Full Length Peer Reviewed Articles

Psychometric Properties of ImPACT (Reliability and Validity)

The Immediate Post-Concussion Assessment and Cognitive Testing battery and traditional neuropsychological measures: a construct and concurrent validity study.

Allen BJ, Gfeller JD.

PRIMARY OBJECTIVE: This study examined the construct and concurrent validity of ImPACT, a computerized neuropsychological test battery used for evaluating sports-related concussion.

RESEARCH DESIGN: Approximately 100 neurologically intact undergraduates completed ImPACT and a battery of traditional neuropsychological tests utilized by the National Football League (NFL).

METHODS AND PROCEDURES: Participants completed the two batteries in a counterbalanced order. Factor analyses examined the component structure of ImPACT and the NFL battery's factor structure. Correlational analyses assessed relationships among variables within and across the two batteries.

MAIN RESULTS: A four-factor solution explaining 70% of variance was found with the NFL battery, including general memory, mental processing speed, verbal memory and processing speed and auditory and verbal working memory. A five-factor solution explaining 69% of variance was found with the ImPACT battery, with components assessing forced choice efficiency, verbal and visual memory, inhibitory cognitive abilities, visual processing abilities with a memory component and a factor with a single loading from Colour Match Total Commissions. Correlations revealed a range of significant and non-significant correlations between the two batteries.

CONCLUSIONS: While both batteries overlap regarding their assessed constructs (e.g. memory, inhibitory cognitive abilities) notable differences in their factor structures were present as well.


Sensitivity and specificity of subacute computerized neurocognitive testing and symptom evaluation in predicting outcomes after sports-related concussion.

Lau BC, Collins MW, Lovell MR.

BACKGROUND: Concussions affect an estimated 136 000 high school athletes yearly. Computerized neurocognitive testing has been shown to be appropriately sensitive and specific in diagnosing concussions, but no studies have assessed its utility to predict length of recovery. Determining prognosis during subacute recovery after sports concussion will help clinicians more confidently address return-to-play and academic decisions.

PURPOSE: To quantify the prognostic ability of computerized neurocognitive testing in combination with symptoms during the subacute recovery phase from sports-related concussion.

STUDY DESIGN: Cohort study (prognosis); Level of evidence, 2.

METHODS: In sum, 108 male high school football athletes completed a computer-based neurocognitive test battery within 2.23 days of injury and were followed until returned to play as set by international guidelines. Athletes were grouped into protracted recovery (>14 days; n = 50) or short-recovery (≤14 days; n = 58). Separate discriminant function analyses were performed using total symptom score on Post-Concussion Symptom Scale, symptom clusters (migraine, cognitive, sleep, neuropsychiatric), and Immediate Postconcussion Assessment and Cognitive Testing neurocognitive scores (verbal memory, visual memory, reaction time, processing speed).

RESULTS: Multiple discriminant function analyses revealed that the combination of 4 symptom clusters and 4 neurocognitive composite scores had the highest sensitivity (65.22%), specificity (80.36%), positive predictive value (73.17%), and negative predictive value (73.80%) in predicting protracted recovery. Discriminant function analyses of total symptoms on the Post-Concussion Symptom Scale alone had a sensitivity of 40.81%; specificity, 79.31%; positive predictive value, 62.50%; and negative predictive value, 61.33%. The 4 symptom clusters alone discriminant function analyses had a sensitivity of 46.94%; specificity, 77.20%; positive predictive value, 63.90%; and negative predictive value, 62.86%. Discriminant function analyses of the 4 computerized neurocognitive scores alone had a sensitivity of 53.20%; specificity, 75.44%; positive predictive value, 64.10%; and negative predictive value, 66.15%.

CONCLUSION: The use of computerized neurocognitive testing in conjunction with symptom clusters results improves sensitivity, specificity, positive predictive value, and negative predictive value of predicting protracted recovery compared with each used alone. There is also a net increase in sensitivity of 24.41% when using neurocognitive testing and symptom clusters together compared with using total symptoms on Post-Concussion Symptom Scale alone.


Which on-field signs/symptoms predict protracted recovery from sports-related concussion among high school football players?

Lau BC, Kontos AP, Collins MW, Mucha A, Lovell MR.
BACKGROUND: There has been increasing attention and understanding of sport-related concussions. Recent studies show that neurocognitive testing and symptom clusters may predict protracted recovery in concussed athletes. On-field signs and symptoms have not been examined empirically as possible predictors of protracted recovery.

PURPOSE: This study was undertaken to determine which on-field signs and symptoms were predictive of a protracted (≥21 days) versus rapid (≤7 days) recovery after a sports-related concussion. On-field signs and symptoms included confusion, loss of consciousness, posttraumatic amnesia, retrograde amnesia, imbalance, dizziness, visual problems, personality changes, fatigue, sensitivity to light/noise, numbness, and vomiting.

STUDY DESIGN: Cohort study (prognosis); Level of evidence, 2.

METHODS: The sample included 107 male high school football athletes who completed computerized neurocognitive testing within an average 2.4 days after injury, and who were followed until return to play was determined by neuropsychologists using international clinical concussion management guidelines. Athletes were then grouped into rapid (≤7 days, n = 62) or protracted (≥21 days, n = 45) recovery time groups. The presence of on-field signs and symptoms was determined at the time of injury by trained sports medicine professionals (ie, ATC [certified athletic trainer], team physician). A series of odds ratios with χ² analyses and subsequent logistic regression were used to determine which on-field signs and symptoms were associated with an increased risk for a protracted recovery.

RESULTS: Dizziness at the time of injury was associated with a 6.34 odds ratio (95% confidence interval = 1.34-29.91, χ² = 5.44, P = .02) of a protracted recovery from concussion. Surprisingly, the remaining on-field signs and symptoms were not associated with an increased risk of protracted recovery in the current study.

CONCLUSION: Assessment of on-field dizziness may help identify high school athletes at risk for a protracted recovery. Such information will improve prognostic information and allow clinicians to manage and treat concussion more effectively in these at-risk athletes.

American Journal of Sports Medicine, 2011.

Investigating baseline neurocognitive performance between male and female athletes with a history of multiple concussions.

Covassin T, Elbin R, Kontos A, Larson E.

The purpose of this study was to examine, using a dose-response model, sex differences in computerized neurocognitive performance among athletes with a history of multiple concussions.

DESIGN: Retrospective with randomly selected concussion cases from four levels/numbers of previous concussion.

SETTING: Multicentre analysis of NCAA student-athletes.

PARTICIPANTS: Subjects included a total of 100 male and 88 female NCAA athletes.

INTERVENTION: Sex and four mutually exclusive groups of self-reported concussion history: (1) no history of concussion, (2) one previous concussion, (3) two previous concussions, (4) three or more previous concussions.

MAIN OUTCOME MEASUREMENTS: Neurocognitive performance as measured by a computerised neurocognitive test battery (Immediate Postconcussion Assessment Cognitive Testing (ImPACT)).

RESULTS: A dose-response gradient was found for two or more previous concussions and decreased neurocognitive performance. Females with a history of two and three or more concussions performed better than males with a history of two (p=0.001) and three or more concussions (p=0.012) on verbal memory. Females performed better than males with a history of three or more concussions (p=0.021) on visual memory. Finally, there was a significant difference for sex on both motor processing speed and reaction-time composite scores. Specifically, males performed worse than females on both processing speed (p=0.029) and reaction time (p=0.04).

CONCLUSION: The current study provided partial support for a dose-response model of concussion and neurocognitive performance decrements beginning at two or more previous concussions. Sex differences should be considered when examining the effects of concussion history on computerised neurocognitive performance.


Exploring differences in computerized neurocognitive concussion testing between African American and white athletes.

Kontos AP, Elbin RJ, Covassin T, Larson E.

The purpose of the current study was to explore potential differences in pre- and post-concussion performance on a computerized neurocognitive concussion test between African American and White high-school and collegiate student-athletes. A prospective case-control design was used to compare baseline and 2- and 7-day post-concussion computerized neurocognitive performance and symptoms between 48 White and 48 African American athletes matched for age, gender, and concussion history. The Immediate Post-Concussion Assessment Cognitive Test (ImPACT) version 2.0 (NeuroHealth System, LLC, Pittsburgh, PA, USA) computer software program was used to assess neurocognitive function (i.e., verbal and visual memory, motor processing speed, and reaction time) and concussion symptoms. Regardless of race/ethnicity, there were significant decrements in computerized neurocognitive performance and increased symptoms following a concussion for the entire sample. African Americans and Whites did not differ significantly on baseline or post-concussion verbal memory, visual memory, reaction time, and total reported symptoms. However, African American participants were 2.4× more likely to have at least one clinically significant cognitive decline on ImPACT at 7 days post-concussion and scored lower at 7 days post-concussion compared with baseline on processing speed than White participants. The authors concluded that the baseline ImPACT test was culturally equivalent and construct valid for use with these two racial/ethnic groups. However, in contrast, the findings support deleterious performance for the African American athletes compared with the White athletes on the ImPACT post-concussion evaluation that is of critical clinical relevance and warrants further research.

Archives of Clinical Neuropsychology, 2010: 25(8), 734-744.

Examination of the construct validity of ImPACT computerized test, traditional, and experimental neuropsychological measures.


Although computerized neuropsychological screening is becoming a standard for sports concussion identification and management, convergent validity studies are limited. Such studies are important for several reasons: reference to established measures is needed to establish validity; examination of the computerized battery relative to a more traditional comprehensive battery will help understand the strengths and limitations of the computer battery; and such an examination will help inform the output of the computerized battery. We compared scores on the ImPACT™ battery to a comprehensive battery of traditional neuropsychological measures and several experimental measures used in the assessment of sports-related concussion in
54 healthy male athletes. Convergent validity was demonstrated for four of the five ImPACT™ domain scores. Two cognitive domains often compromised as a result of mild TBI were not directly identified by the ImPACT™ battery: sustained attention and auditory working memory. Affective symptoms correlated with performance on measures of attention and working memory. In this healthy sample the correlations between the domains covered by ImPACT™ and the neuropsychological battery supports ImPACT™ as a useful screening tool for assessing many of the cognitive factors related to mTBI. However, the data suggest other sources of data need to be considered when identifying and managing concussions.

Clinical Neuropsychology. 2010: 24(8), 1309-1325.

Immediate post-concussion assessment and cognitive testing (ImPACT) practices of sports medicine professionals.
Covassin T, Elbin RJ, Stillier-Ostrowski J, Kontos AP.

CONTEXT: Computerized neurocognitive testing is becoming popular among clinicians evaluating sport-related concussions across all levels of sport. Baseline neurocognitive testing has been recommended to provide more accurate representation of the preconcussion cognitive status of individual athletes. However, little is known about the use of baseline neurocognitive testing in concussion assessment and management.

OBJECTIVE: To examine implementation and practice trends of sports medicine professionals using baseline neurocognitive testing at the high school and collegiate levels.

DESIGN: Quantitative survey research.

SETTING: Online survey.

PATIENTS OR OTHER PARTICIPANTS: Certified athletic trainers (ATs) from approximately 1209 US institutions listed on the ImPACT Web site were recruited. A total of 399 ATs completed the survey, for a response return rate of 32.7%.

MAIN OUTCOME MEASURE(S): Survey questions addressed educational level, years of certification, employment setting, percentage of athletes baseline tested, and accuracy of baseline tests. Other items addressed postconcussive neurocognitive testing protocols and scenarios for return-to-play decisions based on neurocognitive testing.

RESULTS: Nearly all ATs (94.7%) administered baseline computerized neurocognitive testing to their athletes. However, only 51.9% examined these baseline tests for validity. The majority of ATs indicated that they administer baseline neurocognitive tests most frequently to football players (88.4%), followed by women's soccer players (78.8%) and men's soccer players (71.2%). Nearly all respondents (95.5%) stated that they would not return a symptomatic athlete to play if the athlete's neurocognitive scores were back to baseline. However, when asked if they would return an athlete who is symptom free but who scores below his or her baseline, 86.5% responded no, 9.8% responded yes, and 3.8% indicated that it depended on the importance of the competition.

CONCLUSIONS: The use of baseline testing, baseline testing readministration, and postconcussion protocols among ATs is increasing. However, the ATs in this study reported that they relied more on symptoms than on neurocognitive test scores when making return-to-play decisions.


Neurocognitive and symptom predictors of recovery in high school athletes.
Lau BC, Lovell MR, Collins MW, Pardini JE.

OBJECTIVES: The purpose of this study was to identify specific symptom and neuropsychological test patterns that might serve as prognostic indicators of recovery in concussed high school football players. The recently proposed simple versus complex concussion classification was examined and specific symptom clusters were identified.

DESIGN: Case-control study.

SETTING: High school football.

PARTICIPANTS: Subjects were 108 recently concussed male high school football athletes between the ages of 13 and 19 (mean, 16.01) years.

ASSESSMENT OF RISK FACTORS: Participants were evaluated by utilizing the Immediate Postconcussion Assessment and Cognitive Testing computer-based neurocognitive test battery at before injury and within an average of 2.23 days of injury. All athletes were followed until they met criteria for clinical recovery.

MAIN OUTCOME MEASURES: Symptom ratings and neurocognitive test performance.

RESULTS: Both neurocognitive test results and self-reported symptom data had prognostic value in determining time to clinical recovery. Self-reported cognitive decline, Immediate Postconcussion Assessment and Cognitive Testing reaction time, and migraine headache symptoms were associated with longer time to clinical recovery. Overall, these difficulties were predictive of concussions that were retrospectively classified as complex.

CONCLUSIONS: Specific symptom clusters and neurocognitive test results may have predictive value to classifying and managing concussions.


Long-term test-retest reliability of baseline cognitive assessments using ImPACT.
Schatz, P.

BACKGROUND: Computer-based assessment programs are commonly used to document baseline cognitive performance for comparison with postconcussion testing. There are currently no guidelines for how often baseline assessments should be updated, and no data documenting the test-retest stability of baseline measures over relevant time periods.

PURPOSE: To establish long-term test-retest reliability of baseline assessments using ImPACT, and to compare various statistical methods for establishing test-retest reliability.

STUDY DESIGN: Case series; Level of evidence, 4.

METHODS: Participants were 95 collegiate varsity athletes completing baseline cognitive testing at 2 time periods, approximately 2 years apart. No participant sustained a concussion between assessments. All athletes completed the ImPACT test battery; dependent measures were the composite scores and total symptom scale score.
RESULTS: Intraclass correlation coefficient estimates for visual memory (.65), processing speed (.74), and reaction time (.68) composite scores reflected stability over the 2-year period, with greater variability in verbal memory (.46) and symptom scale (.43) scores. Using reliable change indices and regression-based methods, only a small percentage of participants’ scores showed “reliable” or “significant” change on the composite scores (0%-6%), or symptom scale scores (5%-10%).

CONCLUSION: The current results suggest that college athletes' cognitive performance at baseline remains considerably stable over a 2-year period. These data help establish the effects of longer, clinically pragmatic testing intervals on test-retest reliability.

CLINICAL IMPLICATIONS: The current results suggest that stretching the time between baseline assessments from 1 to 2 years may have little effect on the clinical management of concussions in collegiate athletes. These results should not be generalized to collegiate football players, who were not included in this sample. Youth athletes (high school and younger) should continue to receive annually updated baseline assessments until prospective study of the stability of baseline assessments for this younger age group can be completed.


Computerized neuropsychological profiles of South African versus US athletes: a basis for commentary on cross-cultural norming issues in the sports concussion arena.

Shuttleworth-Edwards AB, Whitefield-Alexander VJ, Radloff SE, Taylor AM, Lovell MR.

Computerized programs are widely used as part of the overall medical management of concussion in order to monitor recovery and facilitate safe return-to-play decisions. Typically, neuropsychological profiles of concussed athletes are compared with baseline and/or normative data in the absence of baseline scores. However, the cultural equivalence of performance on neuropsychological tests cannot be assumed and has not been sufficiently researched. The purpose of this study was to investigate the neuropsychological test profiles of the ImPACT (Immediate Postconcussion Assessment and Cognitive Testing) on age-matched South African (SA) rugby and US football players. Participants included 11,257 English-speaking, predominantly white male athletes from multiple SA and US schools and sports organizations in 3 age groups: 11 to 13 years (SA, n = 301; US, n = 775); 14 to 16 years (SA, n = 997; US, n = 4081); and 17 to 21 years (SA, n = 319; US, n = 4784). ImPACT neuropsychological composite scores (verbal and visual memory, visual motor speed, reaction time, impulse control) and the ImPACT total symptom score, derived from the initial baseline testing, were used for comparison purposes between the targeted groups. Independent t-test comparisons revealed overall equivalence between the SA and US athletes on the neuropsychological measures, but they also revealed consistently higher symptom scores for SA athletes in association with clinically relevant effect sizes. It was concluded that US neurocognitive normative data on the ImPACT test are appropriate for use on South African athletes whose first language is English, whereas culture-specific sensitivity for symptom reporting on this same population should be taken into consideration for management purposes. It is argued that neurocognitive equivalence is less likely to apply in educationally disadvantaged populations. The use of registered psychologists is deemed necessary to provide contextualized interpretations of computerized test scores, thereby protecting against misdiagnosis that may occur within the concussion management arena via actuarial approaches that fail to take sociocultural complexities into account.


Concussion history and postconcussion neurocognitive performance and symptoms in collegiate athletes.

Covassin T, Stearne D, Elbin R.

CONTEXT: Athletes are at an inherent risk for sustaining concussions. Research examining the long-term consequences of sport-related concussion has been inconsistent in demonstrating lingering neuropsychological decrements that may be associated with a previous history of concussion.

OBJECTIVE: To determine the relationship between concussion history and postconcussion neurocognitive performance and symptoms in collegiate athletes.

DESIGN: Repeated-measures design.

SETTING: Multi-center analysis of collegiate athletes.

PATIENTS OR OTHER PARTICIPANTS: Fifty-seven concussed collegiate athletes (36 without concussion history, 21 with a history of 2 or more concussions).

INTERVENTION(S): All subjects were administered an Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) neurocognitive test battery, which measures verbal memory, visual memory, reaction time, and visual processing speed and 22 concussion symptoms.

MAIN OUTCOME MEASURE(S): Subjects who sustained a concussion were administered 2 follow-up tests at days 1 and 5 postinjury. Independent variables were history of concussion (no history of concussion, 2 or more concussions) and time (baseline, day 1 postconcussion, or day 5 postconcussion).

RESULTS: A within-subjects effect (time) on ImPACT performance (P < .001), a between-subjects multivariate effect of group (P < .001), and a group-by-time interaction (P = .034) were noted. Athletes with a concussion history performed significantly worse on verbal memory (P = .01) and reaction time (P = .023) at day 5 postconcussion compared with athletes who did not report a previous concussion. No significant group differences were seen at day 5 postinjury on visual memory (P = .167), processing speed (P = .179), or total concussion symptoms (P = .87).

CONCLUSIONS: Concussed collegiate athletes with a history of 2 or more concussions took longer to recover verbal memory and reaction time than athletes without a history of concussion.


Sensitivity of the concussion assessment battery.

Broglie SP, Macciochi SN, Ferrara MS.

OBJECTIVE: Sports medicine clinicians commonly use multiple tests when evaluating patients with concussion. The specific tests vary but often include symptom inventories, posturography, and neuropsychological examinations. The sensitivity of these tests to concussion is vital in reducing the risk for additional injury by prematurely returning an athlete to play. Our study investigated the sensitivity of concussion-related symptoms, a postural control evaluation, and neurocognitive functioning in concussed collegiate athletes.

METHODS: From 1998 to 2005, all high-risk athletes completed a baseline concussion-assessment battery that consisted of a self-reported symptom inventory, a postural control evaluation, and a neuropsychological assessment. Postconcussion assessments were administered within 24 hours of injury to 75 athletes who had physician-diagnosed concussion. Individual tests and the complete battery were evaluated for sensitivity to concussion.
A validation of the post concussion symptom scale in the assessment of complex concussion using cognitive testing and functional MRI.

Chen J, Johnston KM, Collie A, McCrory P, Ptito A.

BACKGROUND: Clinical assessment of cerebral concussion relies on the presence and duration of post concussive symptoms (PCS). Given that these PCS are subjective reports and not always specific to concussion, their usefulness remains to be validated.

OBJECTIVE: To evaluate the usefulness of self-reported PCS by means of cognitive tests and functional MRI (fMRI).

METHOD: 28 male athletes with and without concussion were grouped according to their PCS score. They were then administered a computerised cognitive test battery and submitted to an fMRI session where cerebral activations associated with verbal and non-verbal working memory tasks were analysed.

RESULTS: Behaviourally, response accuracy and speed on the cognitive test battery were comparable for the control and low PCS group. The moderate PCS group showed significantly slower response times than the control group on the matching (p<0.05) and one-back tasks (p<0.05). The functional MRI study showed reduced task related activation patterns in the dorsolateral prefrontal cortex for both low and moderate PCS groups. Activation peaks outside the regions of interest, not seen in the control group, were also noted for both PCS groups. Regression analyses indicated an inverse relationship between PCS scores and performances on several CogSport subtests. Severity of PCS also predicted fMRI blood oxygen level dependent signal changes in cerebral prefrontal regions.

CONCLUSION: Self-reported PCS is associated with an ongoing cerebral haemodynamic abnormality as well as with mild cognitive impairment. These results support the use of the PCS scale in the assessment of cerebral concussion and in monitoring recovery.


Sex differences in neuropsychological function and post-concussion symptoms of concussed collegiate athletes.

Covassin T, Schatz P, Swanik CB.

OBJECTIVE: Our purpose was to determine whether sex differences exist with respect to post-concussion symptoms and neurocognitive function in concussed collegiate athletes.

METHOD: A prospective dependent-sample cohort design was used to compare baseline and post-concussion neuropsychological test scores and endorsed symptoms as functions of serial post-concussion assessment with respect to time and sex. The Immediate Post‐con‐cussion Assessment and Cognitive Testing (ImPACT) battery was administered to a multicenter analysis group of 79 concussed athletes. This computerized neuropsychological test was given to the athletes during the preseason and, on average, 2 and 8 days postinjury.

RESULTS: Multivariate analyses revealed no significant between-group differences on baseline test performance with respect to sex on any of the ImPACT composite scores or on the total symptom score. Multivariate analyses of post-concussion data revealed a significant main effect of time on ImPACT scores, but no main effect of sex was identified, and no time-by-sex interaction existed. Post hoc analysis revealed that concussed female athletes performed significantly worse than concussed male athletes on visual memory tasks (P = 0.001), and analysis of endorsed post-concussion symptoms revealed that concussed men were significantly more likely than concussed women to report post-concussion symptoms of vomiting (P = 0.001) and sadness (P = 0.017). Athletes' scores were examined individually using the reliable-change methodology. At 2 days post-injury, 58% of concussed athletes had one or more reliable incidents of performance decline or increases in symptom reporting. At 8 days post-concussion, 30% of concussed athletes were still showing one or more reliable change from preseason values.

CONCLUSIONS: College athletes exhibit differences on visual memory composite scores and symptoms post-concussion as a function of sex. These data support the importance of evaluating neuropsychological status and post-concussion symptoms in concussed athletes. In addition, these data illustrate the importance of analyzing an individual athlete’s recovery pattern, because individual differences in recovery trajectories may be overshadowed by global norm-group comparisons.

Neurosurgery, 2007: 61(2), 345-351.

Predicting slow recovery from sports-related concussion: the new simple-complex distinction.

Iverson G.

OBJECTIVE: Following the Second International Conference on Concussion in Sport in 2005, a summary agreement statement was published that introduced new terminology for sport-related concussions. This new classification system is binary (ie, "simple" versus "complex" concussions). Athletes who are slow to recover (ie, >10 days) are classified as having complex concussions. The purpose of this study was to determine if high school football players, retrospectively classified as having a simple or a complex concussion, could be differentiated in the first 48 after injury on the basis of symptom reporting or neuropsychological testing.

DESIGN: Case-control study.

SETTING: Pennsylvania high school football programs.

PARTICIPANTS: The total sample consisted of 114 concussed high school football players who were identified through a 3 year prospective cohort study.

INTERVENTIONS: All completed a computerized neuropsychological screening evaluation within 72 hours of injury. They were followed clinically until they recovered and were cleared to return to play. They were classified retrospectively as having a simple (n = 55) or complex (n = 59) concussion based on their recovery times.

MAIN OUTCOME MEASUREMENTS: Neuropsychological test performance and symptom ratings.
RESULTS: Within 72 hours after injury, athletes with complex concussions performed more poorly on neuropsychological testing and reported more symptoms than those with simple concussions. Athletes with complex concussions who were slow to recover were 18 times more likely to have 3 unusually low neuropsychological test scores than those with simple concussions (95% CI = 2.3-144.9). Athletes with previous concussions did not recover more slowly.

CONCLUSIONS: This study provides evidence that supports and refutes the clinical usefulness of the new simple-complex concussion classification system.

Clinical Journal of Sport Medicine, 2007: 17(1), 1731-37.

No cumulative effects for one or two previous concussions.

Iverson GL, Brooks BL, Collins MW, Lovell MR.

BACKGROUND: Sports medicine clinicians and the general public are interested in the possible cumulative effects of concussion.

OBJECTIVE: To examine whether athletes with a history of one or two previous concussions differed in their preseason neuropsychological test performances or symptom reporting.

METHOD: Participants were 867 male high school and university amateur athletes who completed preseason testing with ImPACT version 2.0. They were sorted into three groups on the basis of number of previous concussions. There were 664 athletes with no previous concussions, 149 with one previous concussion, and 54 with two previous concussions. Multivariate analysis of variance was conducted using the verbal memory, visual memory, reaction time, processing speed, and postconcussion symptom composite scores as dependent variables and group membership as the independent variable.

RESULTS: There was no significant multivariate effect, nor were there any significant main effects for individual scores. There was no measurable effect of one or two previous concussions on athletes' preseason neuropsychological test performance or symptom reporting.

CONCLUSION: If there is a cumulative effect of one or two previous concussions, it is very small and undetectable using this methodology.

British Journal of Sports Medicine, 2006: 40, 72-75.

Tracking neuropsychological recovery following concussion in sports.

Iverson GL, Brooks B, Collins MW, Lovell MR.

PRIMARY OBJECTIVE: The purpose of this study was to illustrate the serial use of computerized neuropsychological screening with ImPACT to monitor recovery in a clinical case series of injured athletes.

METHODS AND PROCEDURES: Amateur athletes with concussions (n= 30, average age= 16.1, SD= 2.1 years) underwent pre-season testing and three post-concussion evaluations within the following intervals: 1-2 days, 3-7 days (M= 5.2 days) and 1-3 weeks (M= 10.3 days). The study selection criteria increased the probability of including athletes with slow recovery.

RESULTS: Repeated measures ANOVAs revealed significant main effects for all five composite scores (verbal memory, visual memory, reaction time, processing speed and total symptoms). In group analyses, performance decrements and symptoms relating to concussion appeared to largely resolve by 5 days post-injury and fully resolve by 10 days. Athletes' scores were examined individually using the reliable change methodology. At 1 day post-injury, 90% had two or more reliable declines in performance or increases in symptom reporting. At 10 days, 37% were still showing two or more reliable changes from pre-season levels.

CONCLUSIONS: This study illustrates the importance of analysing individual athletes' test data because group analyses can obscure slow recovery in a substantial minority of athletes.


Measurement of symptoms following sports-related concussion: Reliability and normative data for the Post-Concussion Symptom Scale.


It is important to carefully evaluate self-reported symptoms in athletes with known or suspected concussions. This article presents data on the psychometric and clinical properties of a commonly used concussion symptom inventory-the Post-Concussion Symptom Scale. Normative and psychometric data are presented for large samples of young men (N = 1,391) and young women (N = 355). In addition, data gathered from a concussed sample of athletes (N = 260) seen within 5 days of injury are presented. These groups represent samples of both high school and collegiate athletes. Data from a subsample of 52 concussed athletes seen 3 times post-injury are presented to illustrate symptom reporting patterns during the initial recovery period. General guidelines for the clinical use of the scale are provided.


Recovery from sports concussion in high school and collegiate athletes.

McClincy M, Lovell MR, Pardini J, Collins MW, Spoke MK.

INTRODUCTION: Neuropsychological testing is a valuable tool in concussion diagnosis and management. ImPACT, a computerized neuropsychological testing program, consists of eight cognitive tasks and a 21-item symptom inventory.

METHOD: ImPACT was used to examine the cognitive performance of 104 concussed athletes at baseline, 2, 7 and 14 days post-injury. Dependent measures included composite scores from the ImPACT computerized test battery, as well as a total symptom score from the Post-Concussion Symptom Scale.

RESULTS: Differences between baseline and day 2 post-injury scores were observed for all ImPACT composites (Verbal memory-VERM, visual memory-VISM, processing speed-PROC and reaction time-RT) as well as in total symptom score (SX). At day 7, concussed athletes continued to perform significantly poorer on VERM, VISM, RT and SX. At day 14, only VERM scores were significantly different from baseline.

CONCLUSIONS: Cognitive performance deficits in concussed athletes may persist to 7 and even to 14 days in some cases. In addition to symptom status, the athlete's post-concussion cognitive functioning should be considered when making return-to-play decisions.
**Concussion in professional football: Recovery of NFL and high school athletes assessed by computerized neuropsychological testing-Part 12.**

Pellman EJ, Lovell MR, Viano DC, Casson IR.

OBJECTIVE: Acute recovery from concussion (mild traumatic brain injury) is assessed in samples of NFL and high school athletes evaluated within days of injury.

METHODS: All athletes were evaluated within days of injury using a computer-based neuropsychological test and symptom inventory protocol. Test performance was compared to preinjury baseline levels of a similar but not identical group of athletes who had undergone preseason testing. Statistical analyses were completed using Multivariate Analysis of Variance (MANOVA).

RESULTS: NFL athletes demonstrated a rapid neuropsychological recovery. As a group, NFL athletes returned to baseline performance in a week with the majority of athletes having normal performance two days after injury. High school athletes demonstrated a slower recovery than NFL athletes.

CONCLUSION: Computer-based neuropsychological testing was used within the overall medical evaluation and care of NFL athletes. As found in a prior study using more traditional neuropsychological testing, NFL players did not demonstrate decrements in neuropsychological performance beyond one week of injury. High school players demonstrated more prolonged neuropsychological effects of concussion.


**The “Value Added” of neurocognitive testing in managing sports concussion.**

van Kampen D, Lovell MR, Collins MW, Pardini J.

BACKGROUND: Neurocognitive testing has been endorsed as a “cornerstone” of concussion management by recent Vienna and Prague meetings of the Concussion in Sport Group. Neurocognitive testing is important given the potential unreliability of athlete self-report after injury. Relying only on athletes' reports of symptoms may result in premature return of athletes to contact sport, potentially exposing them to additional injury.

HYPOTHESIS: Use of computer-based neurocognitive testing results in an increased capacity to detect postconcussive abnormalities after injury.

STUDY DESIGN: Case control study; Level of evidence, 3.

METHODS: High school and college athletes with a diagnosed concussion were tested 2 days after injury. Postinjury neurocognitive performance (Immediate Postconcussion Assessment and Cognitive Testing) and symptom (postconcussion symptom) scores were compared with preinjury (baseline) scores and with those of an age- and education-matched noninjured athlete control group. An abnormal test performance was determined statistically with Reliable Change Index scores.

RESULTS: Sixty-four percent of concussed athletes reported a significant increase in symptoms, as judged by postconcussion symptom scores, compared with preinjury baseline at 2 days after injury. Eighty-three percent of the concussed sample demonstrated significantly poorer neurocognitive test results relative to their own baseline performance. The addition of neurocognitive testing resulted in a net increase in sensitivity of 19%. Ninety-three percent of the sample had either abnormal neurocognitive test results or a significant increase in symptoms, relative to their own baseline; 30% of a control group demonstrated either abnormalities in neurocognitive testing or elevated symptoms, as judged by postconcussion symptom scores. For the concussed group, use of symptom and neurocognitive test results resulted in an increased yield of 29% overreliance on symptoms alone. In contrast, 0% of the control group had both symptoms and abnormal neurocognitive testing.

CONCLUSION: Reliance on patients' self-reported symptoms after concussion is likely to result in underdiagnosis of concussion and may result in premature return to play. Neurocognitive testing increases diagnostic accuracy when used in conjunction with self-reported symptoms.


**Validity of ImPACT for measuring attention and processing speed following sports-related concussion.**

Iverson GL, Lovell MR, Collins MW.

The purpose of this study was to examine the validity of ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing), a computerized neuropsychological test battery, for measuring attention and processing speed in athletes with concussions. This was accomplished by comparing the computerized testing to a traditional neuropsychological measure, the Symbol Digit Modalities Test (SDMT). Participants were 72 amateur athletes who were seen within 21 days of sustaining a sports-related concussion (Mean = 9.4, SD = 5.4 days). As predicted, the SDMT correlated more highly with the Processing Speed and Reaction Time composites than the Verbal Memory and Visual Memory Composites from ImPACT. The composite scores from ImPACT and the SDMT were subjected to exploratory factor analysis, revealing a two-factor solution interpreted as Speed/Reaction Time and Memory. It appears as if the Processing Speed Composite, Reaction Time Composite, and SDMT are measuring a similar underlying construct in this sample of concussed amateur athletes.


**Posttraumatic migraine characteristics in athletes following sports-related concussion.**

Mihalik J, Stump J, Collins MW, Lovell MR, Field M, Maroon JC.

OBJECT: The object of this study was to compare symptom status and neurocognitive functioning in athletes with no headache (non-HA group), athletes complaining of headache (HA group), and athletes with characteristics of posttraumatic migraine (PTM group).

METHODS: Neurocognitive tests were undertaken by 261 high-school and collegiate athletes with a mean age of 16.36 ± 2.6 years. Athletes were separated into three groups: the PTM group (74 athletes with a mean age of 16.39 ± 3.06 years), the HA group (124 athletes with a mean age of 16.44 ± 2.51 years), and the non-HA group (63 patients with a mean age of 16.14 ± 2.18 years). Neurocognitive summary scores (outcome measures) for verbal and visual memory, visual motor speed, reaction time, and total symptom scores were collected using ImPACT, a computer software program designed to assess sports-related concussion. Significant differences existed among the three groups for all outcome measures. The PTM group demonstrated significantly greater neurocognitive deficits when compared with the HA and non-HA groups. The PTM group also exhibited the greatest amount of departure from baseline scores.
CONCLUSIONS: The differences among these groups can be used as a basis to argue that PTM characteristics triggered by sports-related concussion are related to increased neurocognitive dysfunction following mild traumatic brain injury. Thus, athletes suffering a concussion accompanied by PTM should be examined in a setting that includes symptom status and neurocognitive testing to address their recovery more fully. Given the increased impairments observed in the PTM group, in this population clinicians should exercise increased caution in decisions about treatment and when the athlete should be allowed to return to play.


Sensitivity and specificity of the ImPACT test battery for concussion in athletes.


This study explored the diagnostic utility of the composite scores of Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and Post Concussion Symptom Scale scores (PCSS). Recently concussed high school athletes (N=72) were tested within 72 h of sustaining a concussion, and data were compared to non-concussed high school athletes with no history of concussion (N=66). Between-groups MANOVA revealed a significant multivariate effect of concussion on test performance (p < .001); univariate ANOVAs revealed all six measures contributed to the between-groups differences. A discriminant function analysis was conducted to measure the ability of the five ImPACT composite scores, as well as the PCSS to classify concussion status. One discriminant function was identified that consisted of the Visual Memory, Processing Speed, and Impulse Control composite scores PCSS, which correctly classified 85.5% of the cases. Approximately 82% of participants in the concussion group and 89% of participants in the control group were correctly classified. Using these data, the sensitivity of ImPACT was 81.9%, and the specificity was 89.4%. As part of a formal concussion management program, ImPACT is a useful tool for the assessment of the neurocognitive and neurobehavioral sequelae of concussion, and can also provide post-injury cognitive and symptom data that can assist a practitioner in making safer return to play decisions.


Cumulative effects of concussion in amateur athletes.

Iverson GL, Gaetz M, Lovell MR, Collins MW.

PRIMARY OBJECTIVE: To examine the possibility that athletes with multiple concussions show cumulative effects of injury.

METHODS AND PROCEDURES: Amateur athletes with a history of three or more concussions were carefully matched (gender, age, education, and sport) with athletes with no prior concussions. All completed a computerized neuropsychological test battery at pre season (ImPACT) and then within 5 days of sustaining a concussion (mean = 1.7 days).

MAIN OUTCOMES AND RESULTS: There were differences between groups in symptom reporting and memory performance. At baseline (i.e. pre season), athletes with multiple concussions reported more symptoms than athletes with no history of concussion. At approximately 2 days post-injury, athletes with multiple concussions scored significantly lower on memory testing than athletes with a single concussion. Athletes with multiple concussions were 7.7 times more likely to demonstrate a major drop in memory performance than athletes with no previous concussions.

CONCLUSIONS: This study provides preliminary evidence to suggest that athletes with multiple concussions might have cumulative effects.


Relation between subjective fogginess and neuropsychological testing following concussion.

Iverson GL, Gaetz M, Lovell MR, Collins MW.

The purpose of this study was to examine the relation between the subjective report of feeling foggy at one-week post concussion and acute neuropsychological outcome. The outcome variables were derived from a computerized neuropsychological screening battery, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). Participants were 110 high school students who sustained a sports-related concussion and were evaluated 5-10 days post injury (M = 6.8 days). Athletes were divided into two groups on the basis of self-reported fogginess. The first group reported no fogginess (n = 91), whereas the second group reported experiencing some degree of fogginess (n = 19) on a 6-point scale. The athletes with persistent fogginess experienced a large number of other post-concussion symptoms, compared to the athletes with no reported fogginess. In addition, the athletes with persistent fogginess had significantly slower reaction times, reduced memory performance, and slower processing speed. Thus, athletes with any degree of self-reported fogginess at one-week post injury are likely to have adverse effects from their concussions in multiple domains.


Grade 1 or “ding” concussions in high school athletes.

Lovell MR, Collins MW, Iverson GL, Johnston KM, Bradley JP.

BACKGROUND: Recent concussion management guidelines have suggested that athletes with mild (grade 1) concussions may be returned to play if asymptomatic for 15 minutes. The purpose of this study was to assess the utility of a current concussion management guideline in classifying and managing mild concussion.

HYPOTHESIS: High school athletes diagnosed with a grade 1 concussion will demonstrate measurable decline in neuropsychological functioning that persists during the 1st week of recovery.

STUDY DESIGN: Prospective study designed to evaluate neuropsychological functioning both prior to and following concussion.

METHODS: Forty-three high school athletes completed neuropsychological test performance and symptom ratings prior to the season and at two times during the 1st week following mild concussion.

RESULTS: Thirty-six hours after injury, mildly concussed high school athletes demonstrated a decline in memory (P < 0.003) and a dramatic increase in self-reported symptoms (P < 0.00001) compared to baseline performance.

CONCLUSIONS: Athletes with grade 1 concussion demonstrated memory deficits and symptoms that persisted beyond the context in which they were injured. These data suggest that current grade 1 return-to-play recommendations that allow for immediate return to play may be too liberal. Clinical Relevance: A reconsideration of current concussion grading systems appears to be warranted.
Relationship between post-concussion headache and neuropsychological test performance in high school athletes.

Collins MW, Field M, Lovell MR, Iverson G, Johnston KM, Maroon J, Fu FH.

BACKGROUND: The relevance of headache to outcome after sports-related concussion is poorly understood.

HYPOTHESES: High school athletes reporting headache approximately 1 week after injury will have significantly more other concussion symptoms and will perform more poorly on neuropsychological tests than athletes not experiencing headache.

STUDY DESIGN: Prospective cohort study.

METHODS: Study participants included 109 high school athletes who had sustained concussion and who were divided into two groups: those reporting headache 7 days after injury and those reporting no headaches. The two groups were compared regarding on-field markers of concussion severity at the time of injury and symptoms and neurocognitive test results collected via ImPACT, a computerized neuropsychological test battery and postconcussion symptom scale, at a mean of 6.8 days after injury.

RESULTS: Athletes reporting posttraumatic headache demonstrated significantly worse performance on reaction time and memory ImPACT neurocognitive composite scores. These athletes also reported significantly more symptoms other than headache and were more likely to have demonstrated on-field anterograde amnesia.

CONCLUSIONS: Findings suggest that any degree of postconcussion headache in high school athletes 7 days after injury is likely associated with an incomplete recovery after concussion.


On-field predictors of neuropsychological and symptom deficit following sports-related concussion.

Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J.

OBJECTIVE: Investigate the relationship between on-field markers of concussion severity and postinjury neuropsychological and symptom presentation in an athlete-specific population.

DESIGN: Case control study.

SETTING: Multicenter analysis of high school and college athletes.

PARTICIPANTS: A total of 78 athletes sustaining sports-related concussion were selected from a larger sample of 139 concussed athletes. ASSESSMENT OF PREDICTOR VARIABLES: On-field presence of disorientation, posttraumatic amnesia, retrograde amnesia, and loss of consciousness.

MAIN OUTCOME MEASURES: ImPACT, a computerized neuropsychological test battery, was administered pre-season and, on average, 2 days postinjury. Good postinjury presentation (n = 44) was defined as no measurable change, relative to baseline, in terms of both ImPACT memory and symptom composite scores. Poor presentation (n = 34) was defined as a 10-point increase in symptom reporting and 10-point decrease in memory functioning (exceeding the 80% confidence interval for measurement error on ImPACT). Athletes failing to meet good or poor selection criteria (n = 61) were not included in the analysis.

RESULTS: Odds ratios revealed that athletes demonstrating poor presentation at 2 days postinjury were over 10 times more likely (P < 0.001) to have exhibited retrograde amnesia following concussive injury when compared with athletes exhibiting good presentation. Similarly, athletes with poor presentation were over 4 times more likely (P < 0.013) to have exhibited posttraumatic amnesia and at least 5 minutes of mental status change. There were no differences between good and poor presentation groups in terms of on-field loss of consciousness.

CONCLUSIONS: The presence of amnesia, not loss of consciousness, appears predictive of symptom and neurocognitive deficits following concussion in athletes. Athletes presenting with on-field amnesia should undergo comprehensive and individualized assessment prior to returning to sport participation. Continued refinement of sports concussion grading scales is warranted in lieu of consistent findings that brief loss of consciousness is not predictive of concussion injury severity.


Interpreting change on ImPACT following sports concussion.

Iverson GL, Lovell MR, Collins MW.

The purpose of this study was to examine the psychometric characteristics of Version 2.0 of ImPACT (Immediate Postconcussion Assessment and Cognitive Testing). The focus was on the stability of the test scores and the calculation of reliable change confidence intervals for the test-retest difference scores. A sample of 56 nonconcussed adolescents and young adults completed the test battery on two occasions. Test-retest coefficients, reliable change difference scores, and confidence intervals for measurement error are provided. These reliable change parameters were applied to a second sample of 41 concussed amateur athletes who were tested preseason and within 72 hr of injury. Applying these confidence intervals allows more precise determinations of deterioration, improvement, and recovery in the initial days following concussion.


Recovery from mild concussion in high school athletes.


OBJECT: A computerized neuropsychological test battery was conducted to evaluate memory dysfunction and self-reporting of symptoms in a group of high school athletes who had suffered concussion.

METHODS: Neuropsychological performance prior to and following concussion was compared with the test performance of an age-matched control group. Potentially important diagnostic markers of concussion severity are discussed and linked to recovery within the 1st week of injury.
CONCLUSIONS: High school athletes who had suffered mild concussion demonstrated significant declines in memory processes relative to a noninjured control group. Statistically significant differences between preseason and postinjury memory test results were still evident in the concussion group at 4 and 7 days postinjury. Self-reported neurological symptoms such as headache, dizziness, and nausea resolved by Day 4. Duration of on-field mental status changes such as retrograde amnesia and posttraumatic confusion was related to the presence of memory impairment at 36 hours and 4 and 7 days postinjury and was also related to slower resolution of self-reported symptoms. The results of this study suggest that caution should be exercised in returning high school athletes to the playing field following concussion. On-field mental status changes appear to have prognostic utility and should be taken into account when making return-to-play decisions following concussion. Athletes who exhibit on-field mental status changes for more than 5 minutes have longer-lasting postconcussive symptoms and memory decline.


General Issues

Post-concussion cognitive declines and symptomatology are not related to concussion biomechanics in high school football players.

Broglio SP, Eckner JT, Surma T, Kuchler JS.

Concussion is a major public health concern with nearly 4 million injuries occurring each year in the United States. In the acute post-injury stage concussed individuals demonstrate cognitive function and motor control declines as well as increased symptom reports. Researchers have hypothesized the severity of these impairments to be related to impact magnitude. Using the Head Impact Telemetry System (HITS) to record head impact biomechanics, we sought to correlate pre and post-concussive impact characteristics with declines in cognitive performance and increases in concussion related symptoms. Over four seasons, 19 high school football athletes wearing instrumented helmets sustained 20 diagnosed concussions. Each athlete completed a baseline computer-based symptom and cognitive assessment during the pre-season and a post-injury assessment within 24 hours of injury. Correlational analyses identified no significant relationships between symptom or cognitive performance change scores and impact biomechanics (i.e., time from session start until injury, time from the previous impact, peak linear acceleration, peak rotational acceleration, and HIT-severity profile). Nor were there any significant relationships between change scores and the number of impacts, cumulative linear acceleration, cumulative rotational acceleration, or cumulative HIT-severity profile values associated with all impacts prior to or following the injury. This investigation is the first to examine the relationship between concussion impact characteristics, including cumulative impact profiles, and post-morbid outcomes in high school athletes. There appears to be no association between head impact biomechanics and post-concussive outcomes. As such, the use of biomechanical variables to predict injury severity does not appear feasible at this time.


A history of sport-related concussion on event-related brain potential correlates of cognition.

Broglio SP, Moore RD, Hillman CH.

Over the past decade, a growing body of research has detailed persistent changes to neuroelectric indices of cognition in amateur and professional athletes with a concussion history. Here, we review the relevant neuroelectric findings on this relationship while considering the duration from the last concussive event. Collectively, the findings support a negative relation of concussive injury to neuroelectric indices of brain health and cognition in the presence of normal clinical findings. The results suggest that event-related brain potentials are especially well-suited for identifying aspects of cognition that remain dysfunctional for an extended period of time, which are otherwise unidentified using standard neuropsychological tests. Such findings also suggest the need for additional research to fully elucidate the extent to which concussive injuries negatively impact brain health and cognition.


Mild traumatic brain injury among a cohort of rugby union players: predictors of time to injury.

Hollis SJ, Stevenson MR, McIntosh AS, Li L, Hirtier S, Shores EA, Collins MW, Finch CF.

This study reports the time to sustain a mild traumatic brain injury (mTBI) among a cohort of community rugby union players. Demographic and player characteristics were collected and players followed up for between one and three playing seasons. 7% of the cohort sustained an mTBI within 10 h of game time, increasing twofold to 14% within 20 h. The mean time to first mTBI was 8 h with an SD of 8.2 (median 6.8 h; IQR: 2.9-11.7 h). Players reporting a recent history of concussion were 20% more likely to sustain an mTBI after 20 h of game time compared with those with no recent history of concussion. Players were likely to sustain an mTBI in shorter time if they trained for <3 h/week (HR = 1.46, p = 0.03) or had a body mass index <27 (HR = 1.77, p = 0.007). The findings highlight modifiable characteristics to reduce the likelihood of shortened time to mTBI.


Diffusion tensor imaging findings are not strongly associated with postconcussional disorder 2 months following mild traumatic brain injury.

Lange RT, Iverson GL, Brubacher JR, Madler B, Heran MK.

OBJECTIVE: To examine the relation between diffusion tensor imaging (DTI) of the corpus callosum and postconcussional symptom reporting following mild traumatic brain injury (MTBI).

PARTICIPANTS: Sixty patients with MTBI and 34 patients with orthopedic/soft-tissue injuries (Trauma Controls) prospectively enrolled from consecutive admissions to a level 1 trauma center.

PROCEDURE: Diffusion tensor imaging of the corpus callosum was undertaken using a Phillips 3T scanner at 6 to 8 weeks postinjury. Participants also completed a postconcussion symptom checklist. The MTBI group was divided into 2 subgroups based on the International Classification of Diseases, Tenth Revision symptom criteria for postconcussion disorder (PCD): PCD Present (n = 21), PCD Absent (n = 39).

MAIN OUTCOME MEASURES: Measures of fractional anisotropy and mean diffusivity for the genu, body, and splenium of the corpus callosum. Participants also completed the British Columbia Post-Concussion Symptom Inventory.

RESULTS: The MTBI group reported more postconcussion symptoms than the trauma controls. There were no significant differences between MTBI and trauma control groups on all DTI measures. In the MTBI sample, there were no significant differences on all DTI measures between those who did and did not meet the International Classification of Diseases, Tenth Revision research criteria for postconcussion disorder.

CONCLUSIONS: These data do not support an association between white matter integrity in the corpus callosum and self-reported postconcussion syndrome 6 to 8 weeks post-MTBI.

Larson MJ, Farrer TJ, Clayson PE.

Recent studies suggest that individuals who have experienced a concussion or mild traumatic brain injury (TBI) show deficits in cognitive control. We tested the hypothesis that behavioral (response time [RT] and error rate) and electrophysiological (N450 and conflict SP components of the event-related potential [ERP]) reflections of conflict monitoring and conflict adaptation would be attenuated in 29 individuals with mild TBI compared to 36 control participants. Groups did not differ in age, sex, years of education, or neuropsychological test performance. Conflict monitoring and conflict adaptation can be seen when behavioral and ERP indices are reduced following high-conflict trials relative to low-conflict trials. Participants completed a Stroop task with 50% congruent and 50% incongruent trials. Behaviorally, both groups showed statistically significant conflict adaptation effects for RTs and error rates; these effects did not differ as a function of group. For ERPs, both groups showed more negative N450 and more positive conflict SP amplitudes on incongruent trials relative to congruent trials. Groups significantly differed in level of conflict adaptation for the conflict SP; controls showed significant conflict adaptation, whereas individuals with mild TBI did not. ERP amplitudes did not correlate with indices of injury severity or time since injury. Findings replicate and extend previous work that suggests the conflict SP is sensitive to conflict adaptation in healthy individuals, but is decreased in individuals across the range of TBI severity. Findings also suggest that mild TBI is associated with intact conflict monitoring, but altered conflict adaptation and adjustment processes.


Schneiders AG, Sullivan SJ, Handcock P, Gray A, McCrory PR.

This study determined the effect of exercise on measures of static and dynamic balance used in the assessment of sports-related concussion (SRC). A balanced three-group cross-over randomized design was used with three levels of exercise verified by blood-lactate, heart rate and "perceived-exertion": no exercise/test (NE), moderate-intensity exercise (ME), and high-intensity exercise (HE). Participants performed two timed balance tasks: tandem gait (TG) and single-leg stance (SLS); pre- and post-exercise and 15 min after exercise. Linear mixed-models with adjusted means and contrasts compared exercise effects. Ninety asymptomatic participants (45male symbol:45female symbol) were recruited. When times were contrasted with NE, HE resulted in a significant decrease in SLS (P<0.001) and TG (P<0.001) performance immediately following exercise. Fifteen minutes of recovery improved SLS (P<0.001) and TG (P=0.011) from post-exercise performance. ME caused a significant decrease in performance in SLS (P=0.038) but not TG (P=0.428). No statistically significant change occurred following ME in any tasks after 15-min recovery (SLS P=0.064; TG P=0.495). Test-retest reliability was considerably higher for the dynamic task compared with the static task. The reliability of static and dynamic balance tasks, and the change in performance following exercise, have implications for the immediate assessment of SRC, as these measures are utilized in concussion assessment instruments.


Talavage TM, Nauman E, Breedlove EL, Yoruk U, Dye AE, Morikagi K, Feuer H, Leverenz LJ.

Head trauma and concussion in football players has recently received considerable attention. Post-mortem evidence suggests that accrual of damage to the brain may occur with repeated blows to the head, even when individual blows fail to produce clinical symptoms. There is an urgent need for improved detection and characterization of head trauma to reduce future injury risk and promote development of new therapies. This study examined neurologic performance and health in the presence of head collision events in high school football players, using longitudinal measures of collision events (HIT system), neurocognitive testing (ImPACT), and functional MRI (fMRI). Longitudinal assessment (including baseline) was conducted in 11 males (ages 15-19) participating on the varsity and junior varsity football teams at a single high school. We expected and observed subjects in two previously described categories: (1) no clinically-diagnosed concussion and no changes in neurocognitive behavior and (2) clinically-diagnosed concussion with changes in neurocognitive behavior. Additionally, we observed players in a previously undiagnosed third category who exhibited no clinically-observed symptoms associated with concussion, but who demonstrated measurable neurocognitive (primarily visual working memory) and neurophysiologic (altered activation in dorsolateral prefrontal cortex, DLPFC) impairments. This new category was associated with significantly higher numbers of head collision events to the top-front of the head, directly above DLPFC. Observation of this category suggests that more players are suffering neurologic injury than are presently detected via traditional concussion-assessment mechanisms. These individuals are unlikely to undergo clinical evaluation and thus continue to participate in football-related activities even when changes in brain physiology (and potential brain health) are present, likely increasing risk of future neurologic injury.


Auditory Processing After Sport-Related Concussions.

Turgeon C, Champoux F, Lepore F, Leclerc S, Ellemberg D.

OBJECTIVE: The aim of the study is to investigate whether sport-related concussions disrupt auditory processes.

DESIGN: Sixteen university athletes participated in the study; eight had one or more sport-related concussions and eight never experienced a concussion. The Frequency Pattern Sequence test, the Duration Pattern Sequence test, the Synthetic Sentence Identification test, and the Staggered Spondaic Word test were used to assess auditory processing.

RESULTS: All nonconcussed athletes have normal auditory processing. In contrast, more than half of the concussed athletes had deficits for one or more of the auditory processing tests.

CONCLUSIONS: The pattern of results suggests that sport-related concussions can disrupt the neurological mechanisms implicated in several auditory processes, including monaural low-redundancy speech recognition, tone pattern recognition, and dichotic listening.

Ear and Hearing, In Press.

The effects of attention capacity on dynamic balance control following concussion.

Catena RD, van Donkelaar P, Chou LS.
The purpose of this study was to examine how individuals modulate attention in a gait/cognition dual task during a 4-week period following a concussion. Ten individuals suffering from a grade 2 concussion and 10 matched controls performed a single task of level walking, a seated auditory Stroop task and a simultaneous auditory Stroop and walking task. Reaction time and accuracy were measured from the Stroop task. Dynamic balance control during gait was measured by the interaction (displacement and velocity) between the center of mass (CoM) and center of pressure (CoP) in the coronal and sagittal planes. Concussed individuals shifted from conservative control of balance (shorter separation between CoM and CoP) immediately after injury to normal balance control over 28 days post-injury. Immediately after injury, correlations analyses using each subject on each testing day as a data point showed that there was a spectrum of deficient performance among concussed individuals on the first testing day. Within a testing session, deficiencies in reaction time of processing involved in the Stroop task were commonly seen with reduce dynamic balance control. However, the prioritization was not always towards the same task between trials. There were no correlations in the control group. Information provided in this study would enhance our understanding of the interaction between attention and gait following concussion.

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The female athlete: the role of gender in the assessment and management of sport-related concussion.

Covassin T, Elbin RJ.

Concussions remain a serious public health concern, with approximately 1.6 million to 3 million sport and recreational traumatic and brain injuries occurring every year in the United States. Most research on concussions has been conducted on male athletes, specifically, football players. However, female sport participation has steadily increased over the past decade. Recent studies suggest that the incidence of and recovery from sport-related concussion varies between male and female athletes, with women having a higher risk of sustaining a concussion and taking a longer time to recover than men. As a result, this article addresses the role of gender in the assessment and management of sport-related concussion.


Concussive brain trauma in the mouse results in acute cognitive deficits and sustained impairment of axonal function.

Creed JA, DiLeonardi AM, Fox DP, Tessier AR, Raghupati R.

Concussive brain injury (CBI) accounts for approximately 75% of all brain-injured people in the United States each year and is particularly prevalent in contact sports. Concussion is the mildest form of diffuse traumatic brain injury (TBI) and results in transient cognitive dysfunction, the neuropathologic basis for which is traumatic axonal injury (TAI). To evaluate the structural and functional changes associated with concussion-induced cognitive deficits, adult mice were subjected to an impact on the intact skull over the midline suture that resulted in a brief apneic period and loss of the righting reflex. Closed head injury also resulted in an increase in the wet weight/dry weight ratio in the cortex suggestive of edema in the first 24 h, and the appearance of Fluoro-Jade-B-labeled degenerating neurons in the cortex and dentate gyrus of the hippocampus within the first 3 days post-injury. Compared to sham-injured mice, brain-injured mice exhibited significant deficits in spatial acquisition and working memory as measured using the Morris water maze over the first 3 days (p<0.001), but not after the fourth day post-injury. At 1 and 3 days post-injury, intraxonal accumulation of amyloid precursor protein in the corpus callosum and cingulum was accompanied by neurofilament dephosphorylation, impaired transport of Fluoro-Gold and synaptophysin, and deficits in axonal conductance. Importantly, deficits in retrograde transport and in action potential of myelinated axons continued to be observed until 14 days post-injury, at which time axonal degeneration was apparent. These data suggest that despite recovery from acute cognitive deficits, concussive brain trauma leads to axonal degeneration and a sustained perturbation of axonal function.


A diffusion tensor imaging study on the white matter skeleton in individuals with sports-related concussion

Cubon VA, Putukian M, Boyer C, Dettwiler A.

Recognizing and managing the effects of cerebral concussion is very challenging, given the discrete symptomatology. Most individuals with sports-related concussion will not score below 15 on the Glasgow Coma Scale, but will present with rapid onset of short-lived neurological impairment, demonstrating no structural changes on traditional magnetic resonance imaging (MRI) and computed tomography (CT) scans. The return-to-play decision is one of the most difficult responsibilities facing the physician, and so far this decision has been primarily based on neurological examination, symptom checklists, and neuropsychological (NP) testing. Diffusion tensor imaging (DTI) may be a more objective tool to assess the severity and recovery of function after concussion. We assessed white matter (WM) fiber tract integrity in varsity level college athletes with sports-related concussion without loss of consciousness, who experienced prolonged symptoms for at least 1 month after injury. Evaluation of fractional anisotropy (FA) and mean diffusivity (MD) of the WM skeleton using tract-based spatial statistics (TBSS) revealed a large cluster of significantly increased MD for concussed subjects in several WM fiber tracts in the left hemisphere, including parts of the inferior/superior longitudinal and fronto-occipital fasciculi, the retrolenticular part of the internal capsule, and posterior thalamic and acoustic radiations. Qualitative comparison of average FA and MD suggests that with increasing level of injury severity (ranging from sports-related concussion to severe traumatic brain injury), MD might be more sensitive at detecting mild injury, whereas FA captures more severe injuries. In conclusion, the TBSS analysis used to evaluate diffuse axonal injury of the WM skeleton seems sensitive enough to detect structural changes in sports-related concussion.


Persistent motor system abnormalities in formerly concussed athletes.


CONTEXT: The known detrimental effects of sport concussions on motor system function include balance problems, slowed motor execution, and abnormal motor cortex excitability.

OBJECTIVE: To assess whether these concussion-related alterations of motor system function are still evident in collegiate football players who sustained concussions but returned to competition more than 9 months before testing.

DESIGN: Case-control study.

SETTING: University laboratory. Patients or Other Participants: A group of 21 active, university-level football players who had experienced concussions was compared with 15 university football players who had not sustained concussions. Intervention(s): A force platform was used to assess centerof-pressure (COP) displacement and COP oscillation regularity (approximate entropy) as measures of postural stability in the upright position. A rapid alternating-movement task was also interval intracortical inhibition and the cortical silent period, presumably reflecting y-aminobutyric acid subtype B receptor-mediated intracortical inhibition. Main Outcome Measure(s): COP displacement and oscillation regularity, motor execution speed, long-interval intracortical inhibition, cortical silent period.

RESULTS: Relative to controls, previously concussed athletes showed persistently lower COP oscillation randomness, normal performance on a rapid alternating-movement task, and more M1 intracortical inhibition that was related to the number of previous concussions.
CONCLUSIONS: Sport concussions were associated with pervasive changes in postural control and more M1 intracortical inhibition, providing neurophysiologic and behavioral evidence of lasting, subclinical changes in motor system integrity in concussed athletes. Key Words: traumatic brain injuries, transcranial magnetic stimulation, clinical neurophysiology, motor control, primary.


Agreement between parents and children on ratings of post-concussive symptoms following mild traumatic brain injury.

Hajek CA, Yeates KO, Taylor HG, Bangert B, Dietrich A, Nuss KE, Rusin J, Wright M.

The level of parent-child agreement on post-concussive symptoms (PCS) was examined in children following mild traumatic brain injuries (TBI). As part of a larger longitudinal study, 186 children with mild TBI and 99 with orthopedic injuries (OI), from 8 to 15 years of age, were recruited prospectively. Parents and children completed the PCS Interview (PCS-I) and the Health and Behavior Inventory (HBI) at 2 weeks, 1 month, 3 months, and 12 months postinjury. Item-level correlations between child and parent ratings on both measures of PCS were significant but modest in both groups. Parent-child correlations for composite scales on the HBI and the total score on the PCS-I were significant in both groups, but somewhat higher in the OI group than in the mild TBI group. Mean symptom ratings tended to be significantly higher for children as compared to parents, especially for somatic symptoms. Parents and children display modest agreement when reporting PCS, their ratings correlate significantly, but children report higher mean levels of symptoms than parents.


Neuropsychological assessment of sports-related concussion.

Johnson EW, Kegel NE, Collins MW.

Assessment of concussion can be challenging for medical practitioners given the different factors associated with each individual injury. The use of neuropsychological testing provides an objective method in the evaluation and management of concussion. Over the last 20 years it has become increasingly useful in the realm of sports concussion and has been deemed a cornerstone of concussion management by the Concussion in Sport group at the International Symposium of Concussion in Sport. Neuropsychological assessment has evolved to using computer-based neurocognitive testing, which has become increasingly common over the last decade, especially in organized sports. Neuropsychological assessment has also proven to be effective in the detection of differences based on several individual factors, including age, gender, and history of prior concussion. Despite its documented value, neuropsychological assessment should be one of several tools used as part of the concussion assessment/management process.


Depression strongly influences postconcussion symptom reporting following mild traumatic brain injury.

Lange RT, Iverson GL, Rose A.

OBJECTIVE: To examine the influence of depression on postconcussion symptom reporting in patients following mild traumatic brain injury (MTBI).

PARTICIPANTS: Sixty patients referred to a specialty clinic following MTBI, 58 outpatients with Structured Clinical Interview for DSM-diagnosed depression, and 72 healthy community control participants.

PROCEDURE: Participants with MTBI were divided into 2 subgroups on the basis of self-reported symptoms of depression (23 MTBI-depressed, 37 MTBI-not depressed). All participants completed a postconcussion symptom questionnaire.

MAIN OUTCOME MEASURE: British Columbia Post-concussion Symptom Inventory.

RESULTS: There were significant differences in total reported postconcussion symptoms among all 4 groups (all P < .002; Cohen's d = 0.68-3.24, large to very large effect sizes; MTBI-depressed > depressed outpatients > MTBI-no depression > healthy controls). There were significant differences in the number of symptoms endorsed (P < .05), with the highest number of symptoms endorsed by the MTBI-depressed group, followed by depressed outpatients, MTBI-no depression, and healthy controls.

CONCLUSIONS: Patients who experience MTBIs and who have a postinjury recovery course complicated by significant depression report more postconcussion symptoms, and more severe symptoms, than (a) outpatients with depression, and (b) patients with MTBIs who do not have significant symptoms of depression.

Cerebrovascular pathophysiology following mild traumatic brain injury.

Len TK, Neary JP.

Mild traumatic brain injury (mTBI) or sport-induced concussion has recently become a prominent concern not only in the athletic setting (i.e. sports venue) but also in the general population. The majority of research to date has aimed at understanding the neurological and neuropsychological outcomes of injury as well as return-to-play guidelines. Remaining relatively unexamined has been the pathophysiological aspect of mTBI. Recent technological advances including transcranial Doppler ultrasound and near infrared spectroscopy have allowed researchers to examine the systemic effects of mTBI from rest to exercise, and during both asymptomatic and symptomatic conditions. In this review, we focus on the current research available from both human and experimental (animal) studies surrounding the pathophysiology of mTBI. First, the quest for a unified definition of mTBI, its historical development and implications for future research is discussed. Finally, the impact of mTBI on the control and regulation of cerebral blood flow, cerebrovascular reactivity, cerebral oxygenation and neuroautonomic cardiovascular regulation, all of which may be compromised with mTBI, is discussed.


The chronic effects of concussion on gait.

Martini DN, Sabin MJ, DePesa SA, Leal EW, Negrete TN, Sosnoff JJ, Broglio SP

OBJECTIVE: To examine the effects of concussion on gait patterns of young adults with and without a history of concussion during single- and dual-task paradigms.

DESIGN: Cross-sectional evaluation.
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SETTING: A research laboratory.

PARTICIPANTS: Persons with (n=28; mean, 6.32y postinjury) and without (n=40) a concussion history.

INTERVENTION: Not applicable.

MAIN OUTCOME MEASURES: A battery of gait analyses during single- and dual-task conditions. Normalized velocity, step length, stride width, number correct from cognitive task, time in single-leg stance, and time in double-leg stance were the variables of interest. Gait was analyzed using an electronic walkway system, and the Brooks visuospatial cognitive task was used to index cognition.

RESULTS: Data analyses using multiple 2-way repeated-measures analyses of variance and correlations indicated that participants with a history of concussion spent significantly more time in a double-leg stance and significantly decreased time in a single-leg stance and had slower gait velocity. There also was a significant negative correlation between number of concussions and time in single-leg stance and positive correlations between number of concussions and time in double-leg stance and double-leg-stance percent.

CONCLUSION: These findings suggest that persons with a history of concussion adopt a more conservative gait strategy.


The prospective course of postconcussion syndrome: The role of mild traumatic brain injury.


Objective: To investigate whether postconcussion syndrome (PCS) represents long-term sequelae associated with mild traumatic brain injury (mTBI). Methods: Prospective consecutive admissions to a Level 1 trauma hospital were assessed a mean 4.9 days and again 106.2 days post-injury. The final sample comprised 62 mTBI and 58 nonbrain injured trauma controls (TC). Change or lack of change in individual PCS-like symptoms and PCS was examined. Multilevel logistic regression was used to analyze whether mTBI predicts 3-month PCS (Time 2; T2); whether predictors of PCS (within 14 days of injury, Time 1; T1) predict 3-month PCS, and how change in these predictors from T1 to T2 were associated with change in PCS status. Variables included demographic, injury-related, financial incentives, neuropsychological, and psychiatric disorder. Results: MTBI did not predict PCS. PCS was comparable (T1: mTBI: 40.3%; TC: 50.0%; T2: mTBI: 46.8%, TC: 48.3%). At T2, 38.6% were new cases of PCS; between 30.8% and 86.2% reported either a new or more frequent symptom. A pre-injury depressive or anxiety disorder (OR = 2.99, 95% CI [1.38, 6.45]), and acute posttraumatic stress (OR = 1.05, 95% CI [1.00, 1.00]) were early markers of PCS, regardless of mTBI. An interaction between time and posttraumatic stress disorder (PTSD) suggested the relationship between the severity of PTSD symptoms and PCS strengthened over time (OR = 2.66, 95% CI [1.08, 6.55]). Pain was related to PCS. Females were more likely than males to have PCS. Conclusion: The data suggest the phenomenon of PCS in trauma patients does not show an association with mTBI. (PsycINFO Database Record (c) 2011 APA, all rights reserved).


Long-term outcomes after uncomplicated mild traumatic brain injury: a comparison with trauma controls.

Ponsford J, Cameron P, Fitzgerald M, Grant M, Mikocka-Walus A.

Abstract The question as to whether mild traumatic brain injury (mTBI) results in persisting sequelae over and above those experienced by individuals sustaining general trauma remains controversial. This prospective study aimed to document outcomes 1 week and 3 months post-injury following mTBI assessed in the emergency department (ED) of a major adult trauma center. One hundred and twenty-three patients presenting with uncomplicated mTBI and 100 matched trauma controls completed measures of post-concussive symptoms and cognitive performance (Immediate Post-Concussion Assessment and Cognitive Testing battery; ImPACT) and pre-injury health-related quality of life (SF-36) in the ED. These measures together with measures of psychiatric status (the Mini-International Neuropsychiatric Interview (MINI)) pre- and post-injury, the Hospital Anxiety and Depression Scale, Visual Analogue Scale for Pain, Functional Assessment Questionnaire, and PTSD Checklist-Specific, were re-administered at follow-up. Participants with mTBI showed significantly more severe post-concussive symptoms in the ED and at 1 week post-injury. They performed more poorly than controls on the Visual Memory subtest of the ImPACT at 1 week and 3 months post-injury. Both the mTBI and control groups recovered well physically, and most were employed 3 months post-injury. There were no significant group differences in psychiatric function. However, the group with mild TBI was more likely to report ongoing memory and concentration problems in daily activities. Further investigation of factors associated with these ongoing problems is warranted.


Early indicators of enduring symptoms in high school athletes with multiple previous concussions.

Schatz P, Moser RS, Covassin T, Karpf R.

BACKGROUND: Despite recent findings of cognitive, emotional, physical, and behavioral symptomatology in retired professional athletes with a history of multiple concussions, there is little systematic research examining these symptoms in high school athletes with a history of concussion.

OBJECTIVE: To identify cognitive, emotional, and physical symptoms, at baseline, in non-concussed high school athletes on the basis of concussion history.

METHODS: A multi-center sample of 616 high school athletes, who completed baseline evaluations, were assigned to groups on the basis of history of concussion (none, one, two or more previous). The Post-Concussion Symptom Scale (PCSS) was administered as part of a computerized neuropsychological test battery, during athletes’ pre-season baseline evaluations. Cross-sectional analyses were used to examine symptoms reported at the time of baseline neuropsychological testing.

RESULTS: High school athletes with a history of two or more concussions showed significantly higher ratings of concussion-related symptoms (cognitive, physical, sleep difficulties) than athletes with a history of one or no previous concussions.

CONCLUSION: It appears that youth athletes who sustain multiple concussions experience a variety of subtle effects, which may be possible precursors to the future onset of concussion-related difficulties.

Neurosurgery, 2011: 68(6), 1562-1567.

Microstructural brain injury in post-concussion syndrome after minor head injury.

Smits M, Houston GC, Dippel DW, Wielopolski PA, Vernooij MW, Koudstaal PJ, Hunink MG, van der Lugt A.
INTRODUCTION: After minor head injury (MHI), post-concussive symptoms commonly occur. The purpose of this study was to correlate the severity of post-concussive symptoms in MHI patients with MRI measures of microstructural brain injury, namely mean diffusivity (MD) and fractional anisotropy (FA), as well as the presence of microhaemorrhages.

METHODS: Twenty MHI patients and 12 healthy controls were scanned at 3 T using diffusion tensor imaging (DTI) and high-resolution gradient recalled echo (HRGRE) T2*-weighted sequences. One patient was excluded from the analysis because of bilateral subdural haematomas. DTI data were preprocessed using Tract Based Spatial Statistics. The resulting MD and FA images were correlated with the severity of post-concussive symptoms in the uncalate fasciculus, the IFO, the internal capsule and the corpus callosum, as well as in the parietal and frontal subcortical white matter. Microhaemorrhages were observed in one patient only.

RESULTS: Comparing patients with controls, there were no differences in MD. FA was decreased in the right temporal subcortical white matter. MD was increased in association with the severity of post-concussive symptoms in the inferior fronto-occipital fasciculus (IFO), the inferior longitudinal fasciculus and the superior longitudinal fasciculus. FA was reduced in association with the severity of post-concussive symptoms in the uncinate fasciculus, the IFO, the internal capsule and the corpus callosum, as well as in the parietal and frontal subcortical white matter. Microhaemorrhages were observed in one patient only.

CONCLUSIONS: The severity of post-concussive symptoms after MHI was significantly correlated with a reduction of white matter integrity, providing evidence of microstructural brain injury as a neuropathological substrate of the post-concussion syndrome.


Long-term neurocognitive dysfunction in sports: what is the evidence?
Solomon GS, Ott SD, Lovell MR.

Although the immediate neurocognitive effects of sports-related concussion are well known, less is known about the intermediate or long-term effects of sports-related concussions. A sample of selected studies of high-school and collegiate athletes is reviewed and the intermediate effects of concussive injuries are discussed, because no long-term empiric data are available with these populations. The evidence for intermediate neurocognitive effects is mixed and not convincing at present in these groups of athletes. Selected studies of professional boxers and American professional football players are also reviewed, and the available data regarding long-term neurocognitive and neuropathologic effects are assessed. The evidence for long-term adverse neurocognitive effects in professional boxers is compelling. Suggestions for future research on relevant biopsychosocial variables affecting response to concussive injury are presented.

Clinical Journal of Sports Medicine, 2011: 30(1), 165-177.

Identifying neurocognitive deficits in adolescents following concussion.
Thomas DG, Collins MW, Saladino RA, Frank V, Raab J, Zuckerbraun NS.

OBJECTIVES: This study of concussed adolescents sought to determine if a computer-based neurocognitive assessment (Immediate Postconcussion Assessment and Cognitive Test [ImpACT]) performed on patients who present to the emergency department (ED) immediately following head injury would correlate with assessments performed 3 to 10 days postinjury and if ED neurocognitive testing would detect differences in concussion severity that clinical grading scales could not.

METHODS: A prospective cohort sample of patients 11 to 17 years of age presenting to the ED within 12 hours of a head injury were evaluated using two traditional concussion grading scales and neurocognitive testing. ED neurocognitive scores were compared to follow-up scores obtained at least 3 days postinjury. Postconcussive symptoms, outcomes, and complications were assessed via telephone follow-up for all subjects.

RESULTS: Sixty patients completed phone follow-up. Thirty-six patients (60%) completed follow-up testing a median of 6 days postinjury. Traditional concussion grading did not correlate with neurocognitive deficits detected in the ED or at follow-up. For the neurocognitive domains of verbal memory, processing speed, and reaction time, there was a significant correlation between ED and follow-up scores trending toward clinical improvement. By 2 weeks postinjury, 23 patients (41%) had not returned to normal activity. At 6 weeks, six patients (10%) still had not returned to normal activity.

CONCLUSIONS: Immediate assessment in the ED can predict neurocognitive deficits seen in follow-up and may be potentially useful to individualize management or test therapeutic interventions. Neurocognitive assessment in the ED detected deficits that clinical grading could not and correlated with deficits at follow-up.


Vestibular rehabilitation for dizziness and balance disorders after concussion.

BACKGROUND AND PURPOSE: Management of dizziness and balance dysfunction is a major challenge after concussion. The purpose of this study was to examine the effect of vestibular rehabilitation in reducing dizziness and to improve gait and balance function in people after concussion.

METHODS: A retrospective chart review of 114 patients (67 children aged 18 years and younger [mean, 16 years; range, 8-18 years]; 47 adults older than 18 years [mean, 41 years; range, 19-73 years]) referred for vestibular rehabilitation was performed. At the time of initial evaluation and discharge, recordings were made of outcome measures of self-report (eg, dizziness severity, Activities-specific Balance Confidence Scale, and Dizziness Handicap Inventory) and gait and balance performance (eg, Dynamic Gait Index, gait speed, and the Sensory Organization Test). A mixed-factor repeated-measures analysis of variance was used to test whether there was an effect of vestibular rehabilitation therapy and age on the outcome measures.

RESULTS: The median length of time between concussion and initial evaluation was 61 days. Of the 114 patients who were referred, 84 returned for at least 1 visit. In these patients, improvements were observed in all self-report, gait, and balance performance measures at the time of discharge (P < .05). Children improved by a greater amount in dizziness severity (P = .005) and conditions 1 (eyes open, fixed support) and 2 (eyes closed, fixed support) of the Sensory Organization Test (P < .025).

DISCUSSION: Vestibular rehabilitation may reduce dizziness and improve gait and balance function after concussion. For most measures, the improvement did not depend on age, indicating that vestibular rehabilitation may equally benefit both children and adults.

CONCLUSIONS: Vestibular rehabilitation should be considered in the management of individuals post concussion who have dizziness and gait and balance dysfunction that do not resolve with rest.
The relationship between psychological distress and baseline sports-related concussion testing.
Bailey CM, Samples HL, Broshek DK, Freeman JR, Barth JT.

OBJECTIVE: This study examined the effect of psychological distress on neurocognitive performance measured during baseline concussion testing.

DESIGN: Archival data were utilized to examine correlations between personality testing and computerized baseline concussion testing. Significantly correlated personality measures were entered into linear regression analyses, predicting baseline concussion testing performance. Suicidal ideation was examined categorically.

SETTING: Athletes underwent testing and screening at a university athletic training facility.

PARTICIPANTS: Participants included 47 collegiate football players 17 to 19 years old, the majority of whom were in their first year of college.

INTERVENTIONS: Participants were administered the Concussion Resolution Index (CRI), an internet-based neurocognitive test designed to monitor and manage both at-risk and concussed athletes. Participants took the Personality Assessment Inventory (PAI), a self-administered inventory designed to measure clinical syndromes, treatment considerations, and interpersonal style.

MAIN OUTCOME MEASURES: Scales and subscales from the PAI were utilized to determine the influence psychological distress had on the CRI indices: simple reaction time, complex reaction time, and processing speed.

RESULTS: Analyses revealed several significant correlations among aspects of somatic concern, depression, anxiety, substance abuse, and suicidal ideation and CRI performance, each with at least a moderate effect. When entered into a linear regression, the block of combined psychological symptoms accounted for a significant amount of baseline CRI performance, with moderate to large effects (r = 0.23-0.30). When examined categorically, participants with suicidal ideation showed significantly slower simple reaction time and complex reaction time, with a similar trend on processing speed.

CONCLUSIONS: Given the possibility of obscured concussion deficits after injury, implications for premature return to play, and the need to target psychological distress outright, these findings heighten the clinical importance of screening for psychological distress during baseline and post-injury concussion evaluations.


Epidemiology of postconcussion syndrome in pediatric mild traumatic brain injury.

Background: Much disagreement exists as to whether postconcussion syndrome (PCS) is attributable to brain injury or to other factors such as trauma alone, preexisting psychosocial problems, or medicolegal issues. We investigated the epidemiology and natural history of PCS symptoms in a large cohort of children with a mild traumatic brain injury (mTBI) and compared them with children with an extracranial injury (ECI).

METHODS: This investigation was a prospective, consecutive controlled cohort study of 670 children who presented to a tertiary referral emergency department with mTBI and 197 children who presented with ECI. For all participants, data were collected by use of a telephone interview of a parent 7 to 10 days after injury. If a change from preinjury symptoms was reported by a parent, follow-up continued monthly until symptom resolution. Outcomes were measured by using the Post Concussion Symptom Inventory, Rivermead Postconcussion Symptom Questionnaire, Brief Symptom Inventory, and Family Assessment Device.

RESULTS: There was a significant difference between the mTBI and ECI groups in their survival curves for time to symptom resolution (log rank [Mantel-Cox] 11.15, P < .001). Three months after injury, 11% of the children in the mTBI group were symptomatic (13.7% of children older than 6 years) compared with 0.5% of the children in the ECI group. The prevalence of persistent symptoms at 1 year was 2.3% in the mTBI group and 0.01% in the ECI group. Family functioning and maternal adjustment did not differ between groups.

CONCLUSIONS: Among school-aged children with mTBI, 13.7% were symptomatic 3 months after injury. This finding could not be explained by trauma, family dysfunction, or maternal psychological adjustment. The results of this study provide clear support for the validity of the diagnosis of PCS in children.


Twelve years of national football league concussion data.

Casson IR, Viano DC, Powell JW, Pellman EJ.

Background: Concussion in the National Football League (NFL) remains an important issue. An initial description of the injury epidemiology involved 6 years from 1996 to 2001.

Hypothesis: The increased attention to concussions may have resulted in team physicians being more conservative in treating players in recent years.

Study Design: Two consecutive 6-year periods (1996-2001 and 2002-2007) were compared to determine changes in the circumstances associated with the injury, the patterns of signs and symptoms, and the players’ time loss from participation in the NFL.

Methods: During 2002-2007, concussions were recorded by NFL team physicians and athletic trainers using the same standardized reporting form used from 1996 to 2001. Player position, type of play, concussion signs and symptoms, loss of consciousness, and medical action taken were recorded.

Results: There were 0.38 documented concussions per NFL game in 2002-2007—7.6% lower than the 0.42 in the earlier period (1996-2001). The injury rate was lower in quarterbacks and wide receivers but significantly higher in tight ends during the second 6 years. The most frequent symptoms were headaches and dizziness; the most common signs were problems with information processing and immediate recall. During 2002-2007, a significantly lower fraction of concussed players returned to the same game, and more were removed from play. Most concussed players (83.5%) returned to play in < 7 days; the percentage decreased to 57.4% with loss of consciousness. The number of players returning in < 7 days was 8% lower during 2002-2007 and 25% lower for those with loss of consciousness.

Conclusion: The most recent 6 years of NFL concussion data show a remarkable similarity to the earlier period. However, there was a significant decrease in the percentage of players returning to the same game, and players were held out of play longer.
Clinical Relevance: There was a more conservative management of concussion in NFL players from 2002 to 2007 even though the clinical signs and symptoms remained similar to the earlier 6-year period.

**Sports Health: A Multidisciplinary Approach, 2010: 2(6), 471-483.**

### The cognitive effects and decrements following concussion.

Covassin T, Elbin RJ.

**Abstract:** Sports-related concussion is an injury that continues to receive attention from both the popular media and sports medicine community. The many different symptom presentations and cognitive decrements that follow concussions, have made this injury difficult to detect and manage. Furthermore, concussed athletes should not always be entrusted to appropriately self-report their concussion symptoms; therefore the burden falls on the clinician and coach. Recent management recommendations call for using a multi-faceted approach to managing concussion, which consists of neurocognitive testing before (ie, baseline/preseason) and after injury. In addition, age, sex, and previous history of concussion have been found to influence the risk and recovery from this injury.


### Tracking neurocognitive performance following concussion in high school athletes.

Covassin T, Elbin RJ, Nakayama Y.

**OBJECTIVE:** To extend previous research designs and examine cognitive performance up to 30 days postconcussion.

**METHOD:** A prospective cohort design was used to examine 2000 athletes from 8 mid-Michigan area high schools to compare baseline neurocognitive performance with postconcussive neurocognitive performance. All concussed athletes were readministered the Immediate Post Assessment and Cognitive Test (ImpACT) at 2, 7, 14, 21, and 30 days postconcussion.

**RESULTS:** A total of 72 high school athletes (aged 15.8 ± 1.34 years) sustained a concussion. A significant within-subjects effect for reaction time (F = 10.01; P = 0.000), verbal memory (F = 3.05; P = 0.012), motor processing speed (F = 18.51; P = 0.000), and total symptoms following an injury (F = 16.45; P = 0.000) was found. Concussed athletes demonstrated a significant decrease in reaction time up to 14 days post concussion (P = 0.001) compared with baseline reaction time. Reaction time returned to baseline levels at 21 days postinjury (P = 0.25). At 7 days postinjury, impairments in verbal memory (P = 0.003) and motor processing speed (P = 0.000) were documented and returned to baseline levels by 14 days postinjury. Concussed athletes self-reported significantly more symptoms at 2 days post concussion (P = 0.000) and exhibited a resolution of symptoms by 7 days postinjury (P = 0.08).

**CONCLUSION:** High school athletes could take up to 21 days to return to baseline levels for reaction time. These data support current recommendations for the conservative management of concussion in the high school athlete.

*Physician and Sportsmedicine, 2010: 38(4), 87-93.*

### The relationship between personality characteristics and postconcussion symptoms in a nonclinical sample.

Garden N, Sullivan KA, Lange RT.

Postconcussive symptoms are relatively common in the acute recovery period following mild traumatic brain injury. However, for a small subset of patients, self-reported postconcussive symptoms continue long after injury. Many factors have been proposed to account for the presence of persistent postconcussive symptoms. The influence of personality traits has been proposed as one explanation. The purpose of this study was to examine the relation between postconcussion-like symptom reporting and personality traits in a sample of 96 healthy participants. Participants completed the British Columbia Postconcussive Symptom Inventory and the Millon Clinical Multiaxial Inventory III (MCMI-III). There was a strong positive relation between the majority of MCMI-III scales and postconcussion-like symptom reporting. Approximately half of the sample met the International Classification of Diseases-10 Criterion C symptoms for Postconcussional Syndrome. Compared with those participants who did not meet this criterion, the PCS group had significant elevations on the negativistic, depression, major depression, dysthymia, anxiety, dependent, sadistic, somatic, and borderline scales of the MCMI-III. These findings support the hypothesis that personality traits can play a contributing role in self-reported postconcussive symptoms.


### Brain functions after sports-related concussion: insights from event-related potentials and functional MRI.

Gosselin N, Saluja RS, Chen JK, Bottari C, Johnston K, Ptito A.

The high incidence of concussions in contact sports and their impact on brain functions are a major cause for concern. To improve our understanding of brain functioning after sports-related concussion, advanced functional assessment techniques, namely event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI), have been recently used in research studies. Contrary to neuropsychological tests that measure verbal and/or motor responses, ERPs and fMRI assess the neural activities associated with cognitive/behavioral demands, and thus provide access to better comprehension of brain functioning. In fact, ERPs have excellent temporal resolution, and fMRI identifies the involved structures during a task. This article describes ERP and fMRI techniques and reviews the results obtained with these tools in sports-related concussion. Although these techniques are not yet readily available, they offer a unique clinical approach, particularly for complex cases (ie, athletes with multiple concussions, chronic symptoms) and objective measures that provide valuable information to guide management and return-to-play decision making.


### Influence of poor effort on self-reported symptoms and neurocognitive test performance following mild traumatic brain injury.

Lange RT, Iverson GL, Brooks BL, Rennison VL.

When considering a diagnosis of postconcussional syndrome, clinicians must systematically evaluate and eliminate the possible contribution of many differential diagnoses, comorbidities, and factors that may cause or maintain self-reported symptoms long after mild traumatic brain injury (MTBI). One potentially significant contributing factor is symptom exaggeration. The purpose of the study is to examine the influence of poor effort on self-reported symptoms (postconcussion symptoms and cognitive complaints) and neurocognitive test performance following MTBI. The MTBI sample consisted of 63 referrals to a concussion clinic, evaluated within 5 months post injury (M = 2.0, SD = 1.0, range = 0.6-4.0), who were receiving financial

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compensation from the Workers' Compensation Board. Participants completed the Post-Concussion Scale (PCS), British Columbia Cognitive Complaints Inventory (BC-CCI), selected tests from the Neuropsychological Assessment Battery Screening Module (S-NAB), and the Test of Memory Malingering (TOMM). Participants were divided into two groups based on TOMM performance (15 fail, 48 pass). There were significant main effects and large effect sizes for the PCS (p < .002, d = 0.79) and BC-CCI (p < .011, d = 0.98) total scores. Patients in the TOMM fail group scored higher than those in the TOMM pass group on both measures. Similarly, there were significant main effects and/or large effect sizes on the S-NAB. Patients in the TOMM fail group performed more poorly on the Attention (p < .004, d = 1.26), Memory (p < .006, d = 1.16), and Executive Functioning (p < .05, d = 0.70) indexes. These results highlight the importance of considering the influence of poor effort, in conjunction with a growing list of factors that can influence, maintain, and/or mimic the persistent postconcussion syndrome.


Post-concussion symptom reporting and the "good-old-days" bias following mild traumatic brain injury.

Lange RT, Iverson GL, Rose A.

The purpose of this study was to examine the influence of the "good-old-days" bias on symptom reporting following mild traumatic brain injury (MTBI). The MTBI sample consisted of 86 patients (51.2% men) referred to a hospital-based concussion clinic in Vancouver, Canada. The majority of patients (83.7%) were evaluated within 3 months following their injury (M = 1.8 months, SD = 1.7, range = 0.2-8.0 months). Patients provided retrospective preinjury symptom ratings on the British Columbia Post-Concussion Symptom Inventory (BC-PSI). Ratings were compared with 177 healthy controls recruited from the community and a local university. MTBI retrospective ratings were significantly lower than the control group on the BC-PSI total score (p < .01, d = 0.27, small effect size) and 6 of the 13 individual items (all p < .05, d = 0.23-0.36, small to medium-small effect sizes). Patients who were currently in litigation reported more post-injury symptoms (p < .009, d = 0.63, medium-large effect size). However, litigation status was not associated with self-reported preinjury retrospective symptom ratings. Consistent with the "good-old-days" bias, patients with MTBI appear to misperceive their preinjury functioning as better than the average person.


Adolescent concussions.

Lee MA, Fine B.

BACKGROUND: The amount of literature dealing with the diagnosis and treatment of adolescent concussions is considerable. Most articles focus on the athlete. This study examines both sports-related and nonsports-related concussions in adolescents, their etiology, mechanisms of injury (categorized by sport), symptoms exhibited, physical findings, computerized tomography scan results and the problem of prolonged recovery (persistent postconcussion syndrome used in this article to mean symptoms lasting over four weeks.) OBJECTIVE: The purpose of this study is to present the data, their significance and a new method of management that has successfully allowed the author's concussed patients to recover more rapidly. METHOD: A retrospective review of 863 adolescent concussions, in 11-year-old to 19-year-old patients, from July 2004 through December 31, 2008. Subjects were seen as a result of referrals largely from the author's practice (Pediatric Healthcare Associates), other physicians, athletic trainers or patients previously treated. All concussions, including nonsports-related concussions, were included in the study. Some patients had multiple concussions; 774 individuals accounted for the 863 concussions. The number of patients by age and the number of concussions they sustained are listed below.


Visual tracking synchronization as a metric for concussion screening.

Maruta J, Suh M, Niogi SN, Mukherjee P, Ghajar J.

Our goal was to determine whether performance variability during predictive visual tracking can provide a screening measure for mild traumatic brain injury (mTBI). Seventeen subjects with chronic postconcussive syndrome and 9 healthy control subjects were included in this study. Eye movements were recorded with video-oculography as the subject visually tracked a target that moved through a circular trajectory. We compared the variability of gaze positional errors relative to the target with the microstructural integrity of white matter tracts as measured by the fractional anisotropy (FA) parameter of diffusion tensor imaging. Gaze error variability was significantly correlated with the mean FA values of the right anterior corona radiata (ACR) and the left superior cerebellar peduncle tracts that support spatial processing and sustenance of attention, and the genu of the corpus callosum. Because the ACR and the genu are among the most frequently damaged white matter tracts in mTBI, the correlations imply that gaze error variability during visual tracking may provide a useful screening tool for mTBI. Gaze error variability was also significantly correlated with attention and working memory measures in neurocognitive testing; thus, measurement of visual tracking performance is promising as a fast and practical screening tool for mTBI.


Acute effects and recovery after sport-related concussion: a neurocognitive and quantitative brain electrical activity study.

McCrea M, Prichep L, Powell M, Chabot R, Barr WB, Bazarian JJ.

OBJECTIVE: To investigate the clinical utility and sensitivity of a portable, automatic, frontal quantitative electroencephalographic (QEEG) acquisition device currently in development in detecting abnormal brain electrical activity after sport-related concussion.

DESIGN: This was a prospective, non-randomized study of 396 high school and college football players, including cohorts of 28 athletes with concussion and 28 matched controls. All subjects underwent preseason baseline testing on measures of postconcussive symptoms, postural stability, and cognitive functioning, as well as QEEG. Clinical testing and QEEG were repeated on day of injury and days 8 and 45 postinjury for the concussion and control groups.

MAIN OUTCOMES AND RESULTS: The injured group reported more significant postconcussive symptoms during the first 3 days postinjury, which resolved by days 5 and 8. Injured subjects also performed poorer than controls on neurocognitive testing on the day of injury, but no differences were evident on day 8 or day 45. QEEG studies revealed significant abnormalities in electrical brain activity in the injured group on day of injury and day 8 postinjury, but not on day 45.

CONCLUSIONS: Results from the current study on clinical recovery after sport-related concussion are consistent with early reports indicating a typical course of full recovery in symptoms and cognitive dysfunction within the first week of injury. QEEG results, however, suggest that the duration of physiological recovery after concussion may extend longer than observed clinical recovery. Further study is required to replicate and extend these findings in a larger clinical sample, and further demonstrate the utility of QEEG as a marker of recovery after sport-related concussion.

Supporting the student-athlete’s return to the classroom after a sport-related concussion.

McGrath N.

OBJECTIVE: This article provides a framework for school athletic trainers to use in advising colleagues about the health and academic needs of student-athletes presenting with concussions. BACKGROUND: Management of sport-related concussions has been an area of growing concern for school athletic programs. Recent work in this area has highlighted significant risks for student-athletes presenting with these mild traumatic brain injuries. DESCRIPTION: Topics covered include general teaching points for the athletic trainer to use with school colleagues. An integrated model for school management of sport concussion injuries is presented that includes involvement of the student’s athletic trainer, school nurse, guidance counselor, teachers, social worker, psychologist, physicians, and parents. CLINICAL ADVANTAGES: Academic accommodations for specific postconcussion symptoms are proposed that may help the student-athlete strike an optimum balance between rest and continued academic progress during recovery.


High school concussions in the 2008-2009 academic year.

Meehan WP, d’Hemecourt P, Comstock RD.

BACKGROUND: An estimated 136 000 concussions occur per academic year in high schools alone. The effects of repetitive concussions and the potential for catastrophic injury have made concussion an injury of significant concern for young athletes.

PURPOSE: The objective of this study was to describe the mechanism of injury, symptoms, and management of sport-related concussions using the High School Reporting Information Online (HS RIO) surveillance system.

STUDY DESIGN: Descriptive epidemiology study.

METHODS: All concussions recorded by HS RIO during the 2008-2009 academic year were included. Analyses were performed using SPSS software. Chi-square analysis was performed for all categorical variables. Statistical significance was considered for P < .05.

RESULTS: A total of 544 concussions were recorded. The most common mechanism (76.2%) was contact with another player, usually a head-to-head collision (52.7%). Headache was experienced in 93.4%; 4.6% lost consciousness. Most (83.4%) had resolution of their symptoms within 1 week. Symptoms lasted longer than 1 month in 1.5%. Computerized neuropsychological testing was used in 25.7% of concussions. When neuropsychological testing was used, athletes were less likely to return to play within 1 week than those for whom it was not used (13.6% vs 32.9%; P < .01). Athletes who had neuropsychological testing appeared less likely to return to play on the same day (0.8% vs 4.2%; P = .056). A greater proportion of injured, nonfootball athletes had computerized neuropsychological testing than injured football players (23% vs 32%; P = .02).

CONCLUSION: When computerized neuropsychological testing is used, high school athletes are less likely to be returned to play within 1 week of their injury. Concussed football players are less likely to have computerized neuropsychological testing than those participating in other sports. Loss of consciousness is relatively uncommon among high school athletes who sustain a sport-related concussion. The most common mechanism is contact with another player. Some athletes (1.5%) report symptoms lasting longer than 1 month.


Postconcussive symptoms are associated with compensatory cortical recruitment during a working memory task.


BACKGROUND: The severity of sports-related concussion is often characterized by the number and severity of postconcussive symptoms (eg, headache, dizziness, difficulty concentrating). Although the level of postconcussive symptoms after injury is believed to index the severity of the neurological insult sustained, studies examining the relationship between symptom severity and neural functioning in concussed athletes remain rare.

OBJECTIVE: This exploratory study examined the association between self-reported symptom severity and functional activation on a working memory task in a group of 16 recently concussed student athletes.

METHODS: Functional magnetic resonance imaging was used to examine the relationship of symptom severity to brain activation during a working memory task in 16 concussed subjects.

RESULTS: Findings indicated that symptom severity was associated with regionally specific hyperactivation during a working memory task, even though symptom severity was not significantly related to task accuracy.

CONCLUSION: The results add to a growing body of literature that demonstrates that functional neuroimaging may have the potential to serve as a sensitive biomarker of the severity of concussion and mild traumatic brain injury.

Neurosurgery, 2010; 67(4), 1020-1027.

Relationship between subjective test feedback provided by high-school athletes during computer-based assessment of baseline cognitive functioning and self-reported symptoms.

Schatz P, Neidzwski K, Moser RS, Karpf R.

Subjective feedback about distractions or problems encountered during computerized assessment was provided by 538 out of a pool of 1659 high-school athletes who completed baseline testing using ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing). Three types of feedback were included: (a) environmental, (b) computer-based (mechanical), and (c) instruction-based (associated with difficulty understanding test instructions). One-way analyses of variance were conducted and revealed relationships between greater symptom reporting and any type of feedback, environmental feedback, and instruction-based feedback. Increased symptom reporting was noted for female students. Additional relationships were noted between providing computer-based feedback and faster reaction time; and between history of concussion and providing instruction-based feedback. Athletes endorsing more symptoms at baseline scored significantly worse on ImPACT, as reflected in decreased visual performance. Results suggest that feedback provided during computerized assessment may yield information about symptom reporting and test-taking style, which may also be of particular interpretive utility when athletes minimize their symptoms.

Abstracts

Apolipoprotein E genotype and concussion in college athletes.

OBJECTIVE: To evaluate the association between apolipoprotein E (APOE) polymorphisms (E2, C/T Arg158Cys; E4, T/C Cys112Arg; and promoter, g-219) and the history of concussion in college athletes. We hypothesized that carrying 1 or more APOE rare (or minor) allele assessed in this study would be associated with having a history of 1 or more concussions.

DESIGN: Multicenter cross-sectional study.

SETTING: University athletic facilities.

PARTICIPANTS: One hundred ninety-six male football (n = 163) and female soccer (n = 33) college athletes volunteered.

INTERVENTIONS: Written concussion history questionnaire and saliva samples for genotyping.

MAIN OUTCOME MEASURES: Self-reported history of a documented concussion and rare APOE genotype (E2, E4, promoter).

RESULTS: There was a significant association (Wald χ² = 3.82; P = 0.05; odds ratio = 9.8) between carrying all APOE rare alleles and the history of a previous concussion. There was also a significant association (Wald χ² = 3.96, P = 0.04, odds ratio = 8.4) between carrying the APOE promoter minor allele and experiencing 2 or more concussions.

CONCLUSIONS: Carriers of all 3 APOE rare (or minor) alleles assessed in this study were nearly 10 times more likely to report a previous concussion and may be at a greater risk of concussion versus noncarriers. Promoter minor allele carriers were 8.4 times more likely to report multiple concussions and may be at a greater risk of multiple concussions versus noncarriers. Research involving larger samples of individuals with multiple concussions and carriers of multiple APOE rare alleles is warranted.


Brain function decline in healthy retired athletes who sustained their last sports concussion in early adulthood.

Recent studies have shown that the detrimental effects of sports concussions on cognitive and motor function may persist up to a few years post-injury. The present study sought to investigate the effects of having sustained a sports concussion more than 30 years prior to testing on cognitive and motor functions. Nineteen healthy former athletes, in late adulthood (mean age = 60.79; SD = 5.16), who sustained their last sport-related concussion in early adulthood (mean age = 26.05; SD = 9.21) were compared with 21 healthy former athletes with no history of concussion (mean age = 58.89; SD = 9.07). Their neuropsychological tests sensitive to age-related changes in cognition were administered. An auditory oddball paradigm was used to evoke P3a and P3b brain responses. Four TMS paradigms were employed to assess motor cortex excitability: (i) resting motor threshold; (ii) paired-pulse intracortical inhibition and intracortical facilitation; (iii) input/output curve and (iv) cortical silent period (CSP). A rapid alternating movement task was also used to characterize motor system dysfunctions. Relative to controls, former athletes with a history of concussion had: (i) lower performance on neuropsychological tests of episodic memory and response inhibition; (ii) significantly delayed and attenuated P3a/P3b components; (iii) significantly prolonged CSP and (iv) significantly reduced movement velocity (bradykinesia). The finding that the P3, the CSP as well as neuropsychological and motor indices were altered more than three decades post-concussion provides evidence for the chronicity of cognitive and motor system changes consequent to sports concussion.


Impact of divided attention during verbal learning in young adults following mild traumatic brain injury.
Blanchet S, Paradis-Giroux AA, Pépin M, McKerral M.

PRIMARY OBJECTIVE: The goal of the present study was to assess the impact of mild traumatic brain injury (MTBI) on episodic memory performance in relation to attentional and executive control processes in young adults.

RESEARCH DESIGN/METHODS: A verbal memory paradigm manipulating attentional load (full attention or divided attention) and semantic congruency between pairs of category-target words during encoding was administrated to 13 individuals with MTBI and 12 normal control participants. Environmental supports during retrieval (free recall, cued recall and recognition modes) were also manipulated.

MAIN OUTCOMES AND RESULTS: Results show that recall performances of individuals with MTBI were similar to those of controls when words were encoded under full attention. In contrast, individuals with MTBI performed worse than control participants when encoding under divided attention, whatever the semantic link between pairs of words.

CONCLUSIONS: By using a sensitive test, one was able to objectively measure subtle impairments in memory performance, suggesting a diminished availability of attentional resources after MTBI. Young adults’ learning of verbal material under divided attention might be compromised by the reduction of cognitive resources following MTBI. These findings are also discussed in light of different factors that can influence cognitive performance.


The persistent effects of concussion on neuroelectric indices of attention.
Broglio SP, Pontifex MB, O’Connor P, Hillman CH.

Mild traumatic brain injuries (mTBIs) that result from participation in sports are a major public health issue affecting 1.6-3.8 million individuals annually. The injury has been postulated as transient and void of long-term consequences when rapidly diagnosed and properly managed. Emerging evidence, however, has suggested an increased risk for late life cognitive dysfunction in those with previous injuries. The purpose of this investigation was to evaluate young adults with and without a history of concussion using a standard clinical assessment and highly sensitive electrophysiological measures for persistent changes in cognitive functioning. Ninety participants (19.7±1.3 years; 44 without mTBI and 46 with previous mTBI) were evaluated using the ImPACT and event-related brain potentials (ERPs) that were recorded during a three-stimulus oddball task. Those with a history of concussion reported an average of 3.4 years post-injury. No significant differences were found between groups on the ImPACT. Significant decrements in the N2 and P3b amplitudes of the stimulus-locked ERP were noted for those with a history relative to those without a history of concussion. Although the previously concussed participants performed equal to those without injury on the clinical cognitive assessment, these findings support the notion that sport mTBI can no longer be thought of as a transient injury resulting in short-lived neurological impairment. It is not clear if these persistent deficits will manifest into clinical pathologies later in life.
History of multiple self-reported concussions is not associated with reduced cognitive abilities.

Bruce JM, Echemendia RJ.

OBJECTIVE: The long-term impact of sports-related concussion is uncertain. Several studies using traditional neuropsychological measures have found a relationship between a previous history of concussion and reduced cognitive abilities. In contrast, studies using computerized neuropsychological measures have typically found no relationship between concussion history and cognition. In the present study, we examined the association between a self-reported concussion history and cognition using traditional and computer-based neuropsychological tests.

METHODS: A computerized neuropsychological battery was administered to a sample of 858 collegiate male athletes. Of this sample, 298 athletes reported a history of concussion. A traditional neuropsychological battery was administered to a separate sample of 479 male collegiate athletes, 187 of whom reported a history of concussion. Finally, both a computerized and a traditional neuropsychological battery were administered to a third distinct sample of 175 male collegiate athletes, 57 of whom reported a history of concussion. Concussion history was assessed via self-report. None of the athletes had been concussed in the 6 months before testing.

RESULTS: No significant association was found between self-reported concussion history and performance on either computerized or traditional neuropsychological tests.

CONCLUSION: Findings suggest that athletes who report a distant history of concussion have minimal enduring neurocognitive deficits. Given conflicting findings in the literature, prospective studies that attempt to identify moderating factors are necessary to help determine who is at risk for long-term cognitive difficulties after concussion.


Concussion in the National Football League: an overview for neurologists.

Casson IR, Pellman EJ, Viano DC.

The authors' studies have yielded a great deal of data regarding the biomechanics of head injury and the clinical picture of mild traumatic brain injury (MTBI) in the National Football League (NFL). The research has demonstrated the link between the effects of biomechanical forces on the brain and the clinical symptomatology of the concussed players. New insights into the mechanisms of injury are leading to new ways of protecting football players from the effects of MTBI. The clinical data validate the effectiveness of the current NFL physician approach to the evaluation and treatment of the player who sustains MTBI. There are still many more questions to answer and much more knowledge to be gained from continuing research in this area.


The role of concussion history and gender in recovery from soccer-related concussion.

Colvin AC, Mullen J, Lovell MR, West RV, Collins MW, Groh M.

BACKGROUND: This study was designed to investigate differences in recovery in male and female soccer athletes.

HYPOTHESES: Soccer players with a history of concussion will perform worse on neurocognitive testing than players without a history of concussion. Furthermore, female athletes will demonstrate poorer performance on neurocognitive testing than male athletes.

STUDY DESIGN: Cohort study (prognosis); Level of evidence, 2.

METHODS: Computer-based neuropsychological testing using reaction time, memory, and visual motor-speed composite scores of the ImPACT test battery was performed postconcussion in soccer players ranging in age from 8 to 24 years (N = 234; 141 females, 93 males). A multivariate analysis of variance was conducted to examine group differences in neurocognitive performance between male and female athletes with and without a history of concussion.

RESULTS: Soccer players with a history of at least 1 previous concussion performed significantly worse on ImPACT than those who had not sustained a prior concussion (F = 2.92, P =.03). In addition, female soccer players performed worse on neurocognitive testing (F = 2.72, P = .05) and also reported more symptoms (F = 20.1, P = .00001) than male soccer players. There was no significant difference in body mass index between male and female players (F =.04, P =.85).

CONCLUSION: A history of concussion and gender may account for significant differences in postconcussive neurocognitive test scores in soccer players and may play a role in determining recovery. These differences do not appear to reflect differences in mass between genders and may be related to other gender-specific factors that deserve further study.


Current sport-related concussion teaching and clinical practices of sports medicine professionals.

Covassin T, Elbin R, Stiller-Ostrowski JL.

CONTEXT: Various consensus and position statements recommend a multifaceted approach when diagnosing a possible concussion. The effectiveness of these materials depends largely on their content being disseminated to educators and to those in the clinical setting.

OBJECTIVE: To identify the concussion management methods and guidelines currently taught in the athletic training classroom and clinical settings and to track the dissemination of the Vienna guidelines throughout the educational curriculum.

DESIGN: A 17-question Internet survey.

SETTING: A Web link was e-mailed to the program directors and certified athletic trainers holding educational positions in athletic training at 300 accredited programs in the United States.

PATIENTS OR OTHER PARTICIPANTS: 513 program directors and athletic trainers.

MAIN OUTCOME MEASURE(S): Survey questions addressed education level, years of certification, employment setting, concussion assessment and return-to-play guidelines used in the clinical setting and the classroom, and clinical and teaching preferences for existing position statements and concussion grading systems. The Vienna guidelines "simple" and "complex" definitions of concussions were provided with the return-to-play stepwise approach.
RESULTS: The National Athletic Trainers’ Association position statement was the most widely used method of assessing, managing (61%), and making return-to-play decisions (47%) among participants. More than half of participants (66%) had never heard of the Vienna guidelines. After reading the Vienna guidelines’ definitions and return-to-play criteria, nearly three-fourths of participants agreed with them. In addition, 68% said that they would use them, and 84% reported that they would teach them to students.

CONCLUSIONS: The majority of program directors and certified athletic trainers used a multidimensional approach to assess and manage a concussion. The National Athletic Trainers’ Association position statement and Vienna guidelines were underused in both the classroom and clinical settings.


Contributions of neuroimaging, balance testing, electrophysiology and blood markers to the assessment of sport-related concussion.

Davis GA, Iversen GL, Guskiewicz KM, Pito A, Johnston KM.

OBJECTIVE: To review the diagnostic tests and investigations used in the management of sports concussion, in the adult and paediatric populations, to (a) monitor the severity of symptoms and deficits, (b) track recovery and (c) advance knowledge relating to the natural history and neurobiology of the injury.

DESIGN: Qualitative literature review of the neuroimaging, balance testing, electrophysiology, blood marker and concussion literature.

INTERVENTION: PubMed and Medline databases were reviewed for investigations used in the management of adult and paediatric concussion, including structural imaging (computerised tomography, magnetic resonance imaging, diffusion tensor imaging), functional imaging (single photon emission computerised tomography, positron emission tomography, functional magnetic resonance imaging), spectroscopy (magnetic resonance spectroscopy, near infrared spectroscopy), balance testing (Balance Error Scoring System, Sensory Organization Test, gait testing, virtual reality), electrophysiological tests (electroencephalography, evoked potentials, event related potentials, magnetoencephalography, heart rate variability), genetics (apolipoprotein E4, channelopathies) and blood markers ($100, neuron-specific enolase, cleaved Tau protein, glutamate).

RESULTS: For the adult and paediatric populations, each test has been classified as being: (1) clinically useful, (2) a research tool only or (3) not useful in sports-related concussion.

CONCLUSIONS: The current status of the diagnostic tests and investigations is analysed, and potential directions for future research are provided. Currently, all tests and investigations, with the exception of clinical balance testing, remain experimental. There is accumulating research, however, that shows promise for the future clinical application of functional magnetic resonance imaging in sport concussion assessment and management.

British Journal of Sports Medicine, 2009: 43(i), i36-i45.

Recurrent concussion and risk of depression in retired professional football players.


PURPOSE: The purpose of our study was to investigate the association between prior head injury and the likelihood of being diagnosed with clinical depression among retired professional football players with prior head injury exposure.

METHODS: A general health questionnaire, including information about prior injuries, the SF-36 (Short Form 36), and other markers for depression, was completed by 2552 retired professional football players with an average age of 53.8 (+/-13.4) yr and an average professional football-playing career of 6.6 (+/-3.6) yr. A second questionnaire focusing on mild cognitive impairment (MCI)-related issues was completed by a subset of 758 retired professional football players (50 yr and older).

RESULTS: Two hundred sixty-nine (11.1%) of all respondents reported having prior or current diagnosis of clinical depression. There was an association between recurrent concussion and diagnosis of lifetime depression (ch2=71.21, df=2, P=0.005), suggesting that the prevalence increases with increasing concussion history. Compared with retired players with no history of concussion, retired players reporting three or more previous concussions (24.4%) were three times more likely to be diagnosed with depression; those with a history of one or two previous concussions (36.3%) were 1.5 times more likely to be diagnosed with depression. The analyses controlled for age, number of years since retirement, number of years played, physical component score on the SF-36, and diagnosed comorbidities such as osteoarthritis, coronary heart disease, stroke, cancer, and diabetes.

CONCLUSION: Our findings suggest a possible link between recurrent sport-related concussion and increased risk of clinical depression. The findings emphasize the importance of understanding potential neurological consequences of recurrent concussion.


Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability.

Heitger MH, Jones RD, Macleod AD, Snell DL, Frampton CM, Anderson TJ.

Post-concussion syndrome (PCS) can affect up to 20%-30% of patients with mild closed head injury (mChI), comprising incomplete recovery and debilitating persistence of post-concussional symptoms. Eye movements relate closely to the functional integrity of the injured brain and eye movement function is impaired post-acutely in mCHI. Here, we examined whether PCS patients continue to show disparities in eye movement function at 3-5 months following mCHI compared with patients with good recovery. We hypothesized that eye movements might provide sensitive and objective functional markers of ongoing cerebral impairment in PCS. We compared 36 PCS patients (adapted World Health Organization guidelines) and 36 individually matched controls (i.e. mCHI patients of similar injury severity but good recovery) on reflexive, anti- and self-paced saccades, memory-guided sequences and smooth pursuit. All completed neuropsychological testing and health status questionnaires. Mean time post-injury was 140 days in the PCS group and 163 days in the control group. The PCS group performed worse on anti-saccades, self-paced saccades, memory-guided sequences and smooth pursuit, suggesting problems in response inhibition, short-term spatial memory, motor-sequence programming, visuospatial processing and visual attention. This poorer oculomotor performance included several measures beyond conscious control, indicating that subcortical functionality in the PCS group was poorer than expected after mCHI. The PCS group had poorer neuropsychological function (memory, complex attention and executive function). Analysis of covariance showed oculomotor differences to be practically unaffected by group disparities in depression and estimated intellectual ability. Compared with neuropsychological tests, eye movements were more likely to be markedly impaired in PCS cases with high symptom load. Poorer eye movement function, and particularly poorer subcortical oculomotor function, correlated more with post-concussive symptom load and problems on activities of daily living whilst poorer neuropsychological function exhibited slightly better correlations with measures of mental health. Our findings that eye movement function in PCS does not follow the normal recovery path of eye movements after mCHI are indicative of ongoing cerebral impairment. Whilst oculomotor and neuropsychological tests partially overlapped in identifying impairment, eye movements showed additional dysfunction in motor/visuospatial areas, response inhibition, visual attention and subcortical function. Poorer subconscious oculomotor function in the PCS group supports the notion that PCS is not merely a psychological entity, but also has a biological substrate. Measurement of oculomotor function may be of value in PCS cases with a high symptom load but an otherwise unremarkable assessment profile. Routine oculomotor testing should be feasible in centres with existing access to this technology.
Incidence, risk, and protective factors of mild traumatic brain injury in a cohort of Australian nonprofessional male rugby players.

Hollis SJ, Stevenson MR, McIntosh AS, Shores EA, Collins MW, Taylor CB.

BACKGROUND: Mild traumatic brain injury (mTBI) is an emerging public health issue in high-contact sports. Understanding the incidence along with the risk and protective factors of mTBI in high-contact sports such as rugby is paramount if appropriate preventive strategies are to be developed.

PURPOSE: To estimate the incidence and identify the risk and protective factors of mTBI in Australian nonprofessional rugby players.

STUDY DESIGN: Cohort study; Level of evidence, 2.

METHODS: A cohort of 3207 male nonprofessional rugby players from Sydney, Australia, was recruited and followed over 1 or more playing seasons. Demographic information, history of recent concussion, and information on risk and protective factors were collected. The incidence of mTBI was estimated and the putative risk and protective factors were modeled in relation to mTBI.

RESULTS: The incidence of mTBI was 7.97 per 1000 player game hours, with 313 players (9.8%) sustaining 1 or more mTBIs during the study. Players who reported always wearing protective headgear during games were at a reduced risk (incident rate ratio [IRR], 0.57; 95% confidence interval [CI], 0.40-0.82) of sustaining an mTBI. In contrast, the likelihood of mTBI was almost 2 times higher among players who reported having sustained either 1 (IRR, 1.75; 95% CI, 1.11-2.76) or more mTBIs (IRR, 1.65; 95% CI, 1.11-2.45) within the 12 months before recruitment.

CONCLUSION: Nonprofessional rugby has a high incidence of mTBI, with the absence of headgear and a recent history of mTBI associated with an increased risk of subsequent mTBI. These findings highlight that both use of headgear and the management of prior concussion would likely be beneficial in reducing the likelihood of mTBI among nonprofessional rugby players, who compose more than 99% of rugby union players in Australia.


The management of sports-related concussion: current status and future trends.

Lovell MR.

This article provides a review of current trends in the management of sports-related concussion. An evidence-based approach to concussion management is presented with a specific focus on return-to-play issues. The use of neuropsychological testing and other diagnostic tools is presented and reviewed.


The neurophysiology and assessment of sports-related head injuries.

Lovell MR.

This article provides a review of contemporary standards for the management of athletes who have sustained a sports-related head injury. Recent research regarding concussion management is reviewed with specific reference to clinical care. The use of neuropsychologic testing in sports also is reviewed, and a systematic protocol for the management of sports-related concussion is presented.


Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance.


CONTEXT: Evidence suggests that athletes engaging in high-intensity activities after concussion have more difficulties with cognitive recovery.

OBJECTIVE: To examine the role postinjury activity level plays in postconcussive symptoms and performance on neurocognitive tests in a population of student-athletes.

DESIGN: Retrospective cohort study with repeated measures of neurocognitive performance and symptom reporting.

SETTING: University-based sports concussion clinic.

PATIENTS OR OTHER PARTICIPANTS: Ninety-five student-athletes (80 males, 15 females; age = 15.88 +/- 1.35 years) were retrospectively assigned to 1 of 5 groups based on a postinjury activity intensity scale.

MAIN OUTCOME MEASURE(S): We employed a regression analysis for repeated measures to evaluate the relationship of activity intensity to symptoms and neurocognitive outcome up to 33 days after concussion. Postconcussion symptom scores and neurocognitive (verbal memory, visual memory, visual motor speed, and reaction time) scores served as the primary outcome measures.

RESULTS: Level of exertion was significantly related to all outcome variables (P < .02 for all comparisons). With multivariate analysis, activity intensity remained significant with respect to visual memory (P = .003) and reaction time (P < .001).

CONCLUSIONS: Activity level after concussion affected symptoms and neurocognitive recovery. Athletes engaging in high levels of activity after concussion demonstrated worse neurocognitive performance. For these tasks, those engaging in moderate levels of activity demonstrated the best performance.

Health status, not head injury, predicts concussion symptoms after minor injury.

McLean SA, Kirsch NL, Tan-Schriner CU, Sen A, Frederiksen S, Harris RE, Maxiner W, Maio RF.

OBJECTIVE: Postconcussion (PC) syndrome etiology remains poorly understood. We sought to examine predictors of persistent PC symptoms after minor injury.

METHODS: Health status, symptom, and injury information were obtained on a sample of patients presenting to the emergency department after minor injury. Postconcussion and cognitive symptoms were assessed at 1, 3, and 12 months.

RESULTS: Among 507 patients enrolled, 339 had head injury. Repeated-measures logistic regression modeling of PC and cognitive symptom presence across time indicated that baseline mental health status and physical health status were most predictive of persistent symptoms. In contrast, head injury presence did not predict persistent PC syndrome.

DISCUSSION: Baseline mental health status and physical health status were associated with persistent PC syndrome after minor injury, but head injury status was not. Further studies of PC syndrome pathogenesis are needed.


Effects of a symptom-free waiting period on clinical outcome and risk of reinjury after sport-related concussion.


OBJECTIVE: This study is the first to investigate the influence of a symptom-free waiting period (SFWP) on clinical outcome and risk of repeat injury after sport-related concussion.

METHODS: This was a prospective, nonrandomized study of 16 624 player seasons from 1999 to 2004, including a cohort of 635 concussed high school and college athletes grouped on the basis of an SFWP or no SFWP observed after their concussion. Clinical outcome in symptoms, cognitive functioning, and postural stability 45 and 90 days postinjury was compared with preinjury baseline. Data on SFWP and same-season repeat concussion were recorded.

RESULTS: An SFWP was observed in 60.3% of cases. There were no significant differences between the SFWP and no SFWP groups in acute injury characteristics or clinical outcome with respect to symptom recovery or postinjury performance on formal neuropsychological and balance testing. Most repeat concussions (79.2%) occurred within 10 days of the initial injury. The rate of repeat concussion was actually higher in the SFWP group (6.4%) than the no SFWP group (0.90%) (P < 0.005), but the repeat concussion subgroup’s SFWP was 2.82 days shorter (95% confidence interval, 0.61-5.03; P < 0.01) and these athletes resumed participation 3.55 days sooner (95% confidence interval, 0.06-7.04; P < 0.05) than those in the SFWP group in which there was no repeat concussion.

CONCLUSION: Our findings suggest that an SFWP did not intrinsically influence clinical recovery or reduce risk of a repeat concussion. The overall risk of same-season repeat concussion seems to be relatively low, but there may be a period of vulnerability that increases risk of repeat concussion during the first 7 to 10 days postinjury. Further study is required to investigate this preliminary finding and help determine whether this risk can be reduced further with specific injury-management strategies.


Consensus statement on concussion in sport – the 3rd international conference on concussion in sport held in Zurich, November 2008.


This paper is a revision and update of the recommendations developed following the 1st (Vienna) and 2nd (Prague) International Symposia on Concussion in Sport. The Zurich Consensus statement is designed to build on the principles outlined in the original Vienna and Prague documents and to develop further conceptual understanding of this problem using a formal consensus-based approach. A detailed description of the consensus process is outlined at the end of this document under the "background" section (see Section 11). This document is developed for use by physicians, therapists, certified athletic trainers, health professionals, coaches and other people involved in the care of injured athletes, whether at the recreational, elite, or professional level. While agreement exists pertaining to principal messages conveyed within this document, the authors acknowledge that the science of concussion is evolving, and therefore management and return-to-play (RTP) decisions remain in the realm of clinical judgment on an individualized basis. Readers are encouraged to copy and distribute freely the Zurich Consensus document and/or the Sports Concussion Assessment Tool (SCAT2) card, and neither is subject to any copyright restriction. The authors request, however, that the document and/or the SCAT2 card be distributed in their full and complete format.


Neurocognitive evaluation of mild traumatic brain injury in the hospitalized pediatric population.

Nance ML, Polk-Williams A, Collins MW, Wiebe DJ.

OBJECTIVE: To test the feasibility of inpatient neurocognitive testing and measure the degree of disability in children hospitalized with mild traumatic brain injury (MTBI).

SUMMARY BACKGROUND DATA: MTBI is common in the pediatric population. A standardized approach to identify neurocognitive impairment and determine optimal time to return to exertional activities (eg, school, sports) is lacking.

METHODS: For a 2-year period, children (age: 11-17 years) hospitalized at a level 1 urban Pediatric Trauma Center with MTBI were prospectively enrolled. Neurocognitive performance was assessed utilizing previously validated computer-based tests (Immediate Postconcussion Assessment and Cognitive Testing) as inpatient and in follow-up clinic after discharge. The feasibility of inpatient testing and the degree neurocognitive impairment and symptomatology were assessed. This study was approved by the IRB and registered with clinicaltrials.gov (NCT00715949).

RESULTS: For the 2 years of study, 116 subjects were prospectively enrolled and tested. The population had a mean age of 14 years and 69.8% were male. On initial in-hospital testing, the overall population demonstrated considerable neurocognitive deficits (mean values for all 4 subtests below 25th percentile, norm 50%) with at least one subtest score below 25% in 95.7% and an abnormal symptom score in 83.4% of patients. In comparing initial testing to follow-up testing (N = 63), significant improvements were noted for all subtests (verbal memory: 28.0% vs. 37.5%, respectively, norm 50%, P = 0.02; visual memory: 24.9% vs. 38.1%, respectively, norm 50%, P < 0.01; visual motor: 21.8% vs. 31.1%, respectively, norm 50%, P = 0.01; reaction time: 21.8% vs. 30.3%, respectively, norm 50%, P = 0.05); with a decline in the symptom score (28.9% vs. 9.2, respectively, norm 0-8, P < 0.01) as well. Patients not seen in follow-up (N = 53) did not differ demographically from those seen in clinic.

CONCLUSIONS: Inpatient neurocognitive testing was feasible in pediatric MTBI patients. Neurocognitive abnormalities were nearly universally present on initial evaluation with significant improvements demonstrated at the time of outpatient follow-up. Return to activity recommendations are thus best deferred for most hospitalized MTBI children until formal assessment can be performed after discharge.

Neurocognitive function of emergency department patients with mild traumatic brain injury.

Peterson SE, Stull MJ, Collins MW, Wang HE.

STUDY OBJECTIVE: We characterize the neurocognitive function of patients presenting to the emergency department (ED) with mild traumatic brain injury.

METHODS: This prospective study took place at an urban, academic ED and Level I trauma center. Case patients consisted of a convenience sample of ED patients aged 18 to 59 years, presenting to the ED with mild traumatic brain injury and having a head computed tomography scan without traumatic abnormalities. Controls consisted of patients aged 18 to 59 years, presenting to the ED with an isolated, nondominant hand extremity injury. We excluded patients with multiple injuries and recent alcohol consumption. Subjects completed a computerized neurocognitive test battery (Immediate Post-concussion Assessment and Cognitive Testing). The primary measures were verbal memory, visual memory, and visual motor and reaction speed. We compared raw and age-normalized neurocognitive performance between case patients and controls by using nonparametric statistics.

RESULTS: We included a total of 23 head-injured case patients and 31 non-head-injured controls. Case patients and controls exhibited similar raw (median 80.1 versus 85.0 points; difference in medians -4.9; P = .26) and age-normalized (31.9 versus 57.4 percentile; difference in medians -25.5; P = .12) verbal memory. Case patients and controls exhibited similar raw (64.6 versus 63.5; difference 1.1; P = .79) and age-normalized (20.8 versus 25.8 percentile; difference -5.0; P = .44) visual memory. Compared with controls, mild traumatic brain injury case patients demonstrated slower raw (31.6 versus 37.0 points; difference -5.4; P = .002) and age-normalized (17.1 versus 57.6 percentile; difference -40.5; P = .001) visual motor speed. Mild traumatic brain injury case patients exhibited slower raw (median 0.66 versus 0.60 seconds; difference 0.06; P = .01) and age-normalized (29.3 versus 42.8 percentile; difference -13.5; P = .009) reaction times.

CONCLUSION: In conclusion, compared with the non-head-injured patients, ED mild traumatic brain injury patients demonstrated subtle but discernible neurocognitive deficits.


OBJECTIVE: The authors sought to define the relationship between gender and postconcussion symptoms (PCSx) at 3 months after sport-related mild traumatic brain injury (mTBI) and, further, to examine whether age (minors vs. adults), source of PCSx reporting (self-reported vs. proxy), previous head injury or loss of consciousness, or the sport type in which the mTBI was incurred explain any observed gender differences in PCSx.

DESIGN: Prospective nested cohort study.

SETTING: Regional trauma center emergency department.

PATIENTS: A total of 260 patients who presented with sport-related mTBI, as defined by American Congress of Rehabilitation Medicine criteria, began the study. The participants who lacked litigation concerning the mTBI and had participated in the follow-up assessment completed the study (n = 215).

ASSESSMENT OF RISK FACTORS: Self, proxy, and interviewer report of age, gender, previous head injury or loss of consciousness, and sport in which injury was sustained.

MAIN OUTCOME MEASUREMENTS: Rivermead Post Concussion Symptoms Questionnaire (RPQ).

RESULTS: Adult females are at greater risk for elevated RPO scores (odds ratio [OR] = 2.89, 95% confidence interval [95% CI] = 1.25-6.71; P = .013) but not female minors (OR = 0.87, 95% CI = 0.45-1.71; P = .695), as compared with male subjects. Adjustment for empirically identified confounders in each age group revealed persisting elevated risk for adult females (OR = 2.57, 95% CI = 1.09-6.08; P = .031), but not minor females (OR = 1.07, 95% CI = 0.52-2.19, P = .852). The risk associated with female gender in adults could not be explained by characteristics of the sports, such as helmeted versus not, or contact versus no contact, in which women incurred mTBIs. No sport characteristics were associated with increased risk of PCSx after mTBI.

CONCLUSIONS: Adult females, but not female minors, are at increased risk for PCSx after sport-related mTBI as compared with male patients. This increased risk cannot be explained by self-report, rather than proxy report, of symptoms, previous head injury or loss of consciousness, age, or sport characteristics. Further research is needed to elucidate the processes of age-differential recovery from mild brain injury in women and how to most effectively incorporate appropriate follow-up after emergency department evaluation.


Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion.

Randolph C, Mills S, Barr WB, McCrea M, Guskiewicz KM, Hammeke TA, Kelly JP.

Self-report post-concussion symptom scales have been a key method for monitoring recovery from sport-related concussion, to assist in medical management, and return-to-play decision-making. To date, however, item selection and scaling metrics for these instruments have been based solely upon clinical judgment, and no one scale has been identified as the “gold standard”. We analyzed a large set of data from existing scales obtained from three separate case-control studies in order to derive a sensitive and efficient scale for this application by eliminating items that were found to be insensitive to concussion. Baseline data from symptom checklists including a total of 27 symptom variables were collected from a total of 16,350 high school and college athletes. Follow-up data were obtained from 641 athletes who subsequently incurred a concussion. Symptom checklists were administered at baseline (preseason), immediately post-concussion, post-game, and at 1, 3, and 5 days post-injury. Effect-size analyses resulted in the retention of only 12 of the 27 variables. Receiver-operating characteristic analyses were used to confirm that the reduction in items did not reduce sensitivity or specificity. The newly derived Concussion Symptom Inventory is presented and recommended as a research and clinical tool for monitoring recovery from sport-related concussion.


Sports concussion: management and predictors of outcome.

Reddy CC, Collins MW.

Interest in sports concussion has grown widely in the last two decades among laypersons and medical professionals. Significant contributions of evidence-based research have led to a better understanding of this multifaceted, but still often elusive, injury. This information has transformed all aspects of concussion management, from on-field evaluation through return-to-play guidelines. The aim of this article is to highlight important research regarding predictors of outcome and treatment protocols. This research has been the basis of the paradigm shift from traditional concussion grading scales to individualized care. Today, concussion management requires a patient-centered approach with individualized assessment, including risk factor analysis, neurocognitive testing, and a thorough symptom evaluation.
Postconcussion syndrome after minor head injury: brain activation of working memory and attention.

Smits M, Dippel DW, Houston GC, Wielopolski PA, Koudstaal PJ, Hunink MG, van der Lugt A.

After minor head injury (MHI) postconcussive symptoms (PCS) such as memory and attention deficits frequently occur. It has been hypothesised that PCS are caused by microstructural damage to the brain due to shearing injury, which is not detectable with conventional imaging, and may be responsible for a functional deficit. The purpose of this study was to correlate functional magnetic resonance imaging brain activation of working memory and selective attention with PCS. 21 MHI patients and 12 healthy controls were scanned at 3T. Stimulation paradigms were the n-back and Counting Stroop tasks to engage working memory and selective attention, respectively. Functional data analysis consisted of random effects group analyses, correlating brain activation patterns with the severity of PCS as evaluated with the Rivermead postconcussion symptoms questionnaire. At minimal working memory load, activation was seen in patients with greater severity of PCS in the working memory network. With an increase of working memory load, increase of activation was more pronounced in patients with greater severity of PCS. At high and increased working memory load, activation associated with the severity of PCS was seen in the posterior parietal area, parahippocampal gyrus, and posterior cingulate gyrus. Activation related to selective attention processing was increased with greater severity of PCS. The increased activity in relation to working memory and attention, and the recruitment of brain areas outside the working memory network at high working memory load, may be considered a reflection of the brain's compensatory response to microstructural injury in patients with PCS.


Understanding of sport concussion by the parents of young rugby players: a pilot study.

Sullivan SJ, Bourne LB, Choie SB, Eastwood BB, Isbister SB, McCrory P, Gray AB.

OBJECTIVE: Establish the knowledge and beliefs of the parents of high school rugby players about concussion.

DESIGN: Descriptive cross-sectional intercept style face-to-face pilot survey.

SETTING: The survey was conducted during high school rugby games.

PARTICIPANTS: Two hundred parents of male high school rugby players who were attending their teenagers’ games.

MAIN OUTCOME MEASURES: Exploratory analysis of the closed- and open-ended questionnaire. Concussion signs and symptoms were subsequently mapped onto the framework of the Sport Concussion Assessment Tool.

RESULTS: Most parents (83%; 165 of 198) reported that they were able to recognize a concussion in their teenager and provide a list of well-accepted signs and symptoms. Nearly all (96%; 188 of 196) were aware of the risks of continuing to play while concussed, and approximately half (51%; 99 of 196) were aware of return-to-play guidelines/recommendations after a concussion.

CONCLUSIONS: Parents of male high school rugby players reported having basic knowledge of concussion symptoms and the seriousness of concussion. Parents are potentially key figures in the detection of a possible concussion in the postgame/practice home environment.


Neural substrates of symptoms of depression following concussion in male athletes with persisting postconcussion symptoms.

Chen JK, Johnston KM, Petrides M, Pilot A.

CONTEXT: Depressed mood is frequently reported by individuals who have sustained cerebral concussion but little is known about the nature of this alteration in mood state.

OBJECTIVE: To investigate whether the symptoms of depression reflect an ongoing pathophysiological change following concussion.

DESIGN: Cohort study with male athletes using functional and structural neuroimaging.

SETTING: Hospital laboratory and imaging facility.

PARTICIPANTS: Fifty-six male athletes with and without concussion were divided into (1) a no depression symptom, concussed group, (2) a mild depression symptom, concussed group, (3) a moderate depression symptom, concussed group, and (4) a healthy control group.

INTERVENTIONS: All athletes filled out a postconcussive symptoms checklist and the Beck Depression Inventory II and underwent a magnetic resonance imaging session, which included T1, T2, and fluid-attenuated inversion recovery sequences, as well as functional magnetic resonance imaging (fMRI), during which they performed a working memory task.

MAIN OUTCOME MEASURES: (1) Behavioral: response speed and accuracy on the working memory task performed during the fMRI session; (2) functional imaging: brain activation patterns associated with the working memory task obtained using blood oxygen level-dependent fMRI; and (3) structural imaging: voxel-based morphometry examining gray matter concentration.

RESULTS: (1) Behavioral: there was no performance difference between the groups; and (2) imaging: athletes with concussion with depression symptoms showed reduced activation in the dorsolateral prefrontal cortex and striatum and attenuated deactivation in medial frontal and temporal regions. The severity of symptoms of depression correlated with neural responses in brain areas that are implicated in major depression. Voxel-based morphometry confirmed gray matter loss in these areas.

CONCLUSIONS: The results suggest that depressed mood following a concussion may reflect an underlying pathophysiology consistent with a limbic-frontal model of depression. Given that depression is associated with considerable functional disability, this finding has important clinical implications for the management of individuals with a cerebral concussion.


Concussion history and postconcussion neurocognitive performance and symptoms in collegiate athletes.
Covassin T, Stearne D, Elbin R.

CONTEXT: Athletes are at an inherent risk for sustaining concussions. Research examining the long-term consequences of sport-related concussion has been inconsistent in demonstrating lingering neurocognitive decrements that may be associated with a previous history of concussion.

OBJECTIVE: To determine the relationship between concussion history and postconcussion neurocognitive performance and symptoms in collegiate athletes.

DESIGN: Repeated-measures design.

SETTING: Multi-center analysis of collegiate athletes.

PATIENTS OR OTHER PARTICIPANTS: Fifty-seven concussed collegiate athletes (36 without concussion history, 21 with a history of 2 or more concussions).

INTERVENTION(S): All subjects were administered an Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) neurocognitive test battery, which measures verbal memory, visual memory, reaction time, and visual processing speed and 22 concussion symptoms.

MAIN OUTCOME MEASURE(S): Subjects who sustained a concussion were administered 2 follow-up tests at days 1 and 5 postinjury. Independent variables were history of concussion (no history of concussion, 2 or more concussions) and time (baseline, day 1 postconcussion, or day 5 postconcussion).

RESULTS: A within-subjects effect (time) on ImPACT performance (P < .001), a between-subjects multivariate effect of group (P < .001), and a group-by-time interaction (P = .034) were noted. Athletes with a concussion history performed significantly worse on verbal memory (P = .01) and reaction time (P = .023) at day 5 postconcussion compared with athletes who did not report a previous concussion. No significant group differences were seen at day 5 postinjury on visual memory (P = .167), processing speed (P = .179), or total concussion symptoms (P = .87).

CONCLUSIONS: Concussed collegiate athletes with a history of 2 or more concussions took longer to recover verbal memory and reaction time than athletes without a history of concussion.


Improving identification and diagnosis of mild traumatic brain injury with evidence: psychometric support for the acute concussion evaluation.

Gioia GA, Collins MW, Isquith PK.

OBJECTIVES: A dearth of standardized assessment tools exists to properly assess and triage mild traumatic brain injury (mTBI) in primary care and acute care settings. This article presents evidence of appropriate psychometric properties for the Acute Concussion Evaluation (ACE), a new structured clinical interview.

PARTICIPANTS: Parent informants of 354 patients, aged 3 to 18 years, with suspected mTBI completed the ACE via telephone interview.

MEASURE: Acute Concussion Evaluation.

RESULTS: Evidence is presented for appropriate item-scale membership, internal consistency reliability as well as content, predictive, convergent/divergent, and construct validity of the ACE symptom checklist.

CONCLUSIONS: Overall, the ACE symptom checklist exhibits reasonably strong psychometric properties as an initial assessment tool for mTBI.


Head impact severity measures for evaluating mild traumatic brain injury risk exposure.

Greenwald RM, Gwin JT, Chu JJ, Crisco JJ.

OBJECTIVE: The aims of this study were to quantify the sensitivity of various biomechanical measures (linear acceleration, rotational acceleration, impact duration, and impact location) of head impact to the clinical diagnosis of concussion in United States football players and to develop a novel measure of head impact severity combining these measures into a single score that better predicts the incidence of concussion.

METHODS: On-field head impact data were collected from 449 football players at 13 organizations (n = 289,916) using in-helmet systems of six single-axis accelerometers. Concussions were diagnosed by medical staff and later associated with impact data. Principal component analysis and a weighting coefficient based on impact location were used to transform correlated head impact measures into a new composite variable, weighted principal component score (wPCS). The predictive power of linear acceleration, rotational acceleration, head injury criterion, and wPCS was quantified using receiver operating characteristic curves. The null hypothesis, that a measure was no more predictive than guessing, was tested (alpha = 0.05). In addition, receiver operating characteristic curves for wPCS and classical measures were directly compared to test the hypothesis that wPCS was more predictive of concussion than were classic measures (alpha = 0.05).

RESULTS: When all of the impacts were considered, every biomechanical measure evaluated was statistically more predictive of concussion than guessing (P < 0.005). However, for the top 1 and 2% of impacts based on linear acceleration, a subset that consisted of 82% of all diagnosed concussions, only wPCS was significantly more predictive of concussion than guessing (P < 0.03); when compared with each other, wPCS was more predictive of concussion than were classical measures for the top 1 and 2% of all of the data (P < 0.04).

CONCLUSION: A weighted combination of several biomechanical inputs, including impact location, is more predictive of concussion than a single biomechanical measure. This study is the first to the authors’ knowledge to quantify improvements in the sensitivity of a biomechanical measure to incidence of concussion when impact location is considered.


Concussion management in child and adolescent athlete.

Lovell MR, Fazio V.
This article reviews the status of concussion management in child and adolescent athletes. Children and adolescent athletes represent a distinct group from adult athletes, although past concussion guidelines have not specifically addressed these differences. It is the position of this article that younger athletes need to be considered as a separate group and that conservative management of concussion is often called for. Neurodevelopmental differences between adult and child athletes are highlighted and new developments in the management of concussion in youth sports are discussed.


Abstracts

Serum cleaved tau does not predict postconcussive syndrome after mild traumatic brain injury.

Ma M, Lindsell CJ, Rosenberry CM, Shaw GJ, Zemlian FP.

OBJECTIVES: Our objective was to determine if the biomarker for axonal injury, serum cleaved tau (C-tau), predicts postconcussive syndrome (PCS) in adults after mild traumatic brain injury (mTBI).

METHODS: C-tau was measured from blood obtained in the emergency department. Outcome was assessed at 3 months post injury using the Rivermead Postconcussion Symptoms Questionnaire and Acute Medical Outcomes SF-36v2 Health Survey (SF-36).

RESULTS: Of 50 patients, there were 15 patients with detectable levels of C-tau, 10 patients with abnormal findings on initial head computed tomography (CT) and 22 patients with PCS. One-third of patients with detectable C-tau and 14.3% of patients without detectable C-tau had abnormal findings on head CT (P = .143). Serum C-tau was not detected more frequently in patients with PCS than those without, neither for all patients (P = .115) nor the subgroup with negative head CT (P = .253).

CONCLUSIONS: C-tau is a poor predictor of PCS after mTBI regardless of head CT result.


Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance.


CONTEXT: Evidence suggests that athletes engaging in high-intensity activities after concussion have more difficulties with cognitive recovery.

OBJECTIVE: To examine the role postinjury activity level plays in postconcussive symptoms and performance on neurocognitive tests in a population of student-athletes.

DESIGN: Retrospective cohort study with repeated measures of neurocognitive performance and symptom reporting.

SETTING: University-based sports concussion clinic.

PATIENTS OR OTHER PARTICIPANTS: Ninety-five student-athletes (80 males, 15 females: age = 15.88 +/- 1.35 years) were retrospectively assigned to 1 of 5 groups based on a postinjury activity intensity scale.

MAIN OUTCOME MEASURE(S): We employed a regression analysis for repeated measures to evaluate the relationship of activity intensity to symptoms and neurocognitive outcome up to 33 days after concussion. Postconcussion symptom scores and neurocognitive (verbal memory, visual memory, visual motor speed, and reaction time) scores served as the primary outcome measures.

RESULTS: Level of exertion was significantly related to all outcome variables (P < .02 for all comparisons). With multivariate analysis, activity intensity remained significant with respect to visual memory (P < .003) and reaction time (P < .001).

CONCLUSIONS: Activity level after concussion affected symptoms and neurocognitive recovery. Athletes engaging in high levels of activity after concussion demonstrated worse neurocognitive performance. For these tasks, those engaging in moderate levels of activity demonstrated the best performance.


Balance control during gait in athletes and non-athletes following concussion.

Parker TM, Osternig LR, van Donkelaar P, Chou LS.

Current literature provides only limited information regarding performance on dynamic motor tasks following concussion. However, recent investigations have suggested that participation in contact sports may have a negative effect on cognitive function without the existence of a medically diagnosed concussion. The purpose of this study was to examine balance control during gait in concussed and uninjured athletes and non-athletes. Twenty-eight Grade 2 concussed individuals (14 athletes and 14 non-athletes) and 28 uninjured matched controls (14 athletes and 14 non-athletes) were assessed for their gait performance within 48 h, 5, 14, and 28 days post-injury under conditions of divided and undivided attention. Athletes, whether concussed or not, walked slower and swayed more and faster than non-athletes. Athletes consistently demonstrated gait imbalance even in the absence of concussion. The findings of this study support the supposition that participation in high-impact sports has a measurable and possibly detrimental effect on balance control in the absence of a medically diagnosed concussion.

Medical Engineering and Physics, 2008: 30(8):959-967.

Biopsychosocial characteristics and neurocognitive test performance in National Football League players: an initial assessment.

Solomon GS, Haase RF.

The use of neurocognitive testing in the assessment of professional athletes sustaining sports-related concussions has become widespread over the past decade. Baseline neurocognitive testing is now a requirement for athletes in the National Football League (NFL). We present preliminary normative data on a computer based neurocognitive test (Immediate Post Concussion Assessment and Cognitive Testing: ImPACT) for 159 NFL athletes. Also included are summary data on basic biopsychosocial characteristics, including medical, psychiatric, chemical dependency, concussion, learning disability/attention deficit disorder, and symptom variables, and the relevance of each to baseline neurocognitive test scores.

Temporal window of metabolic brain vulnerability to concussion: a pilot 1H-magnetic resonance spectroscopic study in concussed athletes-part III.


OBJECTIVE: In the present study, the occurrence of the temporal window of brain vulnerability was evaluated in concussed athletes by measuring N-acetylaspartate (NAA) using proton magnetic resonance (H-MR) spectroscopy.

METHODS: Thirty nonprofessional athletes who had a sport-related concussive head injury were examined for NAA determination by means of H-MR spectroscopy at 3, 15, and 30 days postinjury. All athletes but three suspended their physical activity. Those who continued their training had a second concussive event and underwent further examination at 45 days from the initial injury. The single case of one professional boxer, who was studied before the match and 4, 7, 15, and 30 days after a knockout, is also presented. Before each magnetic resonance examination, patients were asked for symptoms of mild traumatic brain injury, including physical, cognitive, emotional, and sleep disturbances. Data for H-MR spectroscopy recorded in five normal, age-matched, control volunteers, who were previously screened to exclude previous head injuries, were used for comparison. Semi-quantitative analysis of NAA relative to creatine (Cr)- and choline (Cho)-containing compounds was performed from proton spectra obtained with a 3-T magnetic resonance system.

RESULTS: Regarding the values of the NAA-to-Cr ratio (2.21 +/- 0.11) recorded in control patients, singly concussed athletes, at 3 days after the concussion, showed a decrease of 18.5% (1.80 +/- 0.04, P < 0.001). Only a modest 3% recovery was observed at 15 days (1.88 +/- 0.1; P < 0.001); at 30 days postinjury, the NAA-to-Cr ratio was 2.15 +/- 0.1, revealing full metabolic recovery with values not significantly different from those of control patients. These patients declared complete resolution of symptoms at the time of the 3-day study. The three patients who had a second concussive injury before the 15-day study showed an identical decrease of the NAA-to-Cr ratio at 3 days (1.78 +/- 0.08); however, at 15 days after the second injury, a further diminution of the NAA-to-Cr ratio occurred (1.72 +/- 0.07; P < 0.05 with respect to singly concussed athletes). At 30 days, the NAA-to-Cr ratio was 1.82 +/- 0.1, and at 45 days postinjury, the NAA-to-Cr ratio showed complete recovery (2.07 +/- 0.1; not significant with respect to control patients). This group of patients declared a complete resolution of symptoms at the time of the 30-day study.

CONCLUSION: Results of this pilot study carried out in a cohort of singly and doubly concussed athletes, examined by H-MR spectroscopy for their NAA cerebral content at different time points after concussive events, demonstrate that also in humans, concussion opens a temporal window of brain metabolic imbalance, the closure of which does not coincide with resolution of clinical symptoms. The recovery of brain metabolism is not linearly related to time. A second concussive event prolonged the time of NAA normalization by 15 days. Although needing confirmation in a larger group of patients, these results show that NAA measurement by H-MR spectroscopy is a valid tool in assessing the full cerebral metabolic recovery after concussion, thereby suggesting its use in helping to decide when to allow athletes to return to play after a mild traumatic brain injury.

Neurosurgery. 2008; 62(6), 1286-1296.

Neurocognitive performance of concussed athletes when symptom free.

Breglio SP, Macciochi SI, Ferrara MS.

CONTEXT: Concussed athletes may underreport concussion-related symptoms in order to expedite return to play. Whether neurocognitive impairments persist once concussion-related symptoms resolve has yet to be determined. Reliance on athlete-reported, postconcussive symptoms when making return-to-play decisions may expose athletes to subsequent injury if complete recovery has not occurred.

OBJECTIVE: To evaluate the presence of neurocognitive decrements in concussed athletes no longer reporting concussion-related symptoms.

DESIGN: Within-groups design.

SETTING: University research laboratory.

PATIENTS OR OTHER PARTICIPANTS: Twenty-one National Collegiate Athletic Association Division I collegiate athletes (16 men, 5 women). Age = 19.81 +/- 1.25 years, height = 180.95 +/- 10.62 cm, mass = 93.66 +/- 27.60 kg, and previous concussions = 1.76 +/- 2.02.

MAIN OUTCOME MEASURE(S): The ImPACT concussion assessment test was administered to concussed athletes at baseline, when symptomatic (within 72 hours of injury), and when asymptomatic. Index scores of verbal memory, visual memory, visual-motor speed, reaction time, and concussion-related symptoms were recorded at each session. The Symptom Assessment Scale was administered daily after injury to establish when the athlete became asymptomatic.

RESULTS: When assessed within 72 hours of concussion, 81% of the athletes showed deficits on at least 1 ImPACT variable. At the asymptomatic time point, 38% of the concussed athletes continued to demonstrate neurocognitive impairment on at least 1 ImPACT variable.

Neuropsychological test performance of Hawai'i high school athletes: Hawai'i ImPACT normative data.

Tsushima WT, Oshiro R, Zimbra D.

OBJECTIVE: Establishing normative data of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) performance of high school athletes in Hawai'i.

STUDY DESIGN: Pre-season ImPACT testing was performed on 751 participants in football, baseball, basketball, soccer, volleyball, softball, and track from 4 Oahu public high schools. The ImPACT composite scores included measures of Verbal Memory, Visual Memory Processing Speed, and Reaction Time. The descriptive statistical data collected were the group means, standard deviations, standard errors of measurement, distribution of scores and percentile ranks of (1) 262 boys ages 13 to 15; (2) 297 boys ages 16 to 18; and (3) 192 girls ages 13 to 18.

RESULTS: The means and standard deviations of the 4 ImPACT composite scores for the 751 student-athletes in Hawai'i were similar to the ImPACT scores obtained from a master database of ImPACT test results. Although differences between the Hawai'i and mainland data were nonsignificant, there appeared to be a trend revealing somewhat lower scores in the Hawai'i sample of athletes.

DISCUSSION: The similarity in ImPACT test performance of Hawai'i high school athletes as compared to the mainland normative data provides support for the applicability of this computerized neuropsychological battery in Hawai'i. However in view of a trend reflecting slightly lower ImPACT scores among Hawai'i participants, the use of the normative data produced by this study may be desirable in assessing Hawai'i high school athletes.

The relation between post concussion symptoms and neurocognitive performance in concussed athletes.

Fazio VC, Lovell MR, Pardini JE, Collins MW.

The objective of this study was to examine differences in neurocognitive performance between symptomatic concussed athletes, a group of concussed athletes with no subjective symptoms, and a non-concussed control group of athletes. All concussed athletes were evaluated within one week of injury using the ImPACT computerized test battery. Results indicate that concussed athletes who denied subjective symptoms demonstrated poorer performance than control subjects on all four composite scores of the ImPACT test battery (Verbal Memory, Visual Memory, Reaction Time and Processing Speed). However, the concussed but asymptomatic group demonstrated significantly better performance than did the concussed and symptomatic group. Thus, concussed athletes who did not report subjective symptoms were not fully recovered based on neurocognitive testing. This study underscores the importance of neurocognitive testing in the assessment of concussion sequelae and recovery.

NeuroRehabilitation, 2007; 22(3), 207-216.

Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion.

Guzkiewicz KM, Mihalik JP, Shankar V, Marshall SW, Crowell DH, Oliaro SM, Ciocca MF, Hooker DN.

OBJECTIVE: To determine the relationship between recorded head accelerations and impact locations and acute clinical outcome of symptomatology, neuropsychological, and postural stability tests after cerebral concussion in Division I collegiate football players.

METHODS: A prospective field study was used in which accelerometers were embedded in the football helmets of 88 collegiate football players. Linear and rotational accelerations of all head impacts sustained over the course of 2004 to 2006 National Collegiate Athletic Association football seasons were collected in real-time. Change scores were calculated on clinical measures from the players’ preseason baseline to postinjury (within 48 h) and regressed against the recorded linear and rotational accelerations of the head at the time of the concussion.

RESULTS: Thirteen concussions were recorded ranging in impact magnitudes of 60.51 to 168.71 g. Linear regression showed no significant relationships between impact magnitude (linear or rotational acceleration) or impact location and change scores for symptom severity, postural stability, or neurocognitive function (P > 0.05).

CONCLUSION: Our findings suggest that football players are concussed by impacts to the head that occur at a wide range of magnitudes and that clinical measures of acute symptom severity, postural stability, and neuropsychological function all appear to be largely independent of impact magnitude and location. Because of the varying magnitudes and locations of impacts resulting in concussion as well as other factors such as the frequency of subconcussive impacts and number of previous concussions, it may be difficult to establish a threshold for concussive injury that can be applied to all football players.

Neurosurgery, 2007; 61(6), 1244-1253.

Functional brain abnormalities are related to clinical recovery and time-to-play in athletes.


OBJECTIVE: The relationship between athlete reports of symptoms, neuropsychological activation, and neuropsychological functioning is investigated in a sample of high school athletes.

METHODS: All athletes were evaluated using functional magnetic resonance imaging (fMRI), a computer-based battery of neurocognitive tests, and a subjective symptom scale. Athletes were evaluated within approximately 1 week of injury and again after clinical recovery using all assessment modalities.

RESULTS: This study found that abnormal fMRI results during the first week of recovery predicted clinical recovery. As a group, athletes who demonstrated hyperactivation on fMRI scans at the time of their first fMRI scan demonstrated a more prolonged clinical recovery than athletes who did not demonstrate hyperactivation at the time of their first fMRI scan.

CONCLUSION: These results demonstrate the relationship between neuropsychological, neuropsychological, and subjective symptom data in a relatively large sample composed primarily of concussed high school athletes. fMRI represents an important evolving technology for the understanding of brain recovery after concussion and may help shape return-to-play guidelines in the future.

Neurosurgery, 2007; 61(2), 352-359.

Effectiveness of mouthguards in reducing neurocognitive deficits following sports related concussion.

Mihalik JP, McCaffrey MA, Rivera ER, Pardini JE, Guzkieiczewicz K, Collins MW, Lovell MR.

Although it is widely accepted that mouthguards decrease the incidence of dental injuries, there is a controversy among sports medicine professionals as to the effectiveness of mouthguards in decreasing the incidence or severity of sports-related cerebral concussion (SRCC). While some experimental data suggest that this may be the case, there exist a number of reports suggesting that mouthguards do not serve this purpose. These conclusions have been drawn, however, without actually measuring the extent of neurocognitive dysfunction in athletes following sports-related concussion. The purpose of this study was to determine whether mouthguard use reduces the neurocognitive and symptomatic impairments that follow an injurious episode of SRCC. Preseason baseline data were collected as part of an ongoing clinical program that uses a computerized neurocognitive test to assess various faculties of brain function and symptoms reported at the time of testing. Follow-up testing from 180 student-athletes who had sustained an SRCC was analyzed for the purpose of this study. These athletes were separated into one of two groups: those who reported using mouthguards and those who did not. Neurocognitive testing was accomplished using the Immediate Post-Concussion and Assessment Test (ImPACT). Results suggest that neurocognitive deficits at the time of the athletes’ first follow-up assessment did not differ between mouthguard users and non-users, suggesting that mouthguard use does little to reduce the severity of neurocognitive dysfunction and onset of symptoms following sports-related head trauma. However, an interesting finding in this study was that athletes experienced significantly lower neurocognitive test scores and reported higher symptom scores following SRCC regardless of mouthguard use. This emphasizes a thorough clinical evaluation of athletes that have sustained an SRCC. Although it was found in this study that mouthguard use does not decrease the severity of concussion, it is important to note that the use of mouthguards is paramount in reducing maxillofacial and dental trauma and their use should continue to be mandated by athletic associations and supported by all dental and sports medicine professionals.

Dental Traumatology, 2007; 23(1), 14-20.
Comparison of preseason, midseason, and postseason neurocognitive scores in uninjured collegiate football players.

Miller JR, Adamson GJ, Pirk MM, Sweet JC.

BACKGROUND: College football players sustain an average of 3 subconcussive blows to the head per game. Concussions correlate with decreases in standardized neurocognitive test scores. It is not known whether repetitive, subconcussive microtrauma associated with participation in a full season of collision sport affects neurocognitive test scores.

HYPOTHESIS: No difference exists between preseason, midseason, and postseason Standardized Assessment of Concussion (SAC) and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) scores when collegiate football players sustain subconcussive microtrauma from forceful, repetitive contact activity.

STUDY DESIGN: Case series; Level of evidence, 4.

METHODS: Fifty-eight members of a Division III collegiate football team who had no known concussion during the season voluntarily completed the SAC and ImPACT instruments preseason, midseason, and postseason. A repeated measures analysis of variance was used to compare the scores at the 3 time intervals (P < .05).

RESULTS: No statistically significant decreases were found in overall SAC or ImPACT scores or in any of the domains or composites of the tests (P < .05) when preseason, midseason, and postseason scores were evaluated.

CONCLUSIONS: ImPACT and SAC neurocognitive test scores are not significantly altered by a season of repetitive contact in collegiate football athletes who have not sustained a concussion.

CLINICAL RELEVANCE: A diminution in SAC or ImPACT scores in concert with clinical symptoms and findings should be interpreted as evidence of a postconcussive event.


Neuropsychological evaluation in the diagnosis and management of sports-related concussion.


A mild traumatic brain injury in sports is typically referred to as a concussion. This is a common injury in amateur and professional athletics, particularly in contact sports. This injury can be very distressing for the athlete, his or her family, coaches, and school personnel. Fortunately, most athletes recover quickly and fully from this injury. However, some athletes have a slow recovery, and there are reasons to be particularly concerned about re-injury during the acute recovery period. Moreover, some athletes who have experienced multiple concussions are at risk for long-term adverse effects. Neuropsychologists are uniquely qualified to assess the neurocognitive and psychological effects of concussion. The National Academy of Neuropsychology recommends neuropsychological evaluation for the diagnosis, treatment, and management of sports-related concussion at all levels of play.

Archive of Clinical Neuropsychology, 2007: 22(8), 906-916.

Contributions of functional Magnetic Resonance Imaging (fMRI) to sport concussion evaluation.

Ptito A, Chen JK, Johnston KM.

Mild traumatic brain injury (mTBI) in contact sport is a problem of such magnitude that improved approaches to diagnosis, investigation and management are urgent. Concussion has traditionally been described as a transient, fully reversible, cerebral dysfunction. However, this seemingly ‘mild’ injury sometimes results in long-lasting and disabling post-concussion symptoms (PCS) and abnormal neuropsychological profiles characteristic of frontal and/or temporal lobe dysfunction. At present, the pathological changes following concussion remain unclear, but it is now widely accepted that concussion results mainly in functional disturbance rather than structural damage. Therefore, functional imaging techniques can help in demonstrating brain abnormalities undetectable by structural imaging methods. This paper will review the use of functional magnetic resonance imaging (fMRI) in studies of concussion. Our existing and ongoing fMRI studies will be described as examples to highlight the potential and contribution of this non-invasive functional neuroimaging technique in the assessment of sports-related concussion and its management.


Differential rate of recovery in athletes after first and second concussion episodes.

Slobounov S, Slobounov E, Sebastianelli W, Cao C, Newell K.

OBJECTIVE: Clinical observations suggest that a history of previous concussions may cause a slower recovery of neurological function after recurrent concussion episodes. However, direct examination of this notion has not been provided. This report investigates the differential rate of restoring the visual-kinesthetic integration in collegiate athletes experiencing single versus recurrent concussion episodes.

METHODS: One hundred sixty collegiate athletes were tested preseason using multimodal research methodology. Of these, 38 experienced mild traumatic brain injury (MTBI) and were tested on Days 10, 15, and 30 after injury. Nine of these MTBI patients experienced a second MTBI within 1 year after the first brain injury and were retested. The postconcussion symptoms checklist, neuropsychological evaluations, and postural responses to visual field motion were recorded using a virtual reality environment.

RESULTS: All patients were asymptomatic at Day 10 of testing and were cleared for sport participation based on clinical symptoms resolution. Balance deficits, as evident by incoherence with visual field motion postural responses, were present at least 30 days after injury (P < 0.001). Most importantly, the rate of balance symptoms restoration was significantly reduced after a recurrent, second concussion (P < 0.001) compared with those after the first concussion.

CONCLUSION: The findings of this study confirm our previous research indicating the presence of long-term residual visual-motor disintegration in concussed individuals with normal neuropsychological measures. Most importantly, athletes with a history of previous concussion demonstrate significantly slower rates of recovery of neurological functions after the second episode of MTBI.

Neurosurgery, 2007: 61(2);338-44.
Temporal window of metabolic brain vulnerability to concussions: mitochondrial-related impairment—part I.


OBJECTIVE: In the present study, we investigate the existence of a temporal window of brain vulnerability in rats undergoing repeat mild traumatic brain injury (mTBI) delivered at increasing time intervals.

METHODS: Rats were subjected to two diffuse mTBIs (450 g/1 m height) with the second mTBI delivered after 1 (n = 6), 2 (n = 6), 3 (n = 6), 4 (n = 6), and 5 days (n = 6) and sacrificed 48 hours after the last impact. Sham-operated animals were used as controls (n = 6). Two further groups of six rats each received a second mTBI after 3 days and were sacrificed at 120 and 168 hours postinjury. Concentrations of adenine nucleotides, N-acetylated amino acids, oxypurines, nucleosides, free coenzyme A, acetyl CoA, and oxidized and reduced nicotinamide adenine dinucleotides, oxidized nicotinamide adenine dinucleotide phosphate, and reduced nicotinamide adenine dinucleotide, reduced nicotinamide adenine dinucleotide phosphate nicotinic coenzymes were measured in deproteinized cerebral tissue extracts (three right and three left hemispheres), whereas the gene expression of N-acetylaspartic acylase, the enzyme responsible for N-acetylaspartate (NAA) degradation, was evaluated in extracts of three left and three right hemispheres.

RESULTS: A decrease of adenosine triphosphate, adenosine triphosphate/adenosine diphosphate ratio, NAA, N-acetylaspartylglutamate, oxidized and reduced nicotinamide adenine dinucleotide, reduced nicotinamide adenine dinucleotide phosphate, and reduced nicotinamide adenine dinucleotide, reduced nicotinamide adenine dinucleotide phosphate nicotinic coenzymes were measured in deproteinized cerebral tissue extracts (three right and three left hemispheres), whereas the gene expression of N-acetylaspartic acylase, the enzyme responsible for N-acetylaspartate (NAA) degradation, was evaluated in extracts of three left and three right hemispheres.

CONCLUSION: This study shows the existence of a temporal window of brain vulnerability after mTBI. A second concussive event falling within this time range had profound consequences on mitochondrial-related metabolism. Furthermore, because NAA recovery coincided with normalization of all other metabolites, it is conceivable to hypothesize that NAA measurement by 1H-NMR spectroscopy might be a valid tool in assessing full cerebral metabolic recovery in the clinical setting and with particular reference to sports medicine in establishing when to return mTBI-affected athletes to play. This study also shows, for the first time, the influence of TBI on acetyl-CoA, N-acetylaspartate acylase gene expression, and N-acetylaspartylglutamate, thus providing novel data on cerebral biochemical changes occurring in head injury.


Sport-related concussion misunderstandings among youth coaches.

Valovich McLeod TC, Schwartz C, Bay, RC.

OBJECTIVE: To determine the understanding of sport-related concussion among youth sports coaches.

DESIGN: Cross-sectional survey.

SETTING: The survey was administered at coaches’ meetings, following practices, and via mail.

PARTICIPANTS: 156 active youth sports coaches, with 5.88 +/- 3.16 years (range 1-22) of coaching experience.

INTERVENTIONS: An original survey instrument developed to assess concussion knowledge. Internal validity of the instrument was established prior to the study (Cronbach's alpha = 0.83).

MAIN OUTCOME MEASUREMENTS: Scores on the survey instrument reflecting symptom recognition and management knowledge.

RESULTS: For the 16 items comprising the symptom recognition survey, the mean number of correct responses was 9.78 +/- 2.07. Previous coaching education was predictive of better symptom recognition. On the true/false portion, between 49.4% and 61.5% of coaches correctly answered the 4 statements.

CONCLUSION: This investigation revealed that, among youth sports coaches, coaching education was predictive of the ability to recognize signs and symptoms of sport-related concussion. However, several misconceptions about concussion still exist, highlighting that education regarding concussion is necessary. The presence of qualified health care personnel, such as an athletic trainer, at the youth organization level may enhance early recognition, treatment, and referral of concussions.


Concussion in professional football: biomechanics of the struck player—part 14.

Viano DC, Casson IR, Pellman EJ.

OBJECTIVE: Impacts causing concussion in professional football were simulated in laboratory tests to determine collision mechanics. This study focuses on the biomechanics of concussion in the struck player.

METHODS: Twenty-five helmet impacts were reconstructed using Hybrid III dummies. Head impact velocity, direction, and helmet kinematics-matched game video. Translational and rotational accelerations were measured in both players' heads; 6-axis upper neck responses were measured in all striking and five struck players. Head kinematics and biomechanics were determined for concussed players. Head displacement, rotation, and neck loads were determined because finite element analysis showed maximum strains occurring in the midbrain after the high impact forces. A model was developed of the helmet impact to study the influence of neck strength and other parameters on head responses.

RESULTS: The impact response of the concussed player's head includes peak accelerations of 94 +/- 28 g and 6432 +/- 1813 r/s2, and velocity changes of 7.2 +/- 1.8 m/s and 34.8 +/- 15.2 r/s. Near the end of impact (10 ms), head movement is only 20.2 +/- 6.8 mm and 6.9 +/- 2.5 degrees. After impact, there is rapid head displacement involving a fourfold increase to 87.6 +/- 21.2 mm and 29.9 +/- 9.5 degrees with neck tension and bending at 20 ms. Impacts to the front of the helmet, the source of the majority of National Football League concussions, cause rotation primarily around the z axis (superior-inferior axis) because the force is forward of the neck centerline. This twists the head to the right or left an average of 17.6 +/- 12.7 degrees, causing a moment of 17.7 +/- 3.3 Nm and neck tension of 1704 +/- 432 N at 20 ms. The head injury criterion correlates with concussion risk and is proportional to deltaV(4)/d(1.5)
for half-sine acceleration. Stronger necks reduce head acceleration, deltaV, and displacement. Even relatively small reductions in deltaV have a large effect on head injury criterion that may reduce concussion risks because changes in deltaV change head injury criterion through the 4th power.

CONCLUSION: This study addresses head responses causing concussion in National Football League players. Although efforts are underway to reduce impact acceleration through helmet padding, further study is needed of head kinematics after impact and their contribution to concussion, including rapid head displacement, 2-axis rotation, and neck tension up to the time of maximum strain in the midbrain. Neck strength influences head deltaV and head injury criterion and may help explain different concussion risks in professional and youth athletes, women, and children.


The association between the postconcussion symptoms and clinical outcomes for patients with mild traumatic brain injury.

Yang CC, Tu YK, Hua MS, Huang SJ.

BACKGROUND: Postconcussion symptoms (PCS) (such as dizziness, headache, irritability, fatigue, and impaired memory) are common in patients who sustain a mild traumatic brain injury (mTBI). However, few studies have systematically investigated the association between PCS and clinical outcomes in mTBI patients. Therefore, the present study attempted to examine PCS during the disease course and to determine whether PCS adversely affect outcome.

METHODS: This was a prospective, cohort and controlled study of 115 mTBI patients. The PCS checklist was used to identify PCS and the Glasgow Outcome Scale and the Glasgow Outcome Scale-Extended were used to investigate clinical outcomes. All patients were evaluated four times: at 1 week, 2 weeks, 4 weeks, and 8 weeks after the injury.

RESULTS: Physical symptoms such as dizziness and headache were prominent in the early after injury stage (1 and 2 weeks). On the other hand, the psychosocial symptoms, such as depression and irritability, were significant at the late after injury stage (4 and 8 weeks). Dizziness adversely affected clinical outcome at both the early and late stages of the disease, whereas the impact of intracranial lesions and depression on outcome was greatest early and late, respectively.

CONCLUSIONS: The results show that PCS during the disease course and the relationship between PCS and clinical outcome can be systematically evaluated. In fact, different postconcussion symptom domains should be monitored while the disease is progressing.