

Neurocognitive Function of Emergency Department Patients With Mild Traumatic Brain Injury

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Study objective: We characterize the neurocognitive function of patients presenting to the emergency department (ED) with mild traumatic brain injury.

Methods: This prospective study took place at an urban, academic ED and Level I trauma center. Case patients consisted of a convenience sample of ED patients aged 18 to 59 years, presenting to the ED with mild traumatic brain injury and having a head computed tomography scan without traumatic abnormalities. Controls consisted of patients aged 18 to 59 years, presenting to the ED with an isolated, nondominant hand extremity injury. We excluded patients with multiple injuries and recent alcohol consumption. Subjects completed a computerized neurocognitive test battery (Immediate Post-concussion Assessment and Cognitive Testing). The primary measures were verbal memory, visual memory, and visual motor and reaction speed. We compared raw and age-normalized neurocognitive performance between case patients and controls by using nonparametric statistics.

Results: We included a total of 23 head-injured case patients and 31 non-head-injured controls. Case patients and controls exhibited similar raw (median 80.1 versus 85.0 points; difference in medians -4.9 ; $P=.26$) and age-normalized (31.9 versus 57.4 percentile; difference in medians -25.5 ; $P=.12$) verbal memory. Case patients and controls exhibited similar raw (64.6 versus 63.5; difference 1.1; $P=.79$) and age-normalized (20.8 versus 25.8 percentile; difference -5.0 ; $P=.44$) visual memory. Compared with controls, mild traumatic brain injury case patients demonstrated slower raw (31.6 versus 37.0 points; difference -5.4 ; $P=.002$) and age-normalized (17.1 versus 57.6 percentile; difference -40.5 ; $P=.001$) visual motor speed. Mild traumatic brain injury case patients exhibited slower raw (median 0.66 versus 0.60 seconds; difference 0.06; $P=.01$) and age-normalized (29.3 versus 42.8 percentile; difference -13.5 ; $P=.009$) reaction times.

Conclusion: In conclusion, compared with the non-head-injured patients, ED mild traumatic brain injury patients demonstrated subtle but discernible neurocognitive deficits. [Ann Emerg Med. 2008;xx:xxx.]

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INTRODUCTION

Background

Approximately 153,000 patients present annually to US emergency departments (EDs) with a mild traumatic brain injury.¹ Even without CT evidence of intracranial abnormalities, many of these patients may exhibit subtle but significant neurocognitive symptoms and deficits; for example, headaches, anxiety, fatigue, irritability, dizziness, and impaired memory or concentration.² For select patients, these sequelae may prove debilitating, impairing individuals' abilities to attend school, work, or perform other activities of daily living.³ Nearly 38% of ED mild traumatic brain injury patients receive no specific directions for outpatient concussion follow-up.¹ Ponsford et al⁴ found that individuals who did not receive

prompt reevaluation and education reported increased number and severity of symptoms at 3 months postinjury.

An important mild traumatic brain injury management challenge is the early recognition of neurocognitive deficits. According to signs and symptoms alone, clinicians and patients may underestimate the range, significance, and severity of post-mild traumatic brain injury symptoms. Specialized neurocognitive assessments may facilitate early deficit identification in these patients, potentially aiding clinical management.^{5,6} Extensive data describe the utility of baseline neurocognitive testing of athletes.⁷ Using these preinjury values, these studies have described neurocognitive deficits after sports-related mild traumatic brain injury and linked these initial impairments to short- and long-term outcomes.⁸⁻¹⁰

Editor's Capsule Summary*What is already known on this topic*

Mild traumatic brain injury is suspected to result in more morbidity than previously appreciated, but difficulty measuring cognitive and psychomotor symptoms in the emergency department (ED) impairs study of this condition.

What question this study addressed

Can computerized neuropsychiatric testing performed in the ED identify deficits in normal-appearing patients with acute mild traumatic brain injury?

What this study adds to our knowledge

In 23 patients with head injury, relatively abbreviated neuropsychiatric testing identified significantly worse average performance in 2 of 4 domains compared with 31 controls with isolated extremity trauma.

How this might change clinical practice

The ability to practicably measure deficits after mild traumatic brain injury in the ED makes further study of these patients possible. If those with ongoing problems can be diagnosed early, the potential for treatment exists.

Importance

Only limited data characterize neurocognitive impairments in general ED mild traumatic brain injury patients.^{6,11,12} Compared with previous evaluations of sports concussion cohorts, these patients potentially differ in their age, mechanisms of injury, and comorbidities, among other factors. These individuals also do not typically participate in baseline concussion testing programs. The early recognition of neurocognitive impairment after mild traumatic brain injury could lead to improved treatment, as well as long-term outcomes.

Goals of This Investigation

The objective of this study was to characterize neurocognitive deficits in patients presenting to the ED after mild traumatic brain injury. We hypothesized that head-injured case patients would exhibit greater neurocognitive deficits than non-head-injured controls.

MATERIALS AND METHODS**Study Design**

This study was approved by the University of Pittsburgh institutional review board.

In this prospective study, we compared the neurocognitive function of mild traumatic brain injury case patients (aged 18 to 59 years, presenting to the ED with an isolated head injury, a Glasgow Coma Scale [GCS] score of 13 to 15, and a head computed tomography [CT] scan without evidence of intracranial injury) with non-head-injured controls (aged 18 to 59 years, presenting to ED with an isolated nondominant extremity injury).

Setting

This study took place at the ED of the University of Pittsburgh Medical Center Presbyterian Hospital, an urban, academic ED and Level I trauma center caring for more than 50,000 patients annually.

Selection of Participants

We recruited a convenience sample of subjects from patients presenting to the ED. ED physician, resident, and nursing staff alerted the study team to potentially eligible subjects. The study team maintained a physical presence in the ED for 16 hours per day, 5 days per week, supplemented by on-call availability during overnight periods and weekends. We recruited subjects during the study period June 1, 2007, through August 31, 2007.

For case patients, we selected patients aged 18 to 59 years, presenting to the ED with mild traumatic brain injury as a chief complaint and a GCS score of 13 to 15, and subsequently receiving a head CT scan without evidence of intracranial injury. We defined mild traumatic brain injury as any patient self-report of a blow to the head from an injurious mechanism. For controls, we selected patients aged 18 to 59 years, presenting to the ED with an isolated nondominant hand extremity injury (for example, contusions, lacerations, sprains, and fractures) and without evidence of mild traumatic brain injury.

We included patients with a GCS score of 13 to 15 to maintain consistency with previous studies of mild traumatic brain injury.¹³ We excluded disoriented subjects, defined as individuals with Galveston Orientation Amnesia Test score less than 75.^{14,15} We excluded subjects older than 59 years because normalized neurocognitive performance scores were not currently available for this age range. We excluded patients younger than 18 years because the study ED usually does not treat children.

We excluded subjects who reported alcohol consumption within the previous 6 hours. We excluded subjects with known red-green color blindness because the neurocognitive computer test battery required recognition of colors. We excluded subjects with a dominant upper extremity injury or who were unfamiliar with the operation of a computer because the computer-based test battery required the operation of a computer mouse, as well as rudimentary computer operation skills. We excluded major-trauma patients because the cervical immobilization practices of the institution's trauma service precluded allowing patients to sit

up, which was necessary for completion of the computer test battery.

Methods of Measurement

We evaluated neurocognitive function using the computer test battery Immediate Post-concussion Assessment and Cognitive Testing (ImPACT).¹⁶ This proprietary, commercially available software combines several established neurocognitive tests into a single systematic testing platform. Although validated in other settings, the test battery has not been formally validated in the ED.

The computer battery tests performance in 4 neurocognitive domains: verbal memory, visual memory, visual motor speed, and reaction time^{17,18} (Appendix E1, available online at <http://www.annemergmed.com>). Verbal memory characterizes a subject's memory of words. Visual memory tests the subject's ability to remember patterns and shapes. Visual motor speed characterizes the subject's speed at recognizing visualized objects. Reaction time reflects the subject's speed of response to visualized objects. The program rates performance in verbal memory, visual memory, and visual motor speed on a scale of 0 to 100 points, as well as age-normalized percentile ranks. The program also characterizes reaction time in seconds and age-normalized percentile rank.

Using the ImPACT program, we also collected basic demographic and clinical information for each subject, including age, sex, years of education, time since injury, mechanism of injury, and concussion symptoms, described using 7-point (0 to 6) Likert ratings of 22 mild traumatic brain injury symptoms (Appendix E2, available online at <http://www.annemergmed.com>).

An uninterested or distracted subject may provide nonpurposeful responses during neurocognitive testing. ImPACT detects these invalid responses through an "impulse control composite score," adding errors on the interference phase of the "X's & O's" test to commissions from the "color match" test. To be consistent with previous efforts, we excluded impulse control composites scores greater than 30.¹⁹

Subjects completed the computer test battery in the ED either during or after clinical care by using a laptop computer with an external mouse. They completed the test while sitting up either in ED beds or reclining chairs, with adjustable tabletops positioned in front of them. All subjects wore noise-cancelling earmuffs. Whenever possible, we placed subjects in isolated rooms or behind closed curtains to minimize distractions from the ED environment. Subjects completed the test battery only once each. Subjects received a \$10 gift card on completion of a full test. We provided information about mild traumatic brain injury management and optional concussion specialist follow-up evaluation. Two investigators (S.E.P. and M.J.S.) executed the study protocol after receiving baseline training from the University of Pittsburgh Medical Center Sports Concussion Program.

Primary Data Analysis

Iverson et al¹⁸ defined clinically significant differences in ImPACT neurocognitive domain scores. According to this previous work, we estimated that we would require 18 subjects in each group to have 80% power to detect a 9-point difference (SD 9.5) in verbal memory, 8 subjects in each group to detect a 14-point difference (SD 13.4) in visual memory, 8 subjects in each group to detect a 3-point difference (SD 7.6) in visual motor speed, and 34 subjects in each group to detect a 0.06-second difference (SD 0.09) in reaction time. We therefore set the target enrollment at 34 subjects per group.

We excluded results from patients unable to complete the protocol. We compared baseline characteristics with the nonparametric Wilcoxon rank sum test.

Post hoc analyses revealed nonnormal distributions for the neurocognitive domain scores. We therefore performed all comparisons with the nonparametric Wilcoxon rank sum test. We compared raw neurocognitive domain scores between case patients and controls. We also compared age-normalized performance for each domain, converting the raw neurocognitive domain score to a corresponding percentile rank for the each subject's age range.

We used a Bonferroni-corrected *P* value of .025 to reflect 2 comparisons (ie, raw and age-normalized scores) for each of the 4 independent neurocognitive domain scores.²⁰ We performed data analyses with SPSS version 15.0.0 (SPSS, Inc., Chicago, IL), Stata SE v.10 (StataCorp, College Station, TX), and Microsoft Excel (Microsoft, Redmond, WA).

RESULTS

We enrolled a total of 63 subjects, including 25 mild traumatic brain injury case patients and 38 controls (Figure 1). We excluded 1 case patient with a high impulse control composite score and 1 case patient who did not complete the protocol. We excluded 5 controls with high impulse control composite scores and 2 controls who did not complete the protocol. The final analysis included 23 case patients and 31 controls.

Between case patients and controls, there were no statistically significant differences in sex, age, education, Galveston Orientation and Amnesia Score, GCS, time since injury, or concussion symptom inventory scores (Table).

Case patients and controls exhibited similar raw (median 80.1 versus 85.0 points; difference in medians -4.9 ; $P=.26$) and age-normalized (31.9 versus 57.4 percentile; difference in medians -25.5 ; $P=.12$) verbal memory (Figure 2). Case patients and controls exhibited similar raw (64.6 versus 63.5; difference 1.1; $P=.79$) and age-normalized (20.8 versus 25.8 percentile; difference -5.0 ; $P=.44$) visual memory (Figure 3).

Compared with controls, mild traumatic brain injury case patients demonstrated slower raw (31.6 versus 37.0 points; difference -5.4 ; $P=.002$) and age-normalized (17.1 versus 57.6 percentile; difference -40.5 ; $P=.001$) visual motor speed (Figure 4). Mild traumatic brain injury case patients exhibited slower raw (median 0.66 versus 0.60 seconds; difference 0.06;

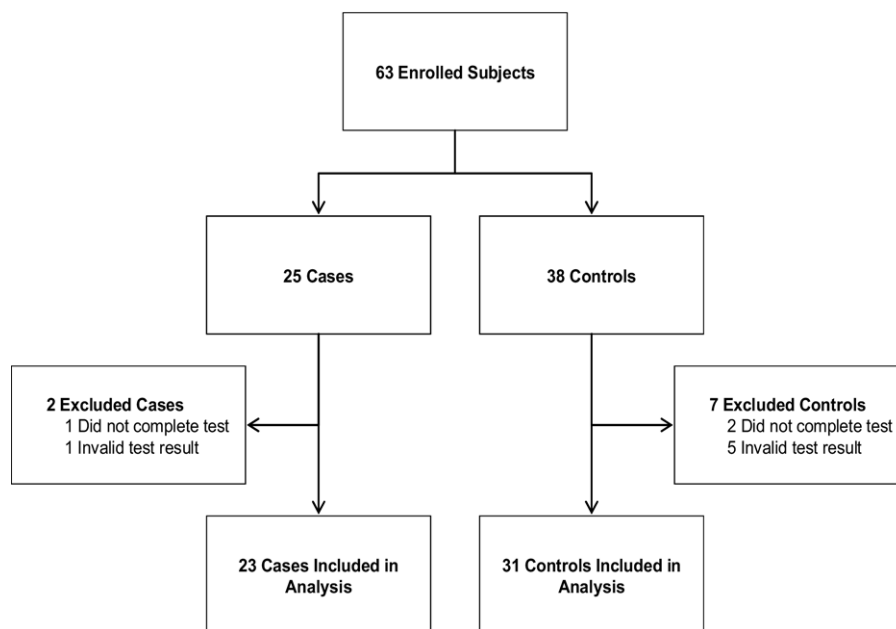


Figure 1. Subject enrollment. “Invalid test result” denotes subjects with neurocognitive testing impulse control composite scores >30 .

Table. Characteristics of participants. All comparisons made by nonparametric Wilcoxon rank sum test.

Characteristic	Mild Traumatic Brain Injury (n=23)	Non-Head Injured (n=31)	P Value
Age, y, median (IQR)	29 (23-42)	29 (22-37)	0.44
Male, No. (%)	12 (52)	18 (58)	0.67
Education level, y, median (IQR)	14 (12-17)	15 (12-16)	0.64
GCS, median (IQR; min-max)	15 (15-15; 14-15)	15 (15-15; 15-15)	0.10
Galveston Orientation and Amnesia Test, median (IQR)	99 (94-100)	100 (95-100)	0.31
Time from injury to ED presentation, h, median (IQR)	11 (3-39)	14 (4-27)	0.93
Mechanism of injury			
Fall	7	10	
Assault	5	2	
Motor vehicle crash	7	0	
Sprain, upper extremity	0	3	
Sprain, lower extremity	0	8	
Laceration, upper extremity	0	4	
Laceration, lower extremity	0	2	
Other	4	2	
Concussion Symptom Inventory Score, median (IQR)	19 (1-32)	5 (1-16)	0.09

$P=.01$) and age-normalized (29.3 versus 42.8 percentile; difference -13.5 ; $P=.009$) reaction times (Figure 5).

LIMITATIONS

We did not evaluate long-term neurocognitive outcomes of the study subjects. Although offered to all, only 2 subjects in this study opted to return for follow-up mild traumatic brain injury care or repeated neurocognitive testing. This observation may signal that subjects did not feel impaired enough to seek follow-up care or that there were other barriers to obtaining this type of specialty care.

Although we selected a reasonable control population for comparison with the head-injured case patients, we may have

observed different results with another cohort of control subjects. Whereas the study team was not blinded to the head injury status of the subjects, the same neurocognitive computer test was used for both case patients and controls. Although we used a standard computer software package for neurocognitive evaluation, other testing modalities or domains may prove equally useful.

We recruited a convenience sample of patients at a single center according to the availability of the study team. We might have included a larger and potentially more heterogeneous range of subjects, had we performed the study at multiple sites and at different times of the year. Additionally, we did not include major trauma patients in this study because of the cervical

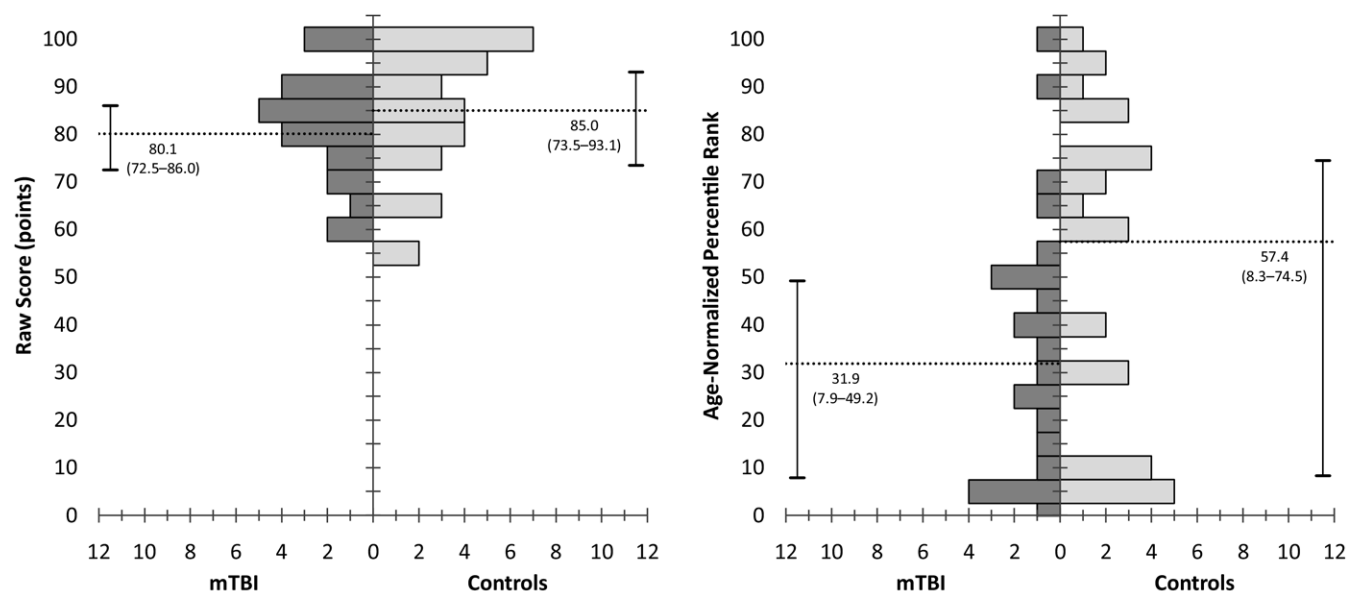


Figure 2. Neurocognitive performance scores—verbal memory. Histograms depict distributions of raw scores (0 to 100) and age-normalized percentile ranks. Vertical axes depict raw scores or age-normalized percentile ranks. Horizontal axes depict numbers of subjects. Dashed lines and corresponding labels denote medians and interquartile ranges. No statistically significant differences in raw scores ($P=.26$) or age-normalized percentile ranks ($P=.12$). *mTBI*, Mild traumatic brain injury.

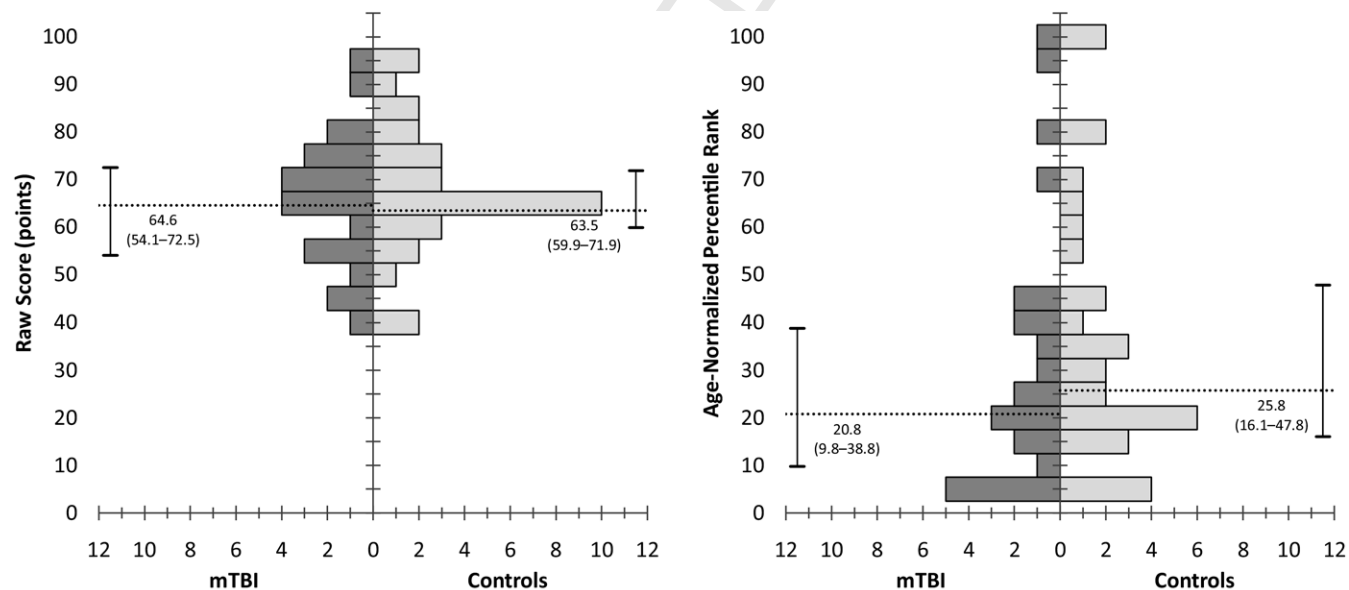


Figure 3. Neurocognitive performance scores—visual memory. Histograms depict distributions of raw scores (0 to 100) and age-normalized percentile ranks. Vertical axes depict raw scores or age-normalized percentile ranks. Horizontal axes depict numbers of subjects. Dashed lines and corresponding labels denote medians and interquartile ranges. No statistically significant differences in raw scores ($P=.79$) or age-normalized percentile ranks ($P=.44$).

immobilization methods used by this institution's trauma service; many of these subjects may have sustained mild traumatic brain injury. We did not attempt to test these patients at later points in their hospital stays. ED presentation delay was extended for many subjects.

The number of recruited subjects decreased below the targeted enrollment of 68 patients (34 per group). However,

the number of subjects included in the analysis (23 case patients and 31 controls) exceeded the minimum required sample sizes for the verbal memory, visual memory, and motor speed domains. For the remaining domain (reaction time), we observed a statistically significant difference in reaction time despite not meeting the targeted projected sample size. We did not recruit additional subjects after the

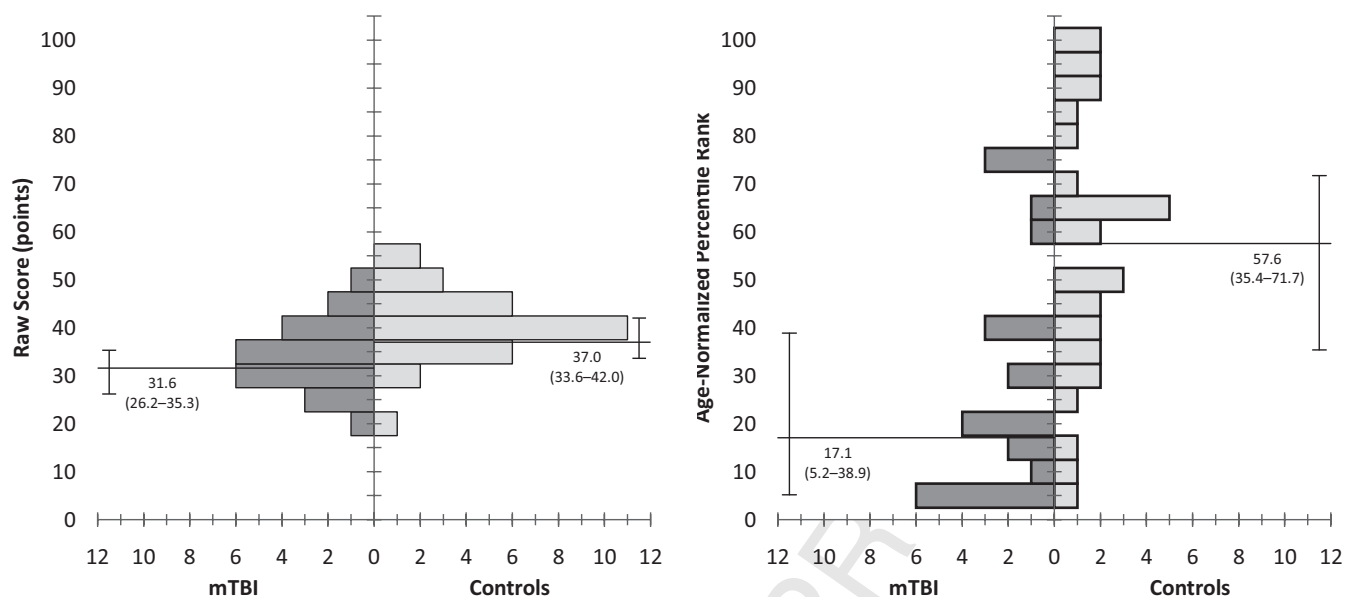


Figure 4. Neurocognitive performance scores—visual motor speed. Histograms depict distributions of raw scores (0 to 100) and age-normalized percentile ranks. Vertical axes depict raw scores or age-normalized percentile ranks. Horizontal axes depict numbers of subjects. Dashed lines and corresponding labels denote medians and interquartile ranges. Statistically significant differences in raw scores ($P=.002$) and age-normalized percentile ranks ($P=.001$).

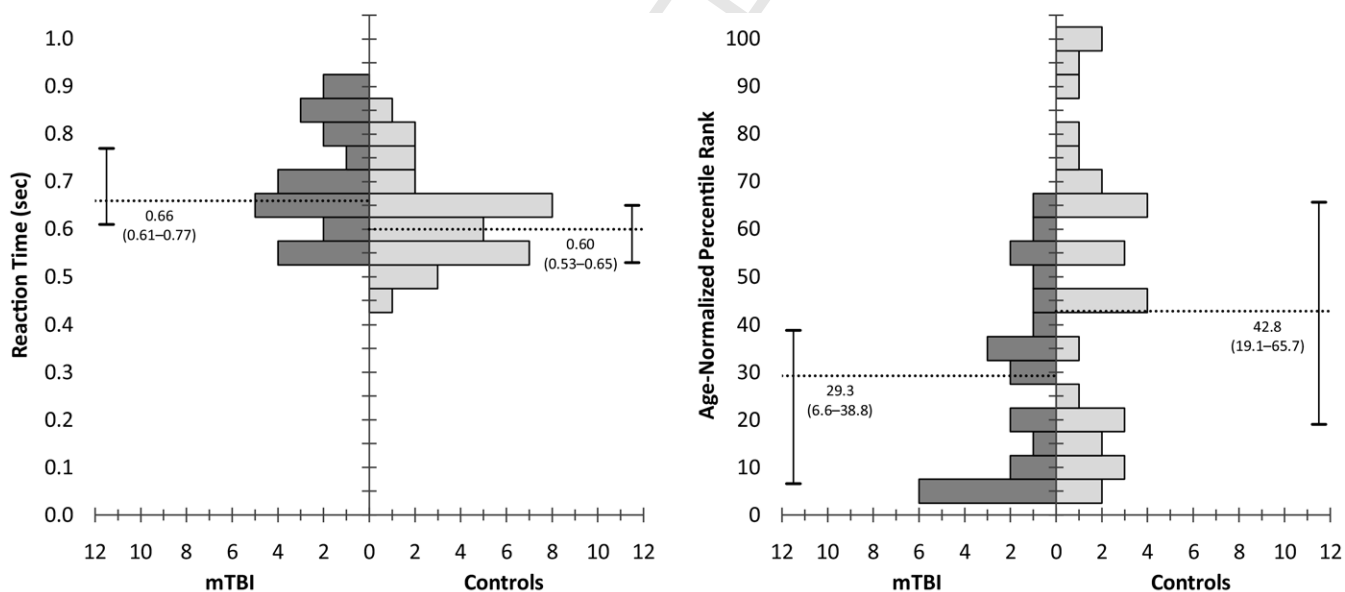


Figure 5. Neurocognitive performance scores—reaction time. Histograms depict distributions of reaction times (seconds) and age-normalized percentile ranks. Vertical axes depict reaction time or age-normalized percentile ranks. Horizontal axes depict numbers of subjects. Dashed lines and corresponding labels denote medians and interquartile ranges. Statistically significant differences in raw reaction time ($P=.01$) and age-normalized percentile ranks ($P=.009$).

planned 12-week study period because of the unavailability of research staff.

The results of this study apply only to individuals with isolated head injuries. Distracting factors (for example, a fracture) or altered sensorium (for example, medication or alcohol intoxication) may confound the results of neurocognitive testing. Distractions posed by the ED

environment may have interfered with performance on the computer test battery. We attempted to minimize these distractions by situating each subject in an isolated section of the ED and requiring the subject to wear noise-cancelling earmuffs. However, the testing conditions for our series likely differ from those used in previous outpatient efforts.

Neurocognitive performance may vary between individuals. In customary outpatient sports medicine practice, clinicians compare postinjury scores with baseline scores obtained at the beginning of the sports season.²¹ In this effort, we did not have baseline preinjury performance scores. We addressed this limitation by comparing neurocognitive scores with those of non-head-injured controls.

DISCUSSION

In this study we identified neurocognitive deficits in patients presenting to the ED after mild traumatic brain injury. Our effort illustrates the potential utility and limitations of ED-based neurocognitive testing in advancing initial mild traumatic brain injury recognition and evaluation. Patients with mild traumatic brain injury may demonstrate neurocognitive deficits despite having no visible intracranial abnormalities on head CT scan; for example, difficulty with concentrating, memory, or even performing simple math.¹¹ Even subtle neurocognitive deficits may prove debilitating, preventing victims from working or otherwise functioning in society.¹² Early diagnosis is essential in mild traumatic brain injury therapy. Subjects receiving early specialist care after mild traumatic brain injury report fewer overall symptoms, social disability and psychological sequelae.^{4,22}

Previous mild traumatic brain injury evaluations in ED settings have identified similar neurocognitive deficits.⁶ However, the methods used in these efforts had practical limitations precluding routine clinical use. For example, paper-based neuropsychological test batteries require a trained neuropsychologist or psychometrist for administration, scoring, and interpretation.^{23,24} A previous ED effort used computer-based neurocognitive testing but relied on separate paper-based symbol matching trials.⁶ The ImpACT software used in this study combines these different neurocognitive tasks into a single evaluation battery that does not require specialized test administration skills. This is one of the first efforts to apply this modality in the ED setting.

In this series, mild traumatic brain injury case patients exhibited impairments in visual motor speed and reaction time, without statistically appreciable verbal or visual memory score deficits. Although this observation may reflect the true lack of verbal or visual memory deficits in these subjects, another potential contributing factor is selection bias. Our effort included subjects presenting to a single academic urban ED during a defined 3-month study period. With a larger, more heterogeneous selection of patients recruited at other times of the year, we may have observed individuals with more appreciable deficits in these domains. Also, because of the cervical immobilization practices of our institution's trauma service, we did not include trauma patients; these individuals may have experienced more severe head injuries with more pronounced neurocognitive impairments. Compared with other efforts, the subjects in this series appeared to have sustained less severe head injuries with less pronounced neurocognitive deficits.²⁵

Although our study alludes to the potential role of early ED-based neurocognitive testing in mild traumatic brain injury, our effort does not evaluate long-term mild traumatic brain injury outcomes or integration of the ED with outpatient mild traumatic brain injury treatment. The salient components of concussion management include early recognition, rest, education, counseling, and reassurance.²⁶ In select cases, there may be a role for pharmacologic therapy for pain, depression, sleep disturbances, other sequelae.²⁷ Recovery from mild traumatic brain injury may require several days or weeks.²⁸ Neurocognitive testing may prove useful for tracking mild traumatic brain injury recovery and determining the appropriate timing for safe return to sports, school, or work.^{3,29} We emphasize that ED-based neurocognitive evaluation composes only one element of comprehensive mild traumatic brain injury management. ED-based neurocognitive testing may provide limited value without the availability of specialty mild traumatic brain injury follow-up care.

Our study did provide several practical observations about ED-based neurocognitive testing. Although not a formal objective of this effort, administering ImpACT in the ED does appear feasible. Subjects had little difficulty understanding the software interface or completing the test. None of the subjects required assistance or direction during testing. Although not a specific endpoint of this study, virtually all subjects completed the ImpACT test within 25 minutes. Because some subjects complained about the length of the test battery, a shorter test may prove useful in the ED setting.

Integration of testing with ED clinical care may also pose additional challenges. To avoid interrupting subjects during ImpACT testing, we occasionally waited for the completion of ED care before initiating the neurocognitive testing process. When possible, we moved subjects to an isolated ED room to minimize disturbances. As discussed previously, we could not include major-trauma patients, many of whom would have sustained significant mild traumatic brain injury; these individuals may benefit from alternate testing modalities. These logistic considerations may pose barriers in select ED settings.

In conclusion, compared with the non-head-injured patients, ED mild traumatic brain injury patients demonstrated subtle but discernible neurocognitive deficits.

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Editor's Capsule Summary: *What is already known on this topic:* Mild traumatic brain injury is suspected to result in more morbidity than previously appreciated, but difficulty measuring cognitive and psychomotor symptoms in the emergency department (ED) impairs study of this condition. *What question this study addressed:* Can computerized neuropsychiatric testing

performed in the ED identify deficits in normal-appearing patients with acute mild traumatic brain injury? *What this study adds to our knowledge:* In 23 patients with head injury, relatively abbreviated neuropsychiatric testing identified significantly worse average performance in 2 of 4 domains compared with 31 controls with isolated extremity trauma. *How this might change clinical practice:* The ability to practicably measure deficits after mild traumatic brain injury in the ED makes further study of these patients possible. If those with ongoing problems can be diagnosed early, the potential for treatment exists.

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APPENDIX: E1.

Neurocognitive domains and subtests used in ImpACT software.

Verbal memory characterizes a subject's memory of words and consists of 3 subtests:

- Word Recognition Paradigm. Tests subject's recall of words shown at the beginning and end of the total test battery (elapsed time approximately 25 minutes).
- Symbol Match Task. Tests the subject's recall of symbol/number associations.
- Letter Memory Task with Accompanying Interference Task. Tests subject's recall of letters shown before and after an interference task (rapid countdown of 25 buttons in order).
- Visual memory characterizes a subject's ability to remember patterns and shapes and consists of 2 subtests:
- Diagram Recognition Paradigm. Tests subject's recall of abstract line drawings and their orientation shown at the beginning and end of the test.
- "X's & O's" Memory Test. Tests subject's recall of X and O patterns and colors.

Visual motor speed characterizes the subject's speed at recognizing visualized objects and consists of 2 subtests:

- Total number correct in the X's & O's Memory Test.
- Speed of 25-button countdown from Letter Memory Task.

Reaction time reflects the subject's speed of response to visualized objects and consists of 3 subtests:

- X's & O's Test. Same test as used in visual memory. Tests speed of subject's recall of X and O patterns and colors.
- Symbol Match Test. Same test as used in verbal memory. Tests speed of subject's recall of symbol/number associations.
- Color Match Test. Tests subject's correct selection of words displayed in different colors.

APPENDIX :E2.

Concussion symptom inventory. Subjects assigned a 7-point (0 to 6) Likert rating for the severity of each symptom. Total score=sum of ratings (range 0 to 132 points).

- Migraine Factors: Headache, nausea, vomiting, balance problems, dizziness, sensitivity to light, sensitivity to noise, numbness or tingling, visual problems.
- Sleep Factors: Trouble sleeping, sleeping less than usual.
- Cognitive Factors: Fatigue, drowsiness, feeling slowed down, feeling mentally "foggy," difficulty concentrating, difficulty remembering, sleeping more than usual.
- Neuropsychiatric Factors: Irritability, sadness, nervousness, feeling more emotional.

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