%	100%	100%
82	5	2	2	1	FC5	100%	80%	80%	93%	93%	100%	80%	90%
83	5	2	2	1	FC6	87%	100%	60%	83%	100%	80%	100%	97%
84	5	2	2	1	FC7	93%	100%	100%	97%	100%	100%	60%	93%
85	5	2	2	1	FC8	80%	80%	60%	77%	100%	80%	100%	97%
86	5	2	2	2	FC9	100%	40%	80%	87%	100%	60%	100%	93%
87	5	2	2	1	FC10	87%	100%	80%	87%	100%	60%	80%	90%