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Multiple Concussions and Neuropsychological Functioning in Collegiate Football Players

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Objective: To document neurocognitive and neurobehavioral consequences of 1 versus 2 concussions.

Design and Setting: Nonequivalent, pretest-posttest cohort design with multiple dependent measures. Participants were selected from a large sample of athletes who participated in a comprehensive, multiuniversity study of football-related concussion.

Subjects: College football players who sustained 1 and 2 grade 1 concussive injuries were matched for age, education, and duration of competitive football.

Measurements: Neuropsychological tests and symptoms checklists.

Results: Multivariate analysis of variance did not show a statistically significant difference in test performance between players with 1 or 2 concussions. Chi square analyses revealed that concussions significantly increased the number of symptom complaints, but symptoms returned to baseline by 10 days postinjury. The effects of 2 injuries did not appear to be significantly greater than that of a single injury. Differences in response to concussion were observed.

Conclusions: Neurocognitive and neurobehavioral consequences of 2 concussions did not appear to be significantly different from those of 1 concussion, but methodologic issues place limitations on data interpretation. Additional studies are needed to clarify the neuropsychological consequences of multiple concussions.

Key Words: sports injuries, neuropsychological tests, symptoms

Over the past 15 years, research pertaining to concussive injuries sustained during athletic endeavors has increased substantially.[1] Findings from these studies have been generally consistent and suggest that concussive injuries in competitive American football can cause time-limited neuropsychological and neurobehavioral problems.[2–4] Although 1 concussion does not appear to result in significant morbidity, the effect of multiple concussions is less clear. In a recent study,[4] a posttest-only control group design was used to compare athletes who had a history of 1 concussion with athletes who had a history of 2 or more concussions. The authors found that athletes who sustained 2 or more concussions reported more neurobehavioral symptoms and had more impairment on selected neuropsychological tests than athletes who had a history of a single concussion. Despite the differences on some neuropsychological measures, athletes with a history of 1 versus 2 or more concussions did not differ on tests of auditory attention, verbal fluency, verbal learning, verbal memory, or fine motor dexterity.[4] In addition, players with 2 or more concussions were aggregated, and the effect of different numbers of concussions was not specified.[4]

Most studies investigating the effects of single or multiple concussions have been retrospective investigations using posttest-only designs.[1] Accordingly, we designed our investigation to prospectively examine the neurobehavioral and neuropsychological consequences of 2 concussive injuries. Players who sustained 2 concussions were compared with players who sustained 1 concussion using a nonequivalent, pretest-posttest comparison design. Players who sustained 1 concussion were used as controls in order to contrast the effects of 1 versus 2 concussions. As mentioned previously, several studies have shown that a single concussion is associated with time-limited neurocognitive impairment. As such, identifying neurocognitive impairment was not the primary focus of our investigation. The primary goal was to determine if a second concussion produced identifiable cognitive deficits above and beyond those observed after a single injury. Based on prior investigations, we hypothesized that players who sustained 2 concussions would evidence significantly greater neurocognitive dysfunction and postconcussive symptoms compared with players who sustained a single injury.

METHODS

Subjects

Participants in this study (n = 24) were selected from a larger sample of athletes who participated in a comprehensive

study of concussive injury in Division I-A collegiate football players. In the initial study, 2300 players were prospectively examined and followed for 4 years to determine the neuropsychological consequences of concussive injuries. During the study period, 195 players sustained grade 1 concussions based on contemporary classification guidelines.[1] Six percent of all players with documented concussions sustained 2 injuries (n = 12). Five of these athletes sustained concussions in the same year (mean separation, 33 days; range, 14 to 70 days), while 7 players sustained concussions in consecutive years (mean separation, 532 days; range, 364 to 686 days). Players who sustained 2 concussions (T_2) were compared with a selected cohort of players who sustained a single concussion (S). Players sustaining 1 concussion were selectively matched with players sustaining 2 concussions based on age, education, years in competitive football, and prior concussion history (none). Players with a single concussion (S) had a mean age of 19.5 years and a mean 8.4 years of experience in competitive football, and players with 2 concussions (T_2) had a mean age of 19.1 years and a mean 9.1 years of experience in competitive football.

METHODS

All players (n = 24) were assessed preseason to establish baseline functioning. In addition to completing a physical examination, players completed several neuropsychological measures, including the Paced Auditory Serial Addition Task (Brainmetric Software, Marlton, NJ),[5] the Trail-Making Tests A and B from the Halstead-Reitan Neuropsychological Test Battery (Reitan Neuropsychological Laboratory, Tucson, AZ),[6] and the Symbol Digit Test (Psychological Assessment Resources, Inc, Odessa FL).[7] These tests were designed to measure various aspects of visual and auditory attention as well as information processing speed. Psychometrics of these instruments can be obtained from various sources.[8] Players also completed a history questionnaire and a symptom checklist.

Players who were suspected of sustaining head injuries during practices or games were examined by certified athletic trainers and physicians using standardized medical and mental status procedures. Players' temporal and spatial orientation and short-term memory were systematically assessed after injury. Players failing items requiring intact orientation and memory were considered to have sustained a concussion and were continuously assessed until resolution of posttraumatic confusion. No players in our study experienced a documented loss of consciousness or posttraumatic confusion lasting longer than 30 minutes, which is consistent with a grade 1 concussion using the American Academy of Neurology and Virginia Neurologic Institute Standards.[1] Players who failed the mental status examination were then assessed at 24 hours, 5 days, and 10 days postinjury using the neuropsychological measures administered during the baseline assessment. Neuropsychological tests were administered by research staff trained in test administration.

RESULTS

Neuropsychological test scores and self-reported symptoms of players who sustained 2 injuries (T_2) were compared with test scores and symptoms of players who sustained a single injury (S) using a between-subjects multivariate analysis of variance (MANOVA). In addition, a within-subjects MANOVA was used to compare scores of players experiencing 2 injuries after their first (T_1) and second (T_2) injuries to determine if a second concussion produced a change in cognitive functioning. Additionally, players who were injured twice in close temporal proximity (mean separation, 33 days) were compared with players who sustained 2 injuries over 2 or more seasons (mean separation, 532 days). Finally, preseason and postseason scores of players with 2 injuries were compared using a within-subjects MANOVA to examine changes over time.

Mean test scores for each group are presented in Table 1. The MANOVA analysis revealed that the test results of players with a single injury (S) did not differ significantly from those of players who sustained 2 injuries, either at the time of their first injury (T_1: $F = 4.2$, $P < .06$) or second injury (T_2: $F = 1.09$, $P < .386$). Within-subjects comparison of players who sustained 2 injuries after their first injury (T_1) and second injury (T_2) revealed no significant differences in test performance ($F = 0.858$, $P < .514$). Comparison of players' preinjury test scores with postseason performance after their second injury revealed a trend toward improved performance ($F = 3.27$, $P < .108$). When the group sustaining 2 concussions was analyzed separately, no differences were noted in test performance between players who sustained injuries in close proximity or in successive seasons ($F = 1.12$, $P < .351$).

Players' self-reported symptoms (headache, dizziness, and memory loss) were summed before completing the analyses (Table 2). Statistical examination of the total number of symptoms using χ^2 analyses revealed a significant effect for time. Both groups (S and T_1) had a statistically significant increase in the number of players with symptoms (headache, dizziness, and memory loss) at 24 hours postinjury ($\chi^2_4 = 22$, $P < .001$) and 5 days postinjury ($\chi^2_4 = 40$, $P < .001$). In contrast, the number of players with symptoms at 10 days postinjury was not significantly different from the number with symptoms preseason ($\chi^2_4 = 0.20$, $P < .50$). Analyses of symptoms with respect to groups revealed significant differences in symptom reports (headache, dizziness, and memory loss) between group S (single injury) and group T_1 after their first injury ($\chi^2_2 = 10.6$, $P < .005$). Players who sustained 2 injuries did not evidence statistically significant differences in symptom reports after first injuries (T_1) and second injuries (T_2) ($\chi^2_2 = 1.41$, $P < .50$). The proportion of patients reporting symptoms also did not differ for players sustaining injuries in close proximity and players sustaining more remote injuries.

DISCUSSION

Our analyses suggest that 2 grade 1 concussive injuries sustained at least 2 weeks apart during competitive American football did not result in significantly more neurocognitive impairment than a single concussive injury. Compared with players who sustained a single injury, players who sustained 2 injuries performed as well as or better on all neuropsychological tests after their first and second concussions. In addition, after a second concussion, there was no evidence of a decrement in test performance relative to the performance observed after players' first concussions. Furthermore, players who sustained 2 concussions performed better on postseason assessments than on preseason examinations.

Analyses of self-reported symptoms revealed a significant effect for time after injury. The number of players reporting symptoms increased significantly after 1 or 2 injuries, but

Table 1. Test Scores in Players With 1 versus 2 Mild Head Injuries*

Test	Time				
	Preseason	24 h Postinjury	5 d Postinjury	10 d Postinjury	Postseason
Trail-Making A					
S	21	22	17.9	17	NA†
T_1	22.8	21.7	18.8	18.6	NA
T_2	22.8	17.6	16.9	15.9	16.6
Trail-Making B					
S	46.8	39	39.8	34.5	NA
T_1	50.5	40.1	35.2	36.1	NA
T_2	50.5	37.4	30.3	29.9	32.9
Symbol Digit					
S	55.7	57.8	62.2	61.3	NA
T_1	62.5	59.2	65.9	70.0	NA
T_2	62.5	61.5	68.8	71.4	71.4
Paced Auditory Serial Addition Task 3					
S	77	81.9	96	88.4	NA
T_1	82.5	86.7	94.4	93.8	NA
T_2	82.5	92.1	96.0	94.6	94.3
Paced Auditory Serial Addition Task 4					
S	65	62	78.5	88.1	NA
T_1	72.4	77.1	90.8	88.1	NA
T_2	72.4	86.6	90.2	93	88.4

*S indicates 1 concussion (control); T_1, 2 concussions (first injury); and T_2, 2 concussions (second injury).
†Not available.

Table 2. Number of Players Reporting Postconcussive Symptoms*

Time	No. Reporting Headache			No. Reporting Dizziness			No. Reporting Memory Loss		
	S	T_1	T_2	S	T_1	T_2	S	T_1	T_2
Preseason	4	3	3	1	1	1	1	1	1
24 h postinjury	8	4	5	2	3	4	2	2	4
5 d postinjury	4	8	7	0	4	5	2	3	3
10 d postinjury	4	2	4	0	2	2	2	1	0

*S indicates 1 concussion (control); T_1, 2 concussions (first injury), and T_2, 2 concussions (second injury).

symptom reports essentially returned to baseline by 10 days postinjury in both groups. The most commonly reported symptom in both groups was headache, but players who sustained 2 concussions reported more symptoms after their first and second concussions when compared with players who sustained a single concussion. Despite the presence of a differential response to the first injury, the frequency of players' symptoms after first and second injuries revealed no statistically significant increase in symptoms after a second injury, whether this injury occurred in close proximity to the first injury or at a more remote time. In other words, even though one group of players experienced more symptoms after their first injury, the responses to their first and second concussions were remarkably similar. Although interesting, the significance of these findings is not entirely clear. Differences in symptom reports could be due to normal variations in injury response accentuated by selective matching. In the future, variability in symptom reports after injury can be examined to assess whether players who experience prominent self-reported symptoms after a concussion are at greater risk for a second concussion.

Despite our findings, several methodologic issues merit discussion. First, the base rate of documented multiple injuries in our sample was quite low (6%).[3] As such, our data are based on a small sample of players who may not adequately represent the population of players who typically sustain multiple injuries. Second, all of our players sustained grade 1 concussions by contemporary classification standards.[9] Although the effect of injury severity is generally consistent across players, the cumulative effects of more severe injuries are unknown. Third, the timing of injuries in our study was variable. For example, only 2 players experienced a second injury within 2 weeks of their first injury. In fact, 7 players did not even sustain both injuries in the same year but rather within 12 to 24 months. Because neurocognitive impairment and neurobehavioral symptoms after 1 concussion resolve rather rapidly,[2–4] the extended time between injuries may have limited the in-

teraction between the first and second injuries. Most importantly, even though we observed no differences between players with proximal versus remote injuries, our sample was too small to definitively answer questions about injury proximity. Finally, none of our players sustained more than 2 concussions, which limits direct comparison with studies assessing players with as many as 10 concussions.[4]

In addition to sample size, injury frequency, and the timing of injuries, test sensitivity issues require comment. For example, a number of neuropsychological tests are susceptible to practice effects.[10] In our study, players who were injured twice were exposed to all tests on at least 7 occasions. Actually, despite being injured, players evidenced improved performance over time regardless of testing time (24 hours, 5 days, 10 days) or injury status (1 or 2 concussions). As such, the genuine neurocognitive consequences of concussions may be obscured by considerable exposure to tests. Of course, an injury with serious neuropsychological consequences would most likely reduce the influence of practice effects, but there was no evidence of a significant decline in neuropsychological test performance for any player in our sample.

A final issue deserving attention is the effect of group research on individual responses to concussion. For example, neurocognitive test data and symptom reports document variability in response to concussions with apparently equivalent clinical features such as duration of posttraumatic amnesia. In other words, the group that experienced 2 concussions did report more symptoms after their first injury, and this reporting continued after their second concussion. Consequently, group studies using aggregated data may obscure differential responses to and recovery from injury. In order to address this issue, investigators have recently recommended using reliable change indexes (RCIs) when conducting research.[11] RCIs are calculated using preinjury and postinjury scores, with mathematical consideration given to the standard error measurement and test reliability. In essence, RCI is a type of effect size. Calculating effect sizes of injuries for individual players may yield information that would be lost when summing group data. For example, players with large injury effects can be examined independently for relationships among injury severity, neurocognitive functioning, and neurobehavioral symptoms.

In spite of the study's limitations, our data suggest that 2 concussions do not result in a statistically or clinically significant increase in neurocognitive deficits relative to a single concussion. There is also no compelling evidence that self-reported symptoms are more common or severe after a second injury. Unfortunately, methodologic limitations do not permit generalization of these data to populations in whom injuries may be more frequent, may occur in closer temporal proximity, or may be more severe. Nonetheless, as documented by other studies, our data do suggest that self-reported symptoms may be sensitive indicators of postinjury neuropsychological impairment.[2] As such, the presence of symptoms should be given serious consideration in return-to-play decisions, regardless of neuropsychological test performance.[1] In any case, further research is needed to more closely examine the effect of multiple concussions on neuropsychological function. Until then, we can have modest confidence in the fact that, although undesirable, 2 grade 1 concussions occurring at least 2 weeks apart did not appear to produce significantly greater impairment than a single injury, at least in this population of collegiate football players.

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