



## Assessing the enduring residual neuropsychological effects of head trauma in college athletes who participate in contact sports

Chad Killam, Robin L. Cautin, Anthony C. Santucci\*

*Manhattanville College, Department of Psychology, 2900 Purchase Street, Purchase, NY 10577, USA*

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### Abstract

The present study examined the enduring residual neuropsychological effects of head trauma in college athletes using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), Postconcussion Syndrome Checklist, and the Stroop task. Based on a brief self-report concussion history survey, male and female athletes who participated in ice hockey, field hockey, lacrosse, and/or soccer were assigned to one of three concussion-history conditions: Non-concussed, Non-recent concussed (i.e., more than 2 years since last concussion), or Recent concussed (i.e., 2 years or less since last concussion). A fourth group of subjects consisting of non-concussed/non-athletes served in the control condition. Group differences emerged on the RBANS when immediate memory, delayed memory, and total scores were analyzed. Specifically, recent concussed athletes and, surprisingly, non-concussed athletes scored lower than control subjects in the two memory domains, whereas all three athlete groups had lower total RBANS scores than those of control subjects. Moreover, recent concussed athletes not only had lower immediate memory scores than control subjects, but also were impaired relative to non-recent concussed athlete subjects in this memory domain. No group differences were detected on the Stroop task or on the Postconcussion Syndrome Checklist. Interestingly, however, the severity of the Postconcussion Syndrome Checklist scores for the two athlete-concussed groups, taken in aggregate, correlated negatively with RBANS scores for attention ( $r = -.65$ ) and delayed memory ( $r = -.61$ ), and with the total RBANS score ( $r = -.59$ ). In recent concussed athletes, lower delayed memory scores correlated with more severe Postconcussion Symptom Checklist scores ( $r = -.90$ ), while more severe/higher number of concussions correlated with increased processing speed on the Stroop interference task ( $r = .90$ ). These findings indicate that recent head injury produces alterations in neuropsychological function, especially that of memory, that resolve with time. More provocatively, the data also suggest that participation

\* Corresponding author. Tel.: +1 914 323 5359; fax: +1 914 323 5311.

*E-mail address:* santuccia@mville.edu (A.C. Santucci).

in contact sports may produce sub-clinical cognitive impairments in the absence of a diagnosable concussion presumably resulting from the cumulative consequences produced by multiple mild head trauma.

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## 1. Introduction

A significant risk to all players of contact sports is head trauma sufficient to produce concussion. Characterized as a sudden or brief impairment of consciousness, concussions resemble a state of generalized seizure activity that may result in tissue deforming collisions with the internal wall of the skull similar to the agitation the brain experiences during other types of closed head injuries (Shaw, 2002).

Alterations to neuropsychological function following concussion is a very real possibility with greater mental impairments being likely evidenced as a result of sustaining a larger number of concussions (Moser & Schatz, 2002). The insidiousness of these neuropsychological deficits in affecting other aspects of mental functioning is highlighted by the fact that these deficits may exacerbate depression (Sawchyn, Brulot, & Strauss, 2000) and impair one's ability to handle daily stress (Machulda, Begquist, Ito, & Chew, 1998). Given the often subtle nature of the neuropsychological deficiencies sustained, the athlete may require extended rest ("bench time") in order for the deficits to fully resolve (Bleiberg et al., 2004; McCrea et al., 2003). Unfortunately, extended recovery time may be underprescribed to the extent that return-to-play decision are based on on-field self-diagnoses—a method that has been shown to be unreliable (Field, Collins, Lovell, & Maroon, 2003). Moreover, determining whether an athlete is ready to return to competition is complicated by the fact that neuropsychological deficits resulting from head injury may be evidenced only when the individual is assessed under challenging cognitive, physical, or neurological conditions (Ewing, McCarthy, Gronwall, & Wrightson, 1980; Slobounov, Sebastianelli, & Simon, 2002). In one study, for example, young males who had sustained a concussion and then reportedly had made a full recovery were impaired when tested under the stress of high altitude (Ewing et al., 1980). Further complications in properly diagnosing changes to neuropsychological function may arise from the fact that impairments may be manifested simply as a result of general play alone and not specifically from any particular event or contact (Rutherford, Stephens, & Potter, 2003). Thus, it is entirely conceivable that an athlete may appear to be intact neuropsychologically, but may evidence mental impairment when performing under physically stressful athletic competitive conditions.

Clearly, the need to properly identify and diagnose the mental and psychological consequences of head trauma in athletes is of critical importance. In this regard, it has been suggested that, in the future, the use of objective neuropsychological assessment instruments should be used to help characterize cognitive function and influence return-to-play decisions subsequent to concussive injuries (Echemendia & Cantu, 2003). In this vein, the present study employed a battery of neuropsychological tests to examine whether college athletes with a self-report

history of concussion were impaired neuropsychologically relative to athletes and non-athletes who never had a diagnosable concussion. We also determined whether recent head injuries in athletes had a more deleterious neuropsychological effect than those sustained earlier in life (i.e., more than 2 years previously).

## 2. Method

### 2.1. Participants

All participants were at least 20 years of age and were undergraduates attending Manhattanville College, a small liberal arts college located in Purchase, NY, whose inter-collegiate athletic teams participate in NCAA's Division III (total  $N=28$ ). Athletes who participated in this study were recruited from the college's athletic department under the condition that they participated in a contact sport at the college. Non-athlete, non-concussed control subjects were recruited from the general student body via classroom announcements. Most athlete participants either played ice hockey, field hockey, lacrosse, or soccer while a few participated in multiple sports. There were no statistical differences among the groups in terms of the age, gender, ethnicity, year-in-college, cumulative grade point average (all  $P$ 's  $> .05$ ; see Table 1), and, in the case of the two concussed groups, Concussion Index scores (see Section 2.2.1) [ $t(9) < 1.0$ ,  $P > .05$ ]. All subjects gave their voluntary informed consent and were told the general nature of the study prior to their participation. The study received the college's Institutional Review Board's approval prior to commencing.

### 2.2. Materials

#### 2.2.1. General Concussion Reference Form

Athletes were initially screened for concussion history using a General Concussion Reference Form that the experimenters constructed. This form provided a brief description of grades 1, 2 and 3 concussions (American Academy of Neurology, 1997; Kelly & Rosenberg, 1997) in order to help subjects identify the severity of prior head injury. In addition, the number of times the individual had been diagnosed within each grade was requested. Subjects were told only to report concussions that had been diagnosed either by a certified athletic trainer or physician. An overall Concussion Index was determined for each head-injured subject by multiplying the grade of each concussion by the frequency that that type of concussion had been sustained and, in the case of multiple concussions of different grades, summing these products together.

#### 2.2.2. Subject Questionnaire Form

Subject's personal information such as cumulative grade point average and collegiate athletic participation history was derived from the Subject Questionnaire Form. This form also requested whether the subject had played organized sports prior to attending college. Finally, because of its association with head injury (Fann, Katon, Uomoto, & Esselman, 1995; Trahan, Ross, & Trahan, 2001), subjects were asked to identify whether they had been diagnosed with

Table 1  
Demographics for the four groups of subjects

Group	Gender ( <i>N</i> )	Mean ( $\pm$ <i>S</i> ) age in years	Median (range) year	Ethnicity	Mean ( $\pm$ <i>S</i> ) reported GPA (4.0 scale)	Mean ( $\pm$ <i>S</i> ) Concussion Index score	Mean ( $\pm$ <i>S</i> ) years since last concussion
Non-athlete/Non-concussed	5 M; 3 F	21.4 ( $\pm$ 0.7)	3.5 (3–4)	6 C; 2 O	3.36 ( $\pm$ 0.22)	0	0
Athlete/Non-concussed	6 M; 3 F	22.0 ( $\pm$ 1.6)	2 (2–4)	7 C; 2 O	3.23 ( $\pm$ 0.48)	0	0
Athlete/Non-recent concussed	3 M; 3 F	21.8 ( $\pm$ 1.2)	3.5 (3–4)	6 C	3.54 ( $\pm$ 0.41)	4.7 ( $\pm$ 3.56)	5.2 ( $\pm$ 2.7)
Athlete/Recent concussed	3 M; 2 F	22.6 ( $\pm$ 1.5)	2.5 (2–4)	4 C; 1 O	3.32 ( $\pm$ 0.35)	6.2 ( $\pm$ 2.95)	0.2 ( $\pm$ 0.5)

M, male; F, female; C, Caucasian; O, other. Year in college: 1, freshman; 2, sophomore; 3, junior, 4, senior.

clinical depression and, if so, the date of the diagnosis. None of the subjects reported to have been diagnosed as such.

### 2.2.3. *Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)*

All participants completed the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), Form A (Randolph, 1998). The test uses standardized norms to assess the status of five cognitive domains [immediate memory (list learning/store memory), visuoconstructional/spatial ability (figure copy/line orientation), language (picture naming/semantic fluency), attention (digit span/coding) and delayed memory (list recall/list recognition/story recall/figure recall)]. The scores from the five domains contribute to an overall total RBANS score (Randolph, Tierney, Mohr, & Chase, 1998).

The RBANS evidences adequate test–retest reliability. Internal consistency for all content indexes averaged across six age groups is high, with reported  $\alpha$ 's ranging from .80 to .88. The RBANS also evidences convergent and divergent validity (Randolph, 1998). Although originally developed for identifying mild cognitive decline in adult populations, the RBANS has demonstrated significant clinical utility with various neurological and neuropsychiatric disorders such as Alzheimer's, (Randolph et al., 1998), Parkinson's (Beatty et al., 2003), and Huntington's (Randolph et al., 1998) disease, schizophrenia (Gold, Queern, Iannone, & Buchanan, 1999; Wilk et al., 2002), and stroke (Larson et al., 2003). More relevant to the present investigation was the use of the RBANS as a neuropsychological screen in youths and adolescents sustaining head trauma as a result of contact sport participation (Moser & Schatz, 2002).

### 2.2.4. *Postconcussion Syndrome Checklist*

Subjects completed the Postconcussion Syndrome Checklist, a Likert-based survey of commonly reported symptoms in individuals suffering from postconcussion syndrome (Gouvier, Cubic, Jones, Brantley, & Cutlip, 1992; Sawchyn et al., 2000). This checklist asks subjects to rate on a scale of 1 (never) to 9 (very frequent, more than once per week) the frequency with which they experience forgetting (e.g., forget where car is parked, forget recent telephone conversations, etc.), anxiety, depression, sensitivity to bright light, fatigue, trouble thinking, dizziness, blurry or double vision, and headaches.

### 2.2.5. *Stroop Task*

A standard Stroop task (Stroop, 1935) was used to assess cognitive automaticity and speed of information processing. Compared to the amount of time required to identify a list of colored blocks or color words, cognitive interference is typically experienced when subjects are asked to read color words that are printed in colored ink different than the semantic meaning of the word (e.g., "RED" printed in blue ink, etc.).

## 2.3. *Procedure*

Each subject was scheduled in advance at a convenient afternoon or early evening time. At the scheduled time, the experimenter escorted each subject to the Psychology Department's behavioral laboratory for the 45 min session. The testing room was of medium size and had

fluorescence lighting, standard laboratory furniture, and a computer. The subject was seated at a table immediately to the left of the experimenter and was first asked to complete the voluntary informed consent form. History of head injury was then determined by the self-reported answers to the General Concussion Reference Form. Based on the subject's responses, he/she was assigned to one of four groups: Non-athlete/Non-concussed control, Athlete/Non-concussed, Athlete/Non-recent concussed (i.e., more than 2 years since the last diagnosable concussion), or Athlete/Recent concussed (i.e., 2 years or less since the last diagnosable concussion). The subject was then asked to complete the brief Subject Questionnaire Form that asked for the individual's year in college, GPA, sports participation history, and whether the individual had been diagnosed and/or treated for clinical depression. The subject was then administered the RBANS, Form A according to the published standard instructions. Finally, participants completed the Postconcussion Syndrome Checklist and were then administered the Stroop task. The Stroop test stimuli were presented via an overhead projector with the room lights turned off. Subjects were instructed to identify the presented colors as quickly as possible. Specifically, subjects were first required to identify the color of each of 27 colored blocks. Subjects were then asked to identify the color in which 27 three-letter non-sense words were printed. Finally, subjects were required to identify the color in which 27 color words were printed. Each color word, however, was printed in colored ink different than the meaning of the word and thus provided a source of interference. Latency to complete each of the three color-naming Stroop tasks was measured with a hand-held stopwatch. After completing these items, subjects were informed that the experiment was completed. Before leaving, subjects were asked whether they had any questions, which were then answered promptly by the experimenter, and were then thanked for their time and participation.

### 3. Results

#### 3.1. RBANS

The mean RBANS scores for each of the four groups, presented in Table 2, were analyzed with separate one-way ANOVAs for independent samples. Significant overall differences were examined further with pairwise post hoc tests (Fisher Least Significant Difference test). Group differences were evaluated at an  $\alpha$  level of .05, unless otherwise noted.

The results from the analyses used to compare group differences for the visuospatial construction, language, and attention domains yielded no significant between-group differences [all  $F$ 's(3, 24) < 1.87, all  $P$ 's > .05]. In contrast, significant overall effects were revealed when immediate [ $F(3, 24) = 4.23, P < .05$ ] and delayed [ $F(3, 24) = 3.17, P < .05$ ] memory scores and total RBANS score [ $F(3, 24) = 4.07, P < .05$ ] were examined. Relative to Non-athlete/Non-concussed control subjects, participants in the Athlete/Non-concussed and Athlete/Recent concussed groups were impaired in the immediate (both  $P$ 's < .05) and delayed ( $P < .05$  for Athlete/Recent concussed group;  $P < .01$  for the Athlete/Non-concussed group) memory domains. Moreover, the total RBANS score for each of the three athlete-groups was significantly lower than that of the Non-athlete/Non-concussed control condition ( $P < .05$  for Athlete/Non-recent concussed group; both  $P$ 's < .01 for the Athlete/Non-concussed and Athlete/Recent

Table 2  
Mean ( $\pm S$ ) RBANS scores for the four groups of subjects

Group	Immediate memory	Visuospatial construction	Language	Attention	Delayed memory	Total
Non-athlete/Non-concussed	93.6 ( $\pm 10.4$ )	95.0 ( $\pm 18.3$ )	97.8 ( $\pm 12.6$ )	111.9 ( $\pm 12.0$ )	98.0 ( $\pm 8.1$ )	98.6 ( $\pm 11.2$ )
Athlete/Non-concussed	80.7 <sup>a</sup> ( $\pm 4.7$ )	84.1 ( $\pm 15.8$ )	95.9 ( $\pm 11.9$ )	103.2 ( $\pm 13.6$ )	85.1 <sup>b</sup> ( $\pm 12.4$ )	86.1 <sup>b</sup> ( $\pm 9.5$ )
Athlete/Non-recent concussed	93.5 ( $\pm 11.0$ )	77.2 ( $\pm 11.6$ )	96.2 ( $\pm 12.1$ )	103.5 ( $\pm 9.9$ )	89.3 ( $\pm 5.6$ )	88.2 <sup>a</sup> ( $\pm 4.2$ )
Athlete/Recent concussed	77.4 <sup>a,c</sup> ( $\pm 16.9$ )	81.4 ( $\pm 8.8$ )	91.0 ( $\pm 17.2$ )	101.4 ( $\pm 15.7$ )	87.6 <sup>a</sup> ( $\pm 4.2$ )	83.8 <sup>b</sup> ( $\pm 6.4$ )

<sup>a</sup> $P \leq 0.05$  and <sup>b</sup> $P < .01$  vs. Non-athlete/Non-concussed; <sup>c</sup> $P < .05$  vs. athlete/Non-recent concussed.

Table 3

Mean ( $\pm$ SD) latencies obtained on the three Stroop tasks for the four groups of subjects

Group	Three Stroop tasks		
	Block colors	Colored non-sense words	Color word interference
Non-athlete/Non-concussed	18.1 ( $\pm$ 3.5)	18.5 ( $\pm$ 2.8)	28.1 ( $\pm$ 5.4)
Athlete/Non-concussed	19.3 ( $\pm$ 3.8)	19.6 ( $\pm$ 3.5)	26.4 ( $\pm$ 8.2)
Athlete/Non-recent concussed	21.9 ( $\pm$ 3.9)	20.4 ( $\pm$ 2.9)	24.5 ( $\pm$ 3.9)
Athlete/Recent concussed	15.8 ( $\pm$ 3.1)	16.8 ( $\pm$ 2.4)	22.3 ( $\pm$ 3.2)

concussed groups). Finally, the most extreme impairment on the RBANS was in the immediate memory domain for participants serving in the Athlete/Recent concussed condition. Not only were these subjects, as noted above, impaired relative to the control group, but they also exhibited significantly lower immediate memory scores relative to the Athlete/Non-recent concussed group ( $P < .05$ ).

### 3.2. Postconcussion Syndrome Checklist

No significant differences among the four groups of subjects were detected when the scores from the Postconcussion Syndrome Checklist were analyzed with a one-way ANOVA for independent samples [ $F(3, 24) < 1.0$ ,  $P > .05$ ] ( $M$ 's  $\pm$  S.D.'s: Non-athlete/Non-concussed =  $3.1 \pm 1.4$ ; Athlete/Non-concussed =  $2.9 \pm 0.9$ ; Athlete/Non-recent concussed =  $3.3 \pm 0.9$ ; and Athlete/Recent concussed =  $3.5 \pm 0.8$ ).

### 3.3. Stroop Task

Again, one-way ANOVAs for independent samples were used to analyze between-group differences. Results from these analyses indicated no statistically significant effects when the latency scores from the Stroop task were analyzed [all  $F$ 's(3, 24)  $< 2.75$ , all  $P$ 's  $< .05$ ] (see Table 3).

### 3.4. Correlations

Scores from the RBANS and latencies from the three Stroop tasks were correlated (Pearson  $r$ ) with subjects' Postconcussion Symptom Checklist scores, Concussion Index, and number of years since last concussion. Results from these analyses indicated that Postconcussion Symptom Checklist scores from the two athlete concussed groups, taken together, were correlated negatively with subjects' attention [ $r(9) = -.65$ ,  $P < .05$ ], delayed memory [ $r(9) = -.61$ ,  $P < .05$ ] and total [ $r(9) = -.59$ ,  $P = .057$ ] scores from the RBANS. Also of interest was the fact that the aggregate RBANS immediate memory scores derived from the two athlete concussed groups showed a non-statistically significant trend toward correlating positively with the number of years since last concussion [ $r(9) = .53$ ,  $P = .10$ ], suggestive of a recovery effect. Moreover, statistically significant correlations were detected when the analyses were limited only to those scores derived from the Athlete/Recent concussed condition. Despite the small

number of subjects in this group, delayed memory scores on the RBANS correlated negatively with subjects' Postconcussion Symptom Checklist scores [ $r(3) = -.90, P < .05$ ], indicating that delayed memory scores on the RBANS may be a good predictor of the extent of sub-clinical neuropsychological impairment. Finally, because processing speed on the Stroop color word interference task in recently concussed athletes was correlated with severity of head injury (as assessed with the Concussion Index) [ $r(3) = .90, P < .05$ ], processing speed may be especially vulnerable to the deleterious effects of more severe recent head injuries.

#### 4. Discussion

The present study's general aim was to characterize the neuropsychological consequences of head injury in college athletes who participate in contact sports using primarily the RBANS. Consistent with the animal literature on brain injury (Hicks, Smith, Lowenstein, Saint Marie, & McIntosh, 1993; Tang, Noda, Hasegawa, & Nabeshima, 1997; Zhou & Riccio, 1995), athletes who reported a recent concussion performed more poorly than control subjects in both immediate and delayed memory domains. Such deficits were specific to memory in that the other cognitive domains assessed by the RBANS were unaffected. Moreover, the enduring residual nature of this memory impairment was evidenced by the fact that the present definition of "recent concussion" included injuries that had occurred within the last 2 years. Additionally, of the two memory domains investigated, the data indicated that immediate memory may be especially vulnerable to the deleterious effects of head trauma in that subjects in the Athlete/Recent concussed group scored lower on this RBANS sub-scale than subjects in the Athlete/Non-recent concussed condition. Said another way, impairments in delayed memory, unlike immediate memory deficits, may resolve with sufficient "bench time." The prospect that such recovery may be time-dependent is reflected in some of our concussed subjects anecdotally reporting having been allowed an adequate amount of time to recuperate, especially in cases of severe concussions, and the non-statistically significant trend of RBANS immediate memory scores derived from the two athlete concussed groups correlating positively with the number of years since last concussion. Finally, other factors such the genotype of our participants (Crawford et al., 2002; Liberman, Stewart, Wesnes, & Troncoso, 2002), the age at which the head injury occurred (Field et al., 2003), and the level of collegiate divisional play (Guskiewicz, Weaver, Padua, & Garrett, 2000) may also have contributed to our findings.

More provocatively and somewhat surprising, the results from the present study also indicated impairments of memory in athletes who reported never having a diagnosable concussion. Thus, the rigor and physical nature associated with participating in contact sports may lead to mild brain injury engendering a certain degree of sub-clinical neuropsychological vulnerability (Rutherford et al., 2003), an effect not unlike that which has been observed in experimental animal models (Hicks et al., 1993). Specifically, it is hypothesized that over time the brain may be especially vulnerable to cumulative mild concussive effects even in the absence of a head injury sufficiently severe to produce a diagnosable concussion or, for that matter, in the absence of significant disturbances to behavior or in mental processing. To be sure, poor test performance does not necessarily indicate the existence of brain damage. Moreover, the study's relatively small cell sizes urge caution when interpreting its findings. But in light of

these disclaimers, the present findings raise a compelling empirical question and have led to the current hypothesis. Consistent with this hypothesis are recent suggestions in the literature that self-report of postconcussion symptoms, especially those associated with memory function (Field et al., 2003), may not accurately reveal the impaired neuropsychological status of head-injured athletes (Delaney, Lacroix, Leclerc, & Johnston, 2002). Ideally, in order to properly assess the impact of head trauma in athletes, participants in contact sports should be administered a pre-season neuropsychological evaluation as a means of establishing baseline parameters (McKeever & Schatz, 2003).

Another interesting finding of the present study was the fact that non-athletes outperformed athletes with respect to the total score of the RBANS. Although this finding was primarily rooted in the poor memory scores of athlete participants, it does lend credibility to the value of using the total RBANS score as a means of assessing global neuropsychological function in collegiate athletes. While we conclude that this finding reflects the increased neuropsychological risk of athletes who participate in contact sports, this result may be more mundanely related to differences in the general intellectual ability of our subjects. This is especially relevant given the fact that prior research examining the relationship between the total scale score of the RBANS and the short-form of the WAIS-R indicated a fairly strong correlation ( $r = .78$ ; Randolph, 1998). However, closer examination of the RBANS subscales reveals that this is unlikely to be the case. Statistically significant differences between athletes and non-athletes were evidenced only in one domain—memory. Moreover, if general intellectual ability were the reason for group differences, one would expect between group differences to exist in other cognitive domains, such as processing speed, an effect that was not observed. Finally, subjects failed to differ on self-reported college GPAs with the average GPA for all four groups of subjects exceeding the institution's definition of "average" academic performance (see Table 1). Thus, it seems reasonable to conclude that group differences do not reflect a disparity in the general intellectual ability of our subjects, but rather reveal a neuropsychological vulnerability resulting from participating in contact sports. It is worth noting, however, that Postconcussion Symptom Checklist scores from the two athlete concussed groups, taken together, were correlated negatively with subjects' scores on the attention sub-scale of the RBANS suggesting that decrements in attention may mediate some of the impairments of memory observed in our subjects.

Although it was not a surprise to discover that recent concussed athletes scored lower than control subjects and non-recent concussed athletes in both memory domains, the finding that non-concussed athletes also performed worse was, as mentioned above, rather unexpected. Such group differences were evident despite the presence of several characteristics that might have otherwise militated against finding statistically significant results. The small sample size, for example, minimized the statistical power of the study. In addition, non-clinical subjects were administered a neuropsychological measure that was originally designed to assess dementia. That statistically significant differences were evidenced despite the presence of mitigating factors render the present findings quite striking. Results may be owed both to the sensitivity of the neuropsychological measure used as well as to the robustness of the effect. Although the RBANS is a relatively new test, recent studies indicate its sensitivity and utility in both clinical (Beatty et al., 2003; Gold et al., 1999; Larson et al., 2003; Randolph et al., 1998; Wilk et al., 2002) and non-clinical (Moser & Schatz, 2002) populations. The present study adds to

a seeming growing body of literature supporting the psychometric properties of the RBANS, especially considering the negative relationship found herein between delayed memory scores on the RBANS and Postconcussion Symptom Checklist scores in subjects serving in the Athlete/Recent concussed condition.

Interpretation of the present findings is bound by certain factors. First and foremost, the study's small sample size compromises its external validity. Thus, caution needs to be taken when attempting to generalize the current findings. In addition, independent groups were established on the basis of self-report data, which may yield less validity than other, more objective, sources (Birdsong, Lash, Thayer, KumeKawa, & Becker, 1992). Future research on concussion in college athletes, therefore, would benefit from supplementing subjects' self-reports with information about the subject obtained from other sources, such as from each subject's doctor, trainer, or coach. Moreover, subjects' general medical histories should be assessed in order to implement more stringent criteria for group selection, thus minimizing within group variance. Given that many of our subjects had been participating in sports for many years, a more detailed assessment of the frequency, duration, and intensity of pre-college and college competitive play might enable future researchers to determine whether the emergence of neuropsychological deficits co-varies with the extent of head trauma (Hinton-Bayre & Geffen, 2002). This is especially relevant given our observed correlation in recently concussed athletes between processing speed on the Stroop interference task and severity of head injury as reflected in subjects' Concussion Index scores. Finally, assessing the duration of "bench time" would enable researchers to test the assumption put forth in the present study that rest from sport participation buffers athletes from the deleterious effects of contact play.

While we are limited in our interpretations of the present study, its findings have compelling implications that highlight the importance of continued exploration in this area of research. Moreover, because impairments were evident even in subjects herein who did not have a history of concussion, an additional practical implication provided by our data is that periodic rest-from-play intervals should be systematically instituted to minimize participation-related neuropsychological deficits in athletes who participate in contact sports.

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