Additional Post-Concussion Impact Exposure May Affect Recovery in Adolescent Athletes

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Abstract

Repeat concussion has been associated with risk for prolonged and pronounced clinical recovery in athletes. In this study of adolescent athletes, we examined whether an additional head impact within 24 h of a sports-related concussion (SRC) is associated with higher symptom burden and prolonged clinical recovery compared with a single-injury group. Forty-two student-athletes (52% male, mean age = 14.9 years) diagnosed with an SRC in a concussion clinic were selected for this study: (1) 21 athletes who sustained an additional significant head impact within 24 h of the initial injury (additional-impact group); (2) 21 single-injury athletes, age and gender matched, who sustained only one discrete concussive blow to the head (single-injury group). Groups did not differ on initial injury characteristics or pre-injury risk factors. The effect of injury status (single- vs. additional-impact) was examined on athlete- and parent-reported symptom burden (at first clinic visit) and length of recovery (LOR). Higher symptom burden was reported by the athletes and parents in the additional-impact group at the time of first visit. The additional-impact group also had a significantly longer LOR compared with the single-injury group. These findings provide preliminary, hypothesis-generating evidence for the importance of immediate removal from play following an SRC to protect athletes from re-injury, which may worsen symptoms and prolong recovery. The retrospective study design from a specialized clinical sample points to the need for future prospective studies of the relationship between single- and additional-impact injuries on symptom burden and LOR.

Key words: athletes; brain injury; concussion; mTBI

Introduction

A CONCUSSION IS A BRAIN INJURY caused by a direct or indirect blow to the head or body that results in significant movement of the brain, temporarily disrupting its metabolic and neurotransmission functioning.¹ Although the majority of adolescents with sport-related concussion (SRC) are reported to recover clinically within 3 weeks, a percentage of athletes continues to have persisting concussion-related symptoms.² Re-injury to the brain prior to full neurometabolic recovery has been hypothesized to increase impairment and prolong recovery.^{3–6} Animal models have demonstrated that a second injury to the brain sustained within 24 h of an initial injury can exacerbate the initial neurometabolic effects, leading to pronounced and prolonged recovery.^{3–6} A similar effect was implicated in a small human sample of adult male athletes ($n=3$), who demonstrated prolonged neurometabolic recovery on magnetic resonance (MR) spectroscopy following a second blow to the head within 15 days of the original SRC.⁷ To date, the effect of an additional head impact during the acute post-concussion phase has not been investigated as a risk factor for longer post-concussion impairment in youth athletes.^{3,4} Reducing risk of a second injury is

at the foundation of the national legislative movement for youth concussion state laws.⁸ Evidence to support the importance of early recognition of concussion and removal from play of the concussed athlete would help to bolster compliance with this mandate.

In this study, we examined whether sustaining a second blow to the head closely following an initial SRC leads to heightened symptom severity and prolonged recovery in middle school and high school athletes. Specifically, we predicted that an additional head impact within 24 h would be associated with higher symptom burden at the time of the first clinical visit, compared with an age- and gender-matched sample of adolescents with concussion who did not sustain an additional blow. We also predicted that youth athletes who sustained an additional head impact would have a longer length of recovery than that of single-injury athletes.

Methods

Participants

Forty-two middle and high school student-athletes (52% male, mean age = 14.9, standard deviation [SD] = 0.87, range = 13–16) diagnosed with an SRC were selected for this study. The diagnosis of

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concussion was initially made by the referring medical providers (athletic trainer, physician) using current clinical criteria (American Academy of Neurology, Centers for Disease Control and Prevention) and confirmed at the time of the clinic visit, using the same diagnostic standards. The two study groups were defined as follows:

1. Additional-impact group: Twenty-one participants sustained a significant blow to the head that caused concussion-related symptoms followed by an additional head impact, occurring >1 min and <24 h after the initial head impact. An additional head impact was defined as a direct blow to the head that caused additional symptoms or worsening of existing symptoms at the time of the second event. The second discrete blow to the head was required to occur >1 min after the initial injury for inclusion in this group to differentiate a distinct second head impact from a single injury involving two immediate hits (e.g., body to head contact, followed by head hitting the ground).
2. Single-injury group: A control group of 21 age- and gender-matched student-athletes who sustained a concussion from a single blow to the head were selected. Detailed and thorough interview of the athlete and parent determined definitively that no additional impact exposure was sustained. See Table 1 for group demographics and injury characteristics.

Inclusion in the study also required the availability of detailed clinical records describing the head impact(s), removal from play, and recovery time. Exclusionary criteria included a major medical condition (e.g., sickle cell, heart disease, etc.), developmental delays, abnormal brain imaging findings (if performed), or the second head impact occurring >24 h after the initial blow prior to recovery. Gender, age, and type of sport were evenly distributed between the groups. Multiple sports were represented in this sample, including soccer, football, lacrosse, wrestling, and ice hockey. According to parent and child report of the concussive events, zero athletes in the additional-impact group and 11 athletes (52%) in the single-injury group were immediately removed from play after the initial blow to

the head (see Table 1). As previously noted, the 10 athletes in the single-injury group who continued to participate did not sustain additional head impacts.

Given the retrospective design of this study, multiple measures were taken to reduce threats to internal validity associated with potential selection bias in this study. First and most significant, the selection process for all study participants, in both the additional-impact and single-injury groups was fully blinded to the dependent variables (length of recovery [LOR], symptom status). To minimize the likelihood of biased selection of the single-injury control group, two different samples of 21 gender- and age-matched control participants were selected for analysis relative to the additional-impact group. Finally, to further enhance the variability of the control group (and reduce the error of estimate), a third control group was generated with two age- and gender-matched control participants selected for every one of the 21 additional-impact athletes.

Procedure

As part of standard care, all participants underwent a clinical evaluation including a detailed account of the injury and review of relevant pre-injury risk factors for protracted recovery using the structured Acute Concussion Evaluation (ACE).⁹

Post-injury symptom breadth and severity was collected using the Post-Concussion Symptom Inventory (PCSI) using both the parent form (PCSI-P) and the adolescent (ages 13–18) self-report form (PCSI-SR13).¹⁰ The PCSI is a developmentally sensitive parent, and child and adolescent (5–18 years) graded symptom checklist validated for assessing post-concussive symptoms. Symptom ratings on both the 20-item parent PCSI form (PCSI-P) and the 21-item adolescent self-report PCSI form (PCSI-SR13) have exhibited strong internal consistency in youth with (Total score $\alpha = 0.90–0.94$) and without concussions (Total score $\alpha = 0.79–0.90$), and a satisfactory 2-week test-retest reliability (intraclass correlation coefficient [ICC] = 0.79–0.89).⁹

At the time of the first clinic visit, parents and adolescents provided ratings of current symptom status on the PCSI, rating the severity of each post-concussion symptom over the time frame of “yesterday and today.” Scores were computed through summing symptom severity ratings for the parent and adolescent forms, producing a PCSI Total Symptom score as well as four symptom subscales (physical, fatigue, emotional, cognitive). To control for the presence of “symptoms” pre-injury, participants also provided retrospective rating of these same symptoms prior to the injury, generating a retrospective baseline (RBL) score. Post-injury scores were statistically adjusted, via regression analyses, controlling for the RBL scores.

Participants in each group received the same process of individualized treatment based on their unique post-concussion symptom profile using an active, progressive model of symptom management and rehabilitation.¹¹ Approval for the study was obtained from the hospital Institutional Review Board.

Study design

Independent variable. Student-athletes were divided into the single-injury or additional-impact group based on the above criteria of sustaining either a single or additional blow to the head, respectively.

Dependent variables. Two dependent variables were defined in this study: (1) Athlete symptom burden was defined as the RBL-adjusted PCSI Total Symptom score on the adolescent (PCSI-SR13) and parent (PCSI-P) forms; (2) Athlete LOR was calculated as the days elapsed between the date of initial injury and the date of recovery. Date of recovery was determined by clinician based on child and parent report of the resolution of symptoms, along with supportive data indicating cognition, balance, and school performance having returned to normal functioning.

TABLE 1. DEMOGRAPHICS AND INJURY INFORMATION

	Single-injury (n = 21)	Additional- impact (n = 21)	P value
Age at injury ^a	14.9 (.89)	14.9 (.89)	n.s.
Males	52%	52%	n.s.
Injury information			
Days to first visit ^b	21 (13); 17	23 (19); 19	0.691
LOC	10%	5%	n.s.
Amnesia ^c	43%	24%	n.s.
Seizures	5%	0%	n.s.
Immediately removed ^d	52%	0%	.001
Patient history			
Previous concussion	31%	43%	n.s.
Headaches ^e	24%	43%	n.s.
Anxiety	0%	14%	0.072
History of depression	0%	5%	n.s.
History of ADHD	0%	5%	n.s.

^aData presented as mean (SD).

^bData presented as mean (SD); median. Represents the number of days between the date of initial injury and the date of first visit to the clinic.

^cIncludes both retrograde and anterograde amnesia.

^dImmediately removed from play following first concussive hit.

^eIncludes a history of non-migraine and/or migraine headaches.

ADHD, attention-deficit hyperactivity disorder; LOC, loss of consciousness; SD, standard deviation.

Statistical analysis

The effect of additional head impact exposure on athlete-reported symptom burden at the first clinic visit was analyzed using two separate analyses: (1) one-way analysis of covariance (ANCOVA) examining group differences in PCSI-SR13 Total Symptom score, covarying the PCSI-SR13 RBL Total Symptom score; (2) one-way multivariate analysis of covariance (MANCOVA) examining group differences (single-injury vs. additional-impact) in the four PCSI-SR13 post-injury subscale totals (physical, cognitive, emotional, and fatigue), controlling for the PCSI-SR13 RBL Total Symptom score. Identical analyses were conducted with the PCSI-P scores. The effect of injury status (single vs. additional) on LOR was analyzed using a one-way ANCOVA, controlling for age. A one-tailed alpha of 0.05 was set for all analyses, given the unidirectional hypotheses. Effect sizes were calculated using Cohen's d^{12} (conventional interpretation of effect sizes: $d=0.2$, small; $d=0.5$, medium; and $d=0.8$, large).

Results

Statistical analyses were conducted comparing the additional-impact group with the three age- and gender-matched single-injury control groups. Consistent results were found regardless of the control sample; therefore, only one set of results is presented.

Additional-impact and symptom burden

Examination of possible covariates. Variables potentially associated with increased symptom burden were first examined in the full sample for possible covariation. No significant relationships were found between PCSI-SR13 or PCSI-P Total Symptom scores and risk factors for greater symptom severity (sex, age at injury, loss of consciousness (LOC) or amnesia as a result of injury, history of depression, learning disabilities [LD], attention-deficit hyper-

activity disorder [ADHD], or headaches). The number of days between initial injury and first visit at the clinic (mean=22 days, SD=16, median=18) was not significantly correlated with symptom burden for either parent or adolescent report and did not vary significantly between the single-injury and additional-impact group. Finally, the removal from play immediately versus continued participation after initial injury was not significantly associated with symptom burden or recovery time within the single-injury group (52% immediately removed, 48% continued participation). As a result, none of these potential covariates were added to the analyses.

PCSI-SR13 report. Athletes in the additional-impact group reported a significantly higher mean symptom rating than the single-injury group (ANCOVA $p=0.041$; $d=0.494$; see Table 2) with a small-moderate effect size. The MANCOVA examining the PCSI-SR13 symptom subscales revealed that athletes who sustained a second blow to the head reported significantly higher levels of cognitive symptoms ($p=0.008$; $d=0.676$) with a moderate effect size, and showed a trend for increased levels of physical ($p=0.052$; $d=0.501$) and fatigue ($p=0.067$; $d=0.415$) symptoms (see Table 2). There were no group differences in adolescent report of emotional symptom burden ($p=0.316$, $d=0.121$).

PCSI-P report. A significant group effect was found for the PCSI-P Total Symptom score as parents of additional-impact athletes reported significantly higher symptom ratings than parents of single-injury athletes ($p=0.002$, $d=0.845$; see Table 2) with a large effect size. Furthermore, as displayed in Table 2, the MANCOVA revealed that parents of athletes in the additional-impact group reported significantly higher symptom ratings across each of the four symptom subscales with moderate-large effect sizes (physical, $p=0.023$, $d=0.649$; cognitive, $p=0.004$, $d=0.822$; emotional, $p=0.003$, $d=0.778$; and fatigue, $p=0.035$, $d=0.570$).

Additional-impact and length of recovery

Examination of possible covariates. Variables possibly associated with prolonged LOR were first examined in the full sample for possible covariation, including age at injury, gender, retro- or anterograde amnesia, history of prior concussion(s), LD, ADHD, depression, anxiety, and headaches. In this sample, age was negatively correlated with LOR ($r=-0.391$, $p<0.05$), that is as adolescents increased in age, the LOR decreased; thus, age was added as a covariate in the model. No other covariates were significantly related to LOR.

The ANCOVA revealed a significant group effect where the additional-impact group had a significantly longer LOR (mean=52.3 days, SD=26.1, median=43) compared with the single-injury group (mean=36.9, SD=19.1, median=35), after controlling for age, with a moderate effect size ($p=0.008$, $d=0.673$).

Discussion

Concussion in youth is recognized as a significant public health issue with particular concern for multiple injuries within a short time frame. The present study provides preliminary evidence for a possible association between a second blow to the head sustained within 24 h of an initial concussion and more significant and prolonged post-concussion impairments in adolescent student-athletes seen in a specialty clinic. Specifically, athletes in this retrospective study who sustained the additional injury had significantly higher parent- and self-reported symptom ratings than those who sustained

TABLE 2. SYMPTOM BURDEN FOLLOWING SINGLE-INJURY OR ADDITIONAL-IMPACT PER ADOLESCENT (PCSI-SR13) AND PARENT (PCSI-P) REPORT

	Single-injury (n=21)	Repeat-injury (n=21)	P value	d
Symptom score total ^a				
Adolescent	19.5 (18.1)	29.4 (21.8)	0.041	0.494
Parent	13.2 (18.2)	33.2 (28.1)	0.002	0.845
Domain symptom score totals ^b				
Physical symptoms				
Adolescent	5.7 (6.6)	10.0 (10.2)	0.052	0.501
Parent	4.6 (7.2)	11.3 (12.7)	0.023	0.649
Cognitive symptoms				
Adolescent	6.7 (6.9)	11.5 (7.3)	0.008	0.676
Parent	3.5 (5.9)	9.8 (9.1)	0.004	0.822
Emotional symptoms				
Adolescent	3.8 (5.8)	3.2 (3.9)	0.316	0.121
Parent	2.1 (3.4)	5.7 (5.6)	0.003	0.778
Fatigue symptoms				
Adolescent	3.2 (3.3)	4.7 (3.9)	0.067	0.415
Parent	3.4 (4.9)	6.4 (5.6)	0.035	0.570

All data are presented as mean (SD) unless otherwise noted.

^aMeans reflect retrospective baseline adjusted PCSI Total Symptom score on the adolescent and parent forms.

^bMeans reflect retrospective baseline adjusted PCSI subscale estimated marginal means on the adolescent and parent forms.

PCSI, Post-Concussion Symptom Inventory; SD, standard deviation.

a concussion without an additional injury. The most robust differences between single- and additional-impact groups according to both adolescent and parent report were observed in the cognitive, physical, and fatigue symptom domains with moderate to large effect sizes. Furthermore, student-athletes who sustained an additional blow to the head within 24 h of an initial concussion had a significantly longer period of recovery than those who sustained a single injury. On average in this relatively small sample, the recovery was over one week longer for the additional-impact group.

Our results build upon prior studies of repeat brain injury in humans and in animal models during the acute post-concussion period. Vagnozzi and colleagues⁷ report delayed physiological effects in a small sample of young adult male athletes who sustained repeat concussive events ($n=3$) within 2 weeks of an initial SRC. These athletes took longer than singly concussed individuals to return to metabolic baseline, but differences in clinical symptom burden and duration were not quantitatively examined.⁷ In rodent models, repeat traumatic brain injury (TBI) within a 24-h window of the initial injury has led to increased axonal injury, longer metabolic recovery, and longer cognitive recovery relative to the single injury group.^{3,5-7} The repeat TBI studies with animals posit the presence of a metabolic “window of vulnerability” following concussion, in which a repeat injury within a specific time frame can exacerbate the adverse effects of the first injury.¹³ The findings of this study provide preliminary support for the presence of increased vulnerability in adolescent athletes for at least 24 h after the initial injury.

Two recent animal studies provide evidence for potential mechanisms associated with the metabolic window of vulnerability. Yuen and associates³ suggest that a second mild TBI (mTBI) within 24 h of the initial injury may cause more axonal injury due to a lower threshold for injury associated with the first mTBI. In addition, Prins and colleagues⁶ posit that longer recovery may be due to a prolonged decrease in glucose metabolism occurring after a second hit within 24 h of the initial injury relative to the single-injury group. These two factors, a lower threshold for axonal injury and depressed glucose metabolism, could explain the lengthened time to recovery in our additional-impact group.

The current sports medicine practice guidelines and youth sport concussion laws explicitly instruct removal of the athlete from play if any concussion signs or symptoms are present. The intent of these rules is to prevent further injury.¹ The majority of the athletes in this sample who sustained additional impacts to the head were re-injured during the same game or practice. Our research generates an initial line of evidence suggesting the need for these practice guidelines and the legislation mandating immediate removal from play to prevent same-day return to play when a concussion is suspected.

Limitations and future directions

Care was taken to control, statistically and through blinded participant matching, for known demographic and pre-injury history factors that might contribute differentially to delayed recovery between the groups (e.g., age, sex, prior concussion history). Although substantial effort was made to control for selection bias, this study presents with several limitations. First, given the clinical nature of the study, the sample was not selected on a prospective, randomized basis. While we accounted for time between the injury and first clinic visit in our analyses, future studies should collect symptom ratings at regulated time intervals after injury. Second, the length of recovery in this clinical sample in this study, although similar to other clinical samples,¹⁴ the recovery times may be longer than that of the full range of injury in adolescent athletes,

limiting the generalizability of these findings. Third, a larger sample size would increase the confidence in these findings, which at this point are largely hypothesis-generating for future studies.

Future studies would benefit from the inclusion of neuroimaging data when comparing athletes with a single blow to the head versus additional impacts to the head within a short time frame. This information would help to better understand the relationships between structural/neurometabolic vulnerability and symptom burden and LOR. Although we examined short-term recovery and symptom outcomes, future studies should also examine any potential for long-term functional effects associated with multiple impacts, across the full developmental age continuum. Whereas the present findings are suggestive and generate important hypotheses, future well-controlled, prospective studies can further investigate the effects of sustaining additional impacts to the head following a concussion.

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Author Disclosure Statement

No competing financial interests exist.

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