SHORT REPORT

Neuropsychological dysfunction following repeat concussions in jockeys

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Background: Single and repeat concussions have a high prevalence in sport. However, there is limited research into longterm risks associated with single and repeat concussions.
Objectives: To determine the effects of single and repeat historical concussions on the neuropsychological functioning and neurological reports of licensed jockeys.
Methods: Six hundred and ninety eight licensed jockeys in the UK were assessed for neurological and neuropsychological symptoms of concussion at least three months after potential episodes.
Results: Jockeys reporting multiple historical injuries versus a single injury showed reliable decrements on a measure of response inhibition and, to a less robust degree, on divided attention. Younger adults showed greater vulnerability.
Conclusions: Repeated concussion is associated with reliable decrements in cognitive performance—even after a three month window for recent recovery.

Approximately 20% of head injuries in the UK are sustained during sports activities.[1] Mild brain injury can result in stress and strain to the neural and/or vascular brain systems, causing neurones to become dysfunctional and potentially vulnerable to subsequent injury.[2] Repeat injury is common in sports.[3 4] However, little is known about the longterm effects of single and/or repeated concussion, or the influence of complicating factors such as age.[5 6]

The identification and management of concussion have recently begun to receive greater attention, particularly in sport. Concussed athletes may be suspended from play for a period of recovery. The length of this ''time out'' period remains controversial because grading systems to classify concussion severity—and hence ''return to play'' decisions—have not received clear empirical support.[7]

Evidence of concussion is difficult to establish. Neuroimaging techniques and electrophysiological measures have had varied success.[6 8 9] Self rating scales for concussion are routinely used, yet the base rate of post-concussion symptoms (PCS) using such scales is high among non-injured controls.[10] Neuropsychological testing has been advocated as a key component in assessing concussion.[2] Most neuropsychological studies report that patients with single, uncomplicated injury show full recovery within three months, with a small number reporting persisting problems.[11] There is much controversy regarding the effects of repeat concussion. In younger men (under 18 years), repeated versus single concussion has been associated with cognitive dysfunction.[12] Macciocchi and colleagues[13] reported that the neuropsychological consequences of two concussions sustained more than two weeks apart did not differ from those of a single injury, whereas Collins and colleagues[3] found that multiple concussion was associated with a worse performance on tasks involving complex attention.

The aim of our study was to identify whether single and multiple historical concussions are associated with deficits in neuropsychological functioning and self-reports of neurological symptoms. We also explored whether age was associated with a greater risk of identifiable symptoms of concussion, after reports that young adults may be more vulnerable to longterm consequences.[1 14]

METHODS

A database was established by the Jockey Club to provide a baseline for monitoring UK licensed jockeys. The database contains demographic background, reports of past concussion(s), neurological symptoms, and neuropsychological test performance. Ethical approval for the study was granted by the Universities of Exeter and Manchester and the Jockey Club, UK.

Demographic information collected included sex, age, years of education, and alcohol consumption in the past 24 hours. Participants were asked to report any history of head injury/concussion, the total number and dates of injuries, and whether concussions were medically verified. In addition, participants were required to report any PCS experienced in the past month, responding to a ''yes/no'' list that included motor, sensory, somatic, cognitive, and mood items.

Participants completed several neuropsychological assessments: general cognitive level and speed of processing with the Speed of Comprehension Test[15]; immediate verbal recall on the Digit Span[16]; executive skills of response initiation/inhibition with the Stroop Neuropsychological Screening Test[17]; sustained and divided attention with Colour Trails 1 and 2[18]; and speed of visuospatial and motor processing with Digit Symbol-Coding.[16]

RESULTS

Data were available on 698 licensed amateur and professional jockeys tested at various locations throughout the UK. Consent for participation in research was provided by 89.8%, providing a research population of 627 ''baseline'' profiles. Nine jockeys' baseline assessments shortly followed a recent concussion; these were removed for the current analysis (N = 618). Ages ranged from 16 to 57 years (mean, 27.10; SD, 7.79); 76% were male and 24% were female. Nine (1.5%) were non-fluent English speakers.

Females reported longer in education than males ($t_{614} = 3.904$; $p < 0.001$; females: mean, 12.37 years; SD, 2.13; males: mean, 11.65; SD, 1.90). There were no sex differences in terms of age ($t_{613} = 0.83$; $p > 0.05$), numbers reporting concussion ($\chi_1^2 = 2.93$; $p > 0.05$), number of concussions ($t_{615} = 1.06$; $p > 0.05$), or number of PCS ($t_{607} = = 0.43$; $p > 0.05$).

Abbreviation: PCS, post-concussion symptoms

One hundred and eight reported historical concussion(s) three months before assessment: 69% male, 31% female. Four occurred during childhood, two in road traffic accidents, and the remaining 102 during sport. Only one case was reported as more severe than concussion/mild head injury. Time since concussion ranged from four months to 27 years (mean, 6.45 years; SD, 6.33). Jockeys reporting historical concussion(s) were reliably older than those reporting no concussion ($t_{614} = 3.15$; $p < 0.05$; no concussion: mean, 26.64; SD, 7.73; concussion(s): mean, 29.23; SD, 7.77), and reported longer in education ($t_{615} = 2.15$; $p < 0.05$; no concussion: mean, 11.75; SD, 1.98; concussion(s): mean, 12.20; SD, 1.97). The number of PCS did not differ ($t_{605} = 0.09$; $p > 0.05$).

Jockeys reporting historical concussion(s) made more Trails 2 "number" errors than those reporting no concussion ($F_{1,613} = 5.36$; $p < 0.05$; no concussion: mean, 15.40; SD, 2.64; concussion(s): mean, 14.69; SD, 3.78; lower score representing inferior accuracy; effect size (η_p^2) = 0.01; table 1). The result only approached significance after correction for unequal variances ($t_{130.12} = 1.84$; $p = 0.067$).

Twenty seven jockeys reported two or more historical concussions. Twenty reported two concussions or did not specify, four reported three, two reported four, and one reported five. Injuries were seven months to 13 years apart (mean, 4.97 years; SD, 4.22). Jockeys with multiple concussions reported longer in education than those with a single concussion ($t_{105} = 2.20$; $p < 0.05$; single: mean, 11.96 years; SD, 1.78; multiple: mean, 12.92 years; SD, 2.37). There were no differences in age ($t_{106} = 0.41$; $p > 0.05$), or number of PCS ($t_{106} = 1.01$; $p > 0.05$). Binary logistic regression was used to determine whether individual PCS were associated with predicting the probability that single or multiple concussions were reported. The predictive capacity did not improve relative to the constant only model.

Individuals reporting multiple historical concussions performed worse on the Stroop colour-word task than those reporting a single concussion ($F_{1,98} = 6.80$, $p < 0.05$; single concussion: mean, 103.42; SD, 10.51; multiple: mean, 97.74; SD, 12.73; $\eta_p^2 = 0.07$), and on Trails 2 ($F_{1,98} = 9.46$; $p < 0.005$; single: mean, 108.70; SD, 9.75; multiple: mean, 103.33; SD, 16.10; $\eta_p^2 = 0.09$). The Stroop task effect remained robust after correction for unequal variances ($t_{38.52} = 2.09$; $p < 0.05$), but the Trails 2 effect did not ($t_{32.58} = 1.64$; $p > 0.05$).

The Stroop task effect was not moderated by age ($F_{4,98} = 0.54$; $p > 0.05$). However, the effect of concussion on Trials 2 standard scores reliably altered according to age ($F_{4,98} = 2.66$; $p < 0.05$; $\eta_p^2 = 0.10$), with younger jockeys showing greater effect of multiple concussion than older jockeys, confirmed by an interaction contrast ($F_{1,98} = 7.30$; $p < 0.01$; $\eta_p^2 = 0.07$).

DISCUSSION

Our results show that single concussion may not lead to clear decrements in performance in athletes, although there is a suggestion of somewhat less efficient self monitoring. Multiple concussions were associated with clear decrements in high level executive/attentional functioning. Younger athletes were more at risk.

Our results are consistent with those of previous reports suggesting that uncomplicated cases of concussion may not necessarily lead to negative longterm consequences.[19] However, multiple concussions appear to be associated with worse longterm outcome.[3 7] Individuals with two or more concussions performed below those with a single concussion on the Stroop colour-word interference task, and, to a less robust degree, on Trails 2. This suggests that multiple concussions may interfere with executive skills, including response initiation/inhibition, divided attention, and concentration. This supports previous reports that attention/executive difficulties may follow multiple concussions.[3 7]

Our findings suggest that younger jockeys may be more affected by multiple concussions. Although there are concerns regarding the robustness of this effect, Ogden and Wolfe[14] similarly reported a greater effect of concussion among young adults on the Trail-Making Test, Part B. Particular neural regions, such as the frontal lobes, do not consolidate development until late adolescence,[20] and thus their functions may be more susceptible to disruption. Therefore, monitoring young adults who sustain multiple injuries may be particularly important.

Unlike previous studies,[21 22] there were no sex differences in terms of the number of concussions or PCS, or the effects of concussion on neuropsychological performance.

Our study has certain limitations. Individuals with a history of concussion are probably more motivated in testing to ensure that they remain in the sport. Therefore, caution is warranted when considering concussed versus non-concussed participants, and for the veracity of self reports in general. It is also likely that a large proportion of jockeys reporting no past concussion may have sustained at least one, as a result of poor symptom education[23] or systematic under reporting.[24]

Future research is recommended to explore the effect of time between multiple concussions and the number of concussions, extending this research to a larger group of athletes.

Our current study underlines the need for the monitoring and management of concussion, particularly in sporting contexts, where prevalence and repeat injury are high. Historical versus no concussion was associated with no robust deficits. Multiple historical concussions were associated with longterm neuropsychological decrements.

Table 1 Test mean and SD for each group: no concussion, concussion (single and multiple), single concussion, and multiple concussion

	No concussion	Concussion (single and multiple)	Single concussion	Multiple concussion
Speed of Comprehension (scaled scores)	9.20 (3.26)	9.78 (3.15)	9.75 (3.02)	9.85 (3.57)
Digit Span (scaled scores)	9.03 (2.50)	9.3 (2.32)	9.33 (2.38)	9.22 (2.17)
Stroop colour word task (raw scores)	100.76 (13.75)	102.00 (11.32)	103.42 (10.51)‡	97.74 (12.73)‡
Colour Trails				
1; time taken (standardised scores)	98.02 (16.74)	97.56 (15.60)	97.96 (14.92)	96.37 (17.73)
2; time taken (standardised scores)	105.55 (3.18)*	107.36 (11.81)	108.70 (9.75)*‡	103.33 (6.10)‡
2; colour errors (percentile scores)	15.59 (2.19)	15.65 (2.00)	15.59 (2.25)	15.81 (0.96)
2; number errors (percentile scores)	15.40 (2.64)*†	14.69 (3.78)†	14.51 (4.08)*	15.26 (2.67)
Digit Symbol-Coding (scaled scores)	8.29 (2.62)†	8.88 (2.39)†	8.81 (2.32)	9.07 (2.62)

Values are mean (SD).
*Significant difference between those with no concussion and a single concussion; †significant difference between those with a no concussion and concussion (single and multiple); ‡significant difference between those with a single concussion and multiple concussion.

Increased vulnerability was found among younger participants. Concussion may not be the mild, transient state that traditional opinion has suggested.

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