ORIGINAL ARTICLE

Concussion history is not a predictor of computerised neurocognitive performance

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Background: The long term effects of self reported concussion on neurocognitive functioning have been found to be variable.
Objectives: To evaluate cognitive performance on the Headminder concussion resolution index (CRI) and ImPACT assessment tests of subjects with and without a history of self reported concussion.
Methods: A retrospective analysis was completed on 235 Headminder CRI baseline assessments and 264 ImPACT baseline assessments. Participants were divided into four groups on the basis of reported number of concussions (zero, one, two, or three). Multivariate analysis of variance was used to evaluate differences between the concussion history groups on the two computer based concussion assessment programs.
Results: Multivariate analysis of variance indicated no significant difference between those with and without a history of concussion on the CRI ($\Lambda = 0.963$, $F_{(15,\ 627.05)} = 0.57$, $p = 0.898$). It also revealed no significant differences between groups on the ImPACT test ($\Lambda = 0.951$, $F_{(12,\ 672.31)} = 1.07$, $p = 0.381$).
Conclusions: The results suggest that either long term cognitive decrements may not be associated with a history of concussion or the decrements may be subtle and undetectable by these computer programs.

Concussion evaluation has undergone considerable changes in the previous decade with the addition of objective tests to complement the physical assessment. Experts now recommend that the concussion assessment protocol include a battery of tests that evaluate self reported concussion related symptoms, postural control, and neurocognitive functioning.[1] Advances in technology allow the postural control and neurocognitive assessments to be completed using computer driven tests. Computer assessments show improvement over traditional testing by meliorating measurement precision of postural sway and cognitive features such as reaction time.[2–5] Although the neurocognitive evaluation is suggested to be the cornerstone of the evaluation, each facet of the assessment battery provides critical information to the clinician making a diagnosis and return to play decision.[6]

Concussion assessment in sport is unique in that there is access to the subject before injury. Athletes at high risk of concussion often perform a baseline test to establish ''normal'' functioning in a pre-concussed state. If an athlete subsequently sustains an injury, the same assessment battery is re-administered. This protocol allows the clinician to establish the level of decrement after injury, track improvements, and make a return to play decision. Some post-concussion assessment protocols are performed serially,[2 7] although it is now advocated that no testing is performed until the athlete is symptom-free to decrease the potential for practice or learning effects.[8] Regardless of the assessment methodology, cognitive deficits associated with sport concussion commonly resolve spontaneously within a matter of days of the injury.[2 9 10]

However, the long term consequences of concussion have yet to be clearly established. There is some evidence that chronic deficits in cognitive functioning may result from multiple sport related concussions. Using a pencil and paper assessment battery, Collins *et al*[11] reported that athletes with two or more concussions performed worse on tests that evaluated executive functioning and information processing. Differences on a similar assessment were also found between jockeys who reported no concussion history and those who reported up to two previous injuries.[12] Pencil and paper assessment batteries have also shown no difference between those suffering multiple sport related concussions and those reporting no history of injury.[13] Furthermore, Iverson *et al*[14] found no difference in the baseline performance on the ImPACT test in those with and without a concussion history. Similarly, a study of Australian rules footballers found no difference between self reported concussion history groups (up to four or more injuries) on the computerised CogSport assessment.[15]

The long term effects of sport concussion are clearly of concern to athletes and the medical personnel charged with their care. Any permanent cognitive deficits resulting from concussion will have life long consequences, yet the evidence is not clear if these deficits exist.

The conflicting body of available research led us to replicate the investigations of Iverson *et al*[14] and Collie *et al*[15] with two distinct computer based assessment programs: the ImPACT and the Headminder concussion resolution index (CRI).

METHODS

This study was completed retrospectively, as data were collected as part of an ongoing sport related concussion study. Over a two year period, a total of 244 collegiate athletes (199 male, 45 female) were administered the CRI (Headminder, Inc, New York, New York, USA) as part of their preseason screening at two universities. We removed any participant from the cohort if they reported attention deficit disorder or learning disability diagnosis (n = 9). These factors have been shown to influence performance on neurocognitive assessments.[11] Each athlete completed a baseline CRI evaluation after reading and signing an informed consent form approved by the respective institutional review board. American footballers accounted for 77.9% of the sample, and women's soccer (11.9%), cheerleading (7.2%), men's basketball (1.7%), and softball (1.3%) were

also represented. The CRI evaluation includes a brief questionnaire designed to collect basic information including age (mean (SD) 20.41 (1.78) years) and the previous number of self reported concussions. We categorised each athlete into one of four groups on the basis of the previous number of reported concussions: zero (n = 163), one (n = 43), two (n = 18), or three (n = 11).

In 2004 and 2005, a total of 270 athletes (187 male and 83 female) were administered the ImPACT assessment (ImPACT Applications, Pittsburgh, Pennsylvania, USA) as part of their preseason screening at one university. Participants who reported an attention deficit disorder or a learning disability diagnosis were removed from further analysis (n = 6). The mean (SD) age of the athletes was 20.07 (1.41) years, and American footballers again represented the largest athlete group, with 57.9% of the sample. Other sports such as women's soccer (13.0%), cheerleading (12.3%), basketball (11.9%), equestrian (2.7%), gymnastics (1.9%), and track and field (0.4%) were also represented. The previous number of concussions reported by this group was as follows: zero (n = 173), one (n = 62), two (n = 15), three (n = 11). All participants read and signed an informed consent form approved by the institutional review board before being tested. Some participants may have completed both the CRI and ImPACT assessments. No athlete reported more than three previous concussive injuries when taking either test.

The CRI is an internet based neuropsychological assessment tool. As previously reported,[4] the test consists of six sub-tests that evaluate cognitive functions such as memory, learning, and information processing speed. Scores from these measures are compiled into three speed scores (simple reaction time, complex reaction time, and processing speed index) and two error scores (simple reaction time errors and complex reaction time errors). The CRI test is sensitive to the effects of concussion,[16] and time to complete a baseline administration is about 20 minutes.

ImPACT is a computer based assessment tool which was developed to evaluate cognitive functioning for concussion assessment. It has been reported to be sensitive to changes in neurocognitive performance after concussion.[17] Briefly, the assessment consists of six modules which are compiled to produce four output scores: verbal memory composite, visual memory composite, visual motor speed composite, and reaction time composite. The ImPACT test was administered according to the manufacturer's recommendations and took approximately 20–25 minutes to complete.[18]

Means and standard deviations were first calculated for each output variable by concussion history group for each of the computer assessments. Box's test evaluated violations to the assumption of covariance matrix homogeneity. We then implemented separate multivariate analyses of variance to evaluate differences between groups for cognitive variables on the CRI and the ImPACT baseline data. A multivariate approach was used as recommended by Kesselman[19] for groups with unequal sample sizes. Statistical significance was assumed at $p<0.05$. All data were evaluated using SPSS version 13.0 (SPSS Inc, Chicago, Illinois, USA).

RESULTS

Tables 1 and 2 present means and standard deviations of the cognitive output scores for the CRI and ImPACT assessment test, respectfully.

A violation to the assumption of covariance matrix homogeneity occurred in the CRI data ($M = 220.05$, $F_{(45,4747.82)} = 4.31$, $p<0.01$). A violation to the assumption of covariance matrix homogeneity also occurred in the ImPACT data ($M = 69.17$, $F_{(30,4462.45)} = 2.08$, $p<0.01$). An evaluation of the log determinates from both datasets indicated a positive relation with group sample size, resulting in a conservative test statistic and a reduction in type I error probability. Multivariate analysis of variance indicated no significant difference between groups with varying history of concussion on the CRI baseline assessment ($\Lambda = 0.963$, $F_{(15, 627.05)} = 0.571$, $p = 0.898$, $\eta^2 = 0.012$) or on the ImPACT baseline assessment ($\Lambda = 0.951$, $F_{(12, 672.31)} = 1.07$, $p = 0.381$, $\eta^2 = 0.017$).

DISCUSSION

This study sought to replicate previous research[14 15] by evaluating baseline performance in those with and without a history of self reported concussion on two computerised neurocognitive assessments. Our data indicate that baseline performance on the CRI and ImPACT concussion assessments do not differ between subjects reporting up to three previous concussions. This information is part of a growing body of literature suggesting that either concussions do not result in chronic changes to cognitive functioning or the computerised neurocognitive batteries administered here do not provide adequate sensitivity to detect subtle decrements.

The evaluation by Iverson *et al*[14] of a mixed sample of high school and amateur athletes showed no differences in performance in those with and without a history of concussion. Athletes were divided by self reported concussion history (up to two) and evaluated on the computerised ImPACT concussion assessment test. The authors concluded that if any long term deficits resulted from concussion, they were small and probably negligible. The evaluation by Collie *et al*[15] of Australian footballers reporting up to four or more previous concussions also found no difference in baseline performance. Other assessments using pencil and paper assessments of exclusively collegiate[13] and professional athletes[20] have shown no difference in neurocognitive performance in those with and without a history of concussion. Guskiewicz *et al*[13] reported similar performance in baseline assessments of 187 participants on a pencil and paper neuropsychological test battery between those reporting previous concussion (up to two) and those without previous injury. In addition, professional American footballers with a history of three or more concussions also showed no difference on a similar pencil and paper assessment

Table 1 Headminder concussion resolution index output scores by previous history of concussion (N = 235)

Self reported concussion history	Complex reaction time	Complex reaction time errors	Simple reaction time	Simple reaction time errors	Processing speed index
Zero (n = 163)	0.70 (0.14)	6.39 (7.75)	0.35 (0.09)	1.94 (4.82)	3.01 (0.80)
One (n = 43)	0.71 (0.11)	6.81 (8.73)	0.36 (0.10)	2.47 (5.97)	2.83 (0.76)
Two (n = 18)	0.68 (0.11)	3.44 (3.29)	0.35 (0.08)	0.50 (0.79)	2.88 (0.57)
Three (n = 11)	0.71 (0.13)	5.00 (4.20)	0.36 (0.07)	0.55 (0.52)	2.83 (0.48)

Values are mean (SD).

Table 2 ImPACT cognitive output scores by previous history of concussion (N = 264)

Self reported concussion history	Memory composite (verbal)	Memory composite (visual)	Visual motor speed	Reaction time
Zero (n = 173)	0.87 (0.09)	0.76 (0.13)	36.99 (7.30)	0.55 (0.07)
One (n = 62)	0.86 (0.09)	0.75 (0.13)	36.43 (7.53)	0.56 (0.07)
Two (n = 18)	0.88 (0.07)	0.77 (0.15)	33.95 (5.74)	0.63 (0.14)
Three (n = 11)	0.93 (0.08)	0.81 (0.16)	39.91 (11.99)	0.57 (0.18)

Values are mean (SD).

battery when compared with those with fewer than three injuries.[20]

Non-significant differences between groups with and without a self reported concussion history may have resulted from one of two possibilities. Firstly, no true differences in neurocognitive functioning may exist between those with and without a history of concussion. Sport related concussion has been described as a transient change in neural functioning, rather than a structural change, which resolves spontaneously within a short time.[1] Animal model studies have shown that a large flux in ions within the cerebral tissue occurs at the time of injury. The imbalance ultimately corrects itself in 7–10 days[21] with the potential for cognitive impairment to occur in the interim. Once the ion shift is corrected, cognitive functioning is restored to the pre-injury state with no long term deficits.

Secondly, Iverson *et al*[14] stated that, if chronic neurocognitive changes do result from concussion, they may be exceptionally small. This would suggest that the computer based concussion assessments used by Iverson *et al* and in this study may not be sensitive to subtle changes in neurocognitive performance associated with the potentially chronic effects of concussion. Previous authors have suggested that one advantage of computer based assessments over the pencil and paper batteries is improved sensitivity to slight changes in cognitive performance immediately after injury. In particular, computer assessments can accurately measure reaction time to the thousandth of a second.[22] Our data did not show differences between groups with and without a self reported concussion history, although it is not known if this aspect of cognitive functioning was directly affected by the injury. If the injury vitiated this cognitive feature, then normal functioning was restored to a level that is undetectable by the computerised tests.

Less sophisticated assessment methodologies have proven effective in detecting long term changes in cerebral functioning after concussion. Collins *et al*[11] performed baseline evaluations on 393 collegiate American football athletes using a pencil and paper assessment battery. The 78 athletes who reported two or more previous concussions performed worse on the trail making B and symbol digit modalities tests than those with no concussion history or only one previous concussive injury. Athletes with only one previous concussive injury did not differ from those reporting no concussion history. This sample included athletes reporting a diagnosed learning disability, but no interaction between reported concussion history and a learning disability on neurocognitive performance was reported. A similar battery of tests was also used to evaluate the baseline performance of 618 jockeys who reported previous concussive injuries. Significantly worse performance was reported on the digit-symbol and colour trails 2 tests.[12] Significant differences seen on pencil and paper tests in these studies may have resulted from measuring different cognitive domains from those assessed by the computerised tests.

The use of a neurocognitive evaluation should continue to be included in the concussion assessment protocol. The CRI and ImPACT tests are both sensitive to acute changes in neurocognitive functioning immediately after concussion. Schatz *et al*[17] evaluated 72 concussed athletes and 66 non-concussed athletes using the ImPACT test. The test correctly identified 82% of the concussed participants. Similarly, Erlanger *et al*[16] reported that 88% of 26 concussed participants were borderline or impaired on cognitive function on one or more of the CRI indices. Sensitivity to concussion may be improved when self reported symptomatology is also evaluated immediately after injury.[23]

Although this study supports other literature showing no difference in baseline performance in those reporting a history of concussions, certain confounding variables may be present in our retrospective study design. The cross sectional analysis does not permit the tracking of individual subject performance and evaluation of cognitive changes that may have occurred with each successive concussion. A prospective investigation tracking the collective influence of concussions on cognitive functioning may better elucidate this matter. The study design also did not allow us to verify self reported data, leaving the potential for differences in the true number of previous concussions sustained by our participants and the quantity reported. Using a large sample of high school athletes, McCrea *et al*[24] found that nearly 53% of concussed athletes did not report their injury to any medical staff. The under-reporting of concussions was related to a lack of comprehension of the importance of the injury, and 36% of the injured athletes did not recognise that they had sustained a concussion. We therefore find it feasible that concussions may have occurred during sport participation before baseline testing at the current institution. The validity of self reported concussion history may be decreased if concussive injuries went unreported.

Finally, we do not know the nature of any of the injuries. Most of the reported injuries were probably a result of sport participation and therefore probably mild traumatic brain injuries. Some injuries, however, may have resulted from other incidences such as falls or automobile accidents and may therefore have been more severe. Other information on the presence or absence of amnesia, loss of consciousness, length of confusion after injury, and duration of symptoms may also have provided some insight into the concussion severity.

CONCLUSIONS

Research findings are making the cumulative effects of cerebral concussion become clearer. Our results support other findings obtained using both computerised and pencil and paper evaluations of the long term effects of sport concussion.[13 14] Chronic neurocognitive decrements from sport concussion may be subtle and undetectable by these assessment techniques or the impaired domains may not be evaluated by the computerised tests. In addition, functional, rather than structural, changes in neurocognitive functioning may later be reversed. These findings deviate from some previous results; however, different sample populations and/or test instrumentation may be a factor. Until putative

What is already known on this topic

- Transient changes in cognitive status are often reported to result from sport related concussion
- Research is mixed on the long term effects of concussion on neurocognitive functioning

What this study adds

- This study adds to a growing body of literature indicating that athletes who report a previous history of concussion do not differ from those without a concussion history on computerised baseline neurocognitive assessments

evidence is presented, the neurocognitive evaluation should remain a part of the assessment battery. These tests have shown sensitivity to the immediate effects of concussion when used in the baseline/follow up model. Baseline scores serve as self controls and offer the most precise information for return to play decisions after a concussive incident.

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COMMENTARY

This paper adds to the growing body of evidence that self reported history of concussion does not predict current cognitive state. In this journal over the past 18 months, three different groups of researchers have examined this issue using three different computerised cognitive test systems (Headminder, CogSport, and ImPACT) in relatively large samples of athletes. All three groups have arrived at the same conclusion. Although this issue can only ever truly be answered by long term, prospective research, the evidence is mounting that self rated history of concussion has very little association with the athlete's current level of cognitive function.

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