

Posttraumatic migraine characteristics in athletes following sports-related concussion

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Object. The object of this study was to compare symptom status and neurocognitive functioning in athletes with no headache (non-HA group), athletes complaining of headache (HA group), and athletes with characteristics of posttraumatic migraine (PTM group).

Methods. Neurocognitive tests were undertaken by 261 high-school and collegiate athletes with a mean age of 16.36 ± 2.6 years. Athletes were separated into three groups: the PTM group (74 athletes with a mean age of 16.39 ± 3.06 years), the HA group (124 athletes with a mean age of 16.44 ± 2.51 years), and the non-HA group (63 patients with a mean age of 16.14 ± 2.18 years). Neurocognitive summary scores (outcome measures) for verbal and visual memory, visual motor speed, reaction time, and total symptom scores were collected using ImPACT, a computer software program designed to assess sports-related concussion.

Significant differences existed among the three groups for all outcome measures. The PTM group demonstrated significantly greater neurocognitive deficits when compared with the HA and non-HA groups. The PTM group also exhibited the greatest amount of departure from baseline scores.

Conclusions. The differences among these groups can be used as a basis to argue that PTM characteristics triggered by sports-related concussion are related to increased neurocognitive dysfunction following mild traumatic brain injury. Thus, athletes suffering a concussion accompanied by PTM should be examined in a setting that includes symptom status and neurocognitive testing to address their recovery more fully. Given the increased impairments observed in the PTM group, in this population clinicians should exercise increased caution in decisions about treatment and when the athlete should be allowed to return to play.

KEY WORDS • concussion • headache • ImPACT • neuropsychological testing • mild traumatic brain injury • high-school athlete

THE management of sports-related mild TBI—for example, concussion or mild head injury—has recently received much media attention as a public health issue. Approximately 2 million people suffer closed head injuries in the US each year.² Furthermore, it has been estimated that 50,000 to 300,000 athletes sustain a concussion each season.^{10,38,41} Over the past 30 years, more than 15 concussion grading scales and return-to-play guidelines have been published to aid in the management of this injury.³ Unfortunately, there is a notable variability in these guidelines and an overall lack of scientific foundation to support any one system as superior.^{7,20,25} These guidelines are predicated on both the presence and duration of loss of consciousness and amnesia.

Abbreviations used in this paper: ANOVA = analysis of variance; HA = headache without migraine symptoms; PCSS = Post-Concussion Symptom Scale; PTM = posttraumatic migraine; SD = standard deviation; TBI = traumatic brain injury.

The occurrence of posttraumatic headache is the most common symptom seen in patients after a sports-related head injury.^{3,22,42} The frequency of posttraumatic headache has been reported to be as high as 86% in athletes following sports-related head trauma.¹⁴ Athletes may suffer from a range of posttraumatic headache types. These include but are not limited to tension-type, migrainelike, clusterlike, and mixed posttraumatic headaches, all of which are similar to their nontraumatic counterparts.¹⁵ It has been reported that head trauma, even mild, may result in migrainelike symptoms. The mechanisms behind which mild TBI may catalyze PTM are still unclear. It has been suggested that trauma may cause PTM by acting as the sole triggering factor, being part of the postconcussion syndrome, triggering the first attack in an otherwise susceptible person, or simply happening by chance.³⁷

Symptoms of posttraumatic migraine are a complication of sports-related concussion that is poorly understood. This may be attributed to the fact that PTM is often reported as

Posttraumatic migraine after sports-related concussion

TABLE 1
Characteristics of athletes in the PTM, HA, and non-HA groups

Characteristic	PTM Group	HA Group	Non-HA Group	Total Sample
no. of athletes (%)	74 (28.4)	124 (47.5)	63 (24.1)	261 (100)
mean age \pm SD (yrs)	16.39 \pm 3.06	16.44 \pm 2.51	16.14 \pm 2.18	16.36 \pm 2.60
sex—no. of athletes (%)				
male	65 (87.8)	96 (77.4)	50 (79.4)	211 (80.8)
female	9 (12.2)	28 (22.6)	13 (20.6)	50 (19.2)
sport—no. of athletes (%)				
football	62 (83.8)	82 (66.1)	45 (71.4)	189 (72.4)
basketball	3 (4.1)	0 (0)	0 (0)	0 (0)
soccer	2 (2.7)	13 (10.5)	9 (14.3)	24 (9.2)
hockey	0 (0)	0 (0)	2 (3.2)	0 (0)
field hockey	0 (0)	8 (6.5)	0 (0)	12 (4.6)
other	7 (9.5)	21 (16.9)	7 (11.1)	36 (13.8)
history of previous concussion—no. of athletes (%)				
yes	20 (27.0)	41 (33.1)	18 (28.6)	79 (30.3)
no	54 (73.0)	83 (66.9)	45 (71.4)	182 (69.7)
baseline information available—no. of athletes (%)				
yes	55 (74.3)	71 (57.3)	36 (57.1)	162 (62.1)
no	19 (25.7)	53 (42.7)	27 (42.8)	99 (37.9)

rare.²⁹ Furthermore, because no laboratory test can be performed to affirm the presence of migraine, it is a diagnosis of exclusion made only after first ruling out other anatomical, metabolic, and physiological causes of headache.³⁰ Migraine, according to the International Headache Society, is an episodic disorder characterized by acute attacks of pain with associated symptoms that often result in disability.¹ These symptoms include but are not limited to headache, nausea, photophobia, and phonophobia. Despite the high levels of disability associated with migraine, it continues to be underdiagnosed and undertreated worldwide.¹

Because PTM is so poorly understood, a specific diagnosis is often not assigned and an optimal course of therapy is not provided for migraine sufferers who seek treatment.¹ In addition, headache is often noted to be a consistent symptom in the young athlete with a postconcussion syndrome who returns to play before headache resolution and later suffers from a second impact syndrome. There is, therefore, a need to understand more fully the relationship between sports-related head trauma and PTM. The object of this study was to compare symptomatology and neurocognitive function in athletes who have suffered concussions without any reported headaches (non-HA group), athletes with postconcussion headache (HA group), and athletes with PTM characteristics (PTM group).

Clinical Material and Methods

Patient Population

Participants in the study included 261 athletes who had suffered concussions. The patients were separated into three groups: the PTM group, the HA group, and the non-HA group. Based on International Headache Society guidelines, athletes with concussions were included in the PTM group simply if they reported the presence of headache, nausea, and either photophobia or phonophobia during their first postconcussion evaluation, without regard to the severity of those symptoms. Athletes who reported headache without nausea, photophobia, or phonophobia were classified in the HA group. Athletes who did not report any headache were classified in the non-HA group. All patients with a history

of learning disability, special education, speech therapy, or attention deficit disorder were excluded from this study. Furthermore, all athletes with a history of alcohol or drug abuse were also excluded from the study. A breakdown of this sample of athletes with concussions by age, sex, sport, history of concussion, and availability of baseline data is provided in Table 1.

The PTM group did not have a significantly more pronounced prestudy history of concussion than the HA or non-HA groups ($\chi^2 = 0.914$, $p = 0.633$). The mean time (\pm SD) from injury to the first follow-up evaluation for all participants was 3.8 ± 5.88 days; this did not differ significantly among the three groups ($F = 2.05$, $p = 0.13$). All study participants were evaluated through the Sports Medicine Concussion Program at the University of Pittsburgh Medical Center. This ongoing clinical program involves the use of computerized neurocognitive tests to assist team medical staff in making return-to-play decisions following the occurrence of sports-related concussion. Sixty-two percent (162 of 261) of patients completed baseline neurocognitive tests during the preseason before sustaining contact. The results of this baseline assessment provided the standard of comparison if the athlete was injured during the school year. In athletes without baseline scores, a set of standardized norms based on age, education level, and sex was used. Athletes were not financially compensated for participation in the program and participation was voluntary.

Protocol and Outcome Measures

The University of Pittsburgh's Internal Review Board approved the involvement of human subjects in this research study. Administration of the ImPACT computerized neuropsychological test battery³¹ was supervised by a team of clinical neuropsychologists, certified athletic trainers, and/or physicians who were thoroughly trained in the administration of the measures. Training was completed at each site through a half-day seminar presented by two of the authors (M.W.C. and M.R.L.). Because ImPACT is a self-administered test battery, all subtests were administered in a standardized manner and the test was automatically scored by

TABLE 2
*ImPACT neurocognitive test modules**

Test Module	Cognitive Processes Measured
word memory	verbal recognition & delayed memory
design memory	visual recognition & delayed memory
Xs & Os	visual working memory & visual processing speed
symbol matching	visual processing speed, learning, & memory
color match	reaction time & impulse control/inhibition
three letters	working memory & visual-motor response speed

* Results from these tests are computed into overall memory, reaction time, and visual-motor speed composite scores.

the computer. Therefore, there was no variation in administration or scoring technique among the participating sites.

ImPACT Battery of Tests. ImPACT is a computer-administered neuropsychological test battery that consists of seven individual test modules used to measure aspects of cognitive functioning including attention, memory, reaction time, and information processing speed. Given the focus of this paper on differentiating neurocognitive characteristics following sports-related concussion in athletes suffering from PTM and those who are not, the memory composite index, reaction time, visual motor speed, and symptom scores were included in this study. A thorough description of the ImPACT test battery and the rationale for the development of the individual tests contained within it has been described in detail previously.³¹ The validity and reliability of the ImPACT Neurocognitive Test has also been previously reported.^{17-19,27,28}

A summary of individual test modules that comprise the ImPACT Neurocognitive Test is provided in Table 2. The ImPACT test battery is designed to minimize practice effect by randomization of stimuli. With the exception of the recognition word memory test (which makes use of five different but equivalent word lists) and the design memory test (which makes use of five different but equivalent design lists), presentation of all stimuli is varied automatically for each examination.

Post-Concussion Symptom Scale. ImPACT also yields a PCSS that is currently being used throughout both amateur and professional sports.²⁶ This Likert scale consists of 22 symptoms commonly associated with concussion, such as headache, dizziness, nausea, and sleep disturbance, which are graded from 0 (asymptomatic) to 6 (severely symptomatic). All athletes were required to provide a self-report of his or her symptoms based on the PCSS, which included both cognitive symptoms, for example, attention deficit or perceived memory dysfunction, and noncognitive symptoms, such as headache, nausea, dizziness, sleep disturbance, emotional changes, and photophobia. These symptoms are identified in Table 3.

Preseason Baseline Evaluation

Baseline data collection was completed for 162 patients. Baseline data were collected during the off season (that is, before preseason contact drills) and, as a result, before any new concussion could be sustained by the athlete. At the baseline session, the following self-reported data were collected: age, native language, years of completed education, history of diagnosed learning disability, and history of concussion. Regarding current concussion history, a standard-

TABLE 3
*Symptoms rated in the postconcussion symptom scale**

headache†	sensitivity to light†
nausea†	sensitivity to noise†
emesis	increased sadness
balance problems	nervousness
dizziness	feeling more emotional
fatigue	numbness or tingling
trouble falling asleep	feeling slowed down
sleeping >usual	sensation of being "in a fog"
sleeping <usual	difficulty w/ concentration
drowsiness	difficulty w/ memory
irritability	visual problem

* Each item is graded from 0 (asymptomatic) to 6 (severely symptomatic).

† Symptoms used to characterize PTM.

ized concussion history questionnaire contained within the ImPACT test battery was administered with the supervision of the test administrator. This questionnaire is structured to gather information regarding concussion history and a description of injuries that have been sustained including presence and length of confusion, loss of consciousness, anterograde amnesia (loss of memory of events occurring after the hit), retrograde amnesia (loss of memory of events occurring prior to the hit), and results of neuroimaging procedures (if any).

Statistical Analysis

Data from our clinical database were pooled and analyzed using Intercooled Stata 7.0 (Stata Corp., College Station, TX). A one-way ANOVA was performed with group (PTM, HA, or non-HA) as the between-group factor and outcome measure as the within-group factor. Post hoc analyses for the one-way ANOVA were performed using the Scheffé multiple-comparison test. Standard t-test techniques were also performed to compare differences in mean scores within each group. These tests were performed to analyze differences between postconcussion measurements compared with individuals' baseline data.

Results

Comparisons Among the PTM, HA, and Non-HA Groups

ImPACT postinjury neurocognitive composite and symptom scores (\pm SDs) for the PTM, HA, and non-HA groups are provided in Table 4.

Neurocognitive Performance: Postinjury. There were significant differences in verbal memory scores among the three groups ($F = 11.71, p < 0.0001$). Post hoc analysis revealed that athletes in the PTM group had significantly lower verbal memory scores postinjury than those in the HA and non-HA groups. Significant differences in verbal memory scores were not observed between the HA and non-HA groups. There was a difference in visual memory scores among the groups ($F = 4.92, p < 0.01$). We observed that athletes in the PTM group had significantly lower visual memory scores postinjury than those in the HA and non-HA groups. Differences in visual memory scores were not observed between the HA and non-HA groups. Differences in visual motor speed scores were observed among the three groups ($F = 10.28, p < 0.0001$). Athletes in the PTM group

TABLE 4

*Postinjury neurocognitive performance and symptom status for 162 athletes in the PTM, HA, and non-HA groups**

Variable	PTM Group		HA Group		Non-HA Group	
	Baseline	Postinjury	Baseline	Postinjury	Baseline	Postinjury
verbal memory†	84.32 ± 8.62‡	72.09 ± 13.47§	84.76 ± 8.25‡	78.96 ± 12.63	87.08 ± 7.22‡	81.79 ± 10.27
visual memory†	73.08 ± 12.83‡	61.0 ± 14.32§	75.69 ± 13.62‡	66.79 ± 12.98	74.74 ± 9.98‡	67.45 ± 14.91
reaction time**	0.595 ± 0.085‡	0.696 ± 0.157§	0.553 ± 0.070‡	0.644 ± 0.143	0.555 ± 0.064	0.583 ± 0.088
visual motor speed†	34.73 ± 6.51‡	29.73 ± 9.70§	35.96 ± 7.53	33.15 ± 8.44	38.44 ± 5.12	36.36 ± 7.20
symptom score**	9.73 ± 8.43‡	39.00 ± 19.40§	8.89 ± 10.59‡	20.92 ± 14.85††	8.23 ± 9.08	10.56 ± 9.75

* Values are expressed as means ± SDs.

† Higher scores indicate better functioning for verbal memory, visual memory, and visual motor speed.

‡ Significant difference (p < 0.01) between baseline score and postinjury score.

§ Significant difference (p < 0.05) in postinjury scores between PTM and HA groups.

|| Significant difference (p < 0.05) in postinjury scores between PTM and non-HA groups.

** Lower scores indicate better functioning for reaction time and symptom scores.

†† Significant difference (p < 0.05) in postinjury scores between HA and non-HA groups.

had lower visual motor speed scores postinjury than those in the HA and non-HA groups. Again, significant differences in visual motor speed were not observed between the HA and non-HA groups; however, the results indicated a trend for athletes in the HA group to obtain lower visual motor speed scores than patients in the non-HA group (p = 0.054). Reaction time scores were significantly different among the three groups (F = 11.63, p < 0.0001). Athletes in the PTM group had significantly lower reaction time scores postinjury than those in the HA and non-HA groups. A significant decrease in reaction time scores was also observed between the HA and non-HA groups (p = 0.018).

Post-Concussion Symptom Scale: Postinjury. Symptom status also differed among the three groups (F = 51.80, p < 0.0001). Athletes in the PTM group reported significantly higher symptom scores, as revealed by post hoc analysis, than those in the HA and non-HA groups. Athletes in the HA group also reported a significantly increased symptom score compared with those in the non-HA group (p = 0.001).

Comparisons Within the PTM, HA, and Non-HA Groups

ImPACT baseline neurocognitive composite and symptom scores (± SDs) for the PTM, HA, and non-HA groups are also provided in Table 4.

Neurocognitive Performance: Comparison of Postinjury and Baseline Neurocognitive Scores. There were significant declines in postinjury verbal memory test scores within the PTM (t = 8.63, p < 0.0001), HA (t = 5.14, p < 0.0001), and non-HA (t = 2.88, p < 0.01) groups when compared with test scores obtained during baseline testing. An analysis of visual memory scores also revealed a departure from baseline (p < 0.001) in the PTM (t = 5.61), HA (t = 4.95), and non-HA (t = 4.01) groups. An increase in reaction time scores was found in the PTM (t = 4.69, p < 0.0001) and HA (t = 5.23, p < 0.0001) groups. Although there was a mean increase in reaction time scores in athletes in the non-HA group, this observation was not statistically significant (t = 1.68, p < 0.11). Visual motor processing speed decreased significantly in athletes in the PTM group (t = 4.06, p < 0.001). Similar yet statistically insignificant trends were also observed in the HA (t = 1.66, p < 0.11) and non-HA (t = 1.88, p < 0.07) groups.

Post-Concussion Symptom Scale: Comparison of Postinjury and Baseline Symptom Scores. An observed trend in our sample indicated an increase in reports of symptom status following injury. Athletes in the PTM group reported the largest mean increase in symptom status scores (t = 11.13, p < 0.0001) compared with their baseline symptom reports. Athletes in the HA group reported a higher mean symptom status score following injury when compared with their pre-season baseline scores (t = 5.91, p < 0.0001). There were no significant trends in symptom status reporting in athletes in the non-HA group (t = 0.27, p < 0.809).

Discussion

Overall, the results of this study lead us to assert that PTM symptoms reported following sports-related concussion are related to a greater decline in neurocognitive performance than that observed in the other two groups. These deficits were observed in two separate ways. The first was a comparison of athletes in the PTM group, those with concussions who reported headache without other PTM characteristics and those who did not report headache at all. The second comparison consisted of an examination of the departure from baseline cognitive functioning following concussive injury. Regarding symptom status, athletes with PTM characteristics also reported more symptoms overall when compared with baseline scores, as well as when compared with other athletes who had suffered concussions. Deficits in neurocognitive function following sports-related concussion have been previously reported.^{3-6,9,12,13,27,32} These reports have also identified some of the inherent differences in neurocognitive recovery between high-school and collegiate athletes following sports-related trauma. Even mild “ding” concussions have been reported to cause neurocognitive impairments in high-school athletes.²⁸

The findings of this study support an increased vigilance on the part of the clinician when confronted with an athlete presenting with migrainelike symptoms following a sports-related head trauma. The findings further emphasize the need to follow the recovery of an athlete more closely. Our results support a detailed assessment of symptoms not only on the field, but also in the follow-up clinical assessment of the injured athlete. This is strengthened by the significant cognitive declines noted primarily in the PTM group, when

compared with baseline scores and with other athletes who have suffered a concussion. Clearly, sports-related concussion is related to increased cognitive impairments regardless of group (PTM, HA, or non-HA). Therefore, it is critical that any athlete sustaining a concussion be followed up not only for symptoms but also for cognitive impairments because their symptoms may also resolve before their neurocognitive deficits.^{26,33}

Trauma acts merely as a trigger for the pathophysiological process resulting in PTM.^{16,35} The pathophysiology behind sports-related mild TBI and PTM are very similarly represented clinically. The pathophysiology behind migraine is hypothesized to involve the trigeminovascular system.²⁴ Release of neuropeptides and substance P from trigeminal nuclei may lead to an inflammatory response responsible for the pathogenesis of migraine.^{23,24,36} Second, there is increasing evidence to support an organic basis in the pathophysiology of mild TBI.^{8,11,40} It is also believed that organic changes may also play a role in the pathogenesis of posttraumatic headache.³⁴ For example, extracellular potassium and intracellular sodium, calcium, and chloride are increased in the brain following a mild TBI and migraine. In both cases there also appears to be an excessive release of excitatory amino acids, especially glutamate. Endogenous opioids such as β -endorphins are increased following a mild TBI and may be reduced in migraine sufferers during headache-free periods. Packard and Ham³⁵ discuss some other biochemical changes, in addition to those aforementioned, associated with mild TBI and migraine.

Headaches are more often found in athletes who have suffered minor head and neck injuries than in individuals who have suffered severe brain injuries.³⁴ Yamaguchi⁴⁴ reported that 33% of severely injured patients in his study complained of severe headache, compared with 72% of mildly injured patients. Nevertheless, the anatomical, biochemical, and physiological basis for why headache occurs at a much higher rate in patients who sustain a mild TBI than in those who sustain a severe TBI remains enigmatic. It is suspected that trauma to the head and neck may trigger the migraine process in an individual who did not previously experience migraine headaches but may have been susceptible to such a disorder.³⁹

Given the findings of this current study, future studies should focus on how a migraine history affects an athlete's neurocognitive function following sports-related head trauma. It has been suggested that head or neck injuries can increase the severity of headaches in patients with preexisting migraine.³⁴ Furthermore, assessing an athlete's family history of migraine and neurocognitive impairments may also lead to a better understanding of which athletes are likely to exhibit PTM symptoms following sports-related concussion. Patients with PTM characteristics may have a genetic predisposition to the migraine complex. Reports of a family history of migraine were noted in 11 of 35 patients with PTM presented by Weiss, et al.⁴³ Finally, in future studies investigators should examine differences in neurocognitive function and symptom status in athletes who exhibit PTM-like symptoms and in those whose symptoms have been formally diagnosed as PTM. Similarly, individuals who suffer from migraine should be compared with those who are experiencing PTM to understand more fully just how much sports-related head trauma can catalyze the neurocognitive deficits we observed in this study. Furthermore, studies in

which relatively new functional magnetic resonance imaging methods are used may allow us to make more appropriate brain-behavior inferences following sports-related head injury.²¹

This study was limited by a relatively small sample size. Second, not all athletes who sustained concussions had completed preseason baseline testing, which further reduced our sample size estimates in our within-group analyses. Also, athletes with concussions were classified into one of three groups based on a self-report of migrainelike symptoms and not based on a clinical diagnosis of PTM or HA. Furthermore, it was observed that athletes in the PTM group experienced more pronounced headaches as well as higher total symptom scores. As such, it may be advantageous to investigate other postconcussion symptom clusters in future studies. Finally, only the initial follow-up test scores were used for the purposes of this study. Given the persistence of neurocognitive dysfunction in our series, it will be useful for investigators in future studies to perform longer follow-up reviews in these patients to document recovery of neurocognitive deficits in athletes who have sustained a sports-related mild TBI and to determine which subgroup (PTM, HA, or non-HA) of athletes takes the longest time to make a full recovery.

Conclusions

This is the first study to provide a comparison of acute neurocognitive impairments after sports-related concussion in athletes who exhibited migraine characteristics, those who complained of headache, and those who did not complain of headache. Our results indicate that athletes suffering from PTM characteristically exhibit more marked deficits in neurocognitive performance and symptom status reporting. Our results and those of previous studies indicate that baseline and postinjury testing protocols should be in place for all levels of athletic competition that place the participants at risk for concussion. Neurocognitive test results, in conjunction with other diagnostic information, can provide valuable information concerning recovery in athletes suffering from PTM and other forms of postconcussion syndromes.

Disclosure

Drs. Lovell, Collins, and Maroon are stockholders in ImPACT Applications, Inc., the company that developed and sells ImPACT software.

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Manuscript received June 2, 2004.

Accepted in final form November 22, 2004.

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