J Head Trauma Rehabil
Vol. 23, No. 4, pp. 230–242

Improving Identification and Diagnosis of Mild Traumatic Brain Injury With Evidence: Psychometric Support for the Acute Concussion Evaluation

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Objectives: A dearth of standardized assessment tools exists to properly assess and triage mild traumatic brain injury (mTBI) in primary care and acute care settings. This article presents evidence of appropriate psychometric properties for the Acute Concussion Evaluation (ACE), a new structured clinical interview. **Participants:** Parent informants of 354 patients, aged 3 to 18 years, with suspected mTBI completed the ACE via telephone interview. **Measure:** Acute Concussion Evaluation. **Results:** Evidence is presented for appropriate item-scale membership, internal consistency reliability as well as content, predictive, convergent/divergent, and construct validity of the ACE symptom checklist. **Conclusions:** Overall, the ACE symptom checklist exhibits reasonably strong psychometric properties as an initial assessment tool for mTBI. **Keywords:** *acute concussion evaluation*, *assessment*, *concussion*, *mild traumatic brain injury*, *postconcussion symptoms*, *triage*

DELIVERING appropriate clinical and rehabilitation services to persons who have sustained a mild traumatic brain injury (mTBI) or concussion, terms used synonymously in this article, requires proper identification and diagnosis of the unique problems inherent in the injury at the outset. This article describes one of the most significant issues for persons with mTBI—initial recognition and identification.[1,2] Although proper treatment/rehabilitation service delivery is a concern for persons with mTBI, such treatment cannot begin without timely identification of the injury and its effects. Mild TBI represents the overwhelming majority of brain injuries with estimates of 75% to 90% of all brain injuries classified as mild.[3,4] Given substantial underidentification of persons with mTBI, the actual incidence is likely much higher.[5] Although the majority of individuals with mTBI recover within a 3-month time period,[6–8] this population nevertheless has important needs that go largely unmet when not properly identified and treated. The greatest challenge to the medical practitioner is appropriate and timely recognition, assessment, and diagnosis. Without state-of-the-art knowledge and clinical tools, mTBI may go undiagnosed and untreated, leaving individuals who have sustained an mTBI with an increased risk for functional problems.[9]

DEFINITION OF mTBI

For the purposes of this article, we use the definition of mTBI provided in the Centers for Disease Control and Prevention's published physician tool kit.[10] An mTBI or *concussion* is defined as

> a complex pathophysiologic process affecting the brain, induced by traumatic biomechanical forces secondary to direct or indirect forces to the head. Disturbance of brain function is related to neurometabolic dysfunction, rather than structural injury, and is typically associated with normal structural neuroimaging findings (ie, CT scan, MRI). MTBI may or may not involve a loss of consciousness (LOC). Mild traumatic brain injury results in a constellation of physical, cognitive, emotional, and sleep-related symptoms. Duration of symptoms are variable and may last for as short as several minutes and last as long as several days, weeks, months, or even longer in some cases.[(10p2)]

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This paper was supported in part by grants from CDC no. U17/CCU323352-01 and NIH no. 5-MOI-RR-020359-02.

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PROBLEMS IN IDENTIFICATION AND DIAGNOSIS OF mTBI

Although our understanding of mTBI and its consequences has increased significantly over the past 5 to 10 years including functional manifestations and relationship to brain mechanisms,[6,11–13] this knowledge is yet to be translated effectively into clinical practice on a broad basis. Without appropriate knowledge of mTBI in the medical community, early identification remains problematic.[14] Although limited dissemination to clinical practitioners of the substantial knowledge regarding mTBI gained over the past 10 years contributes to the problem of underidentification, we have also lacked appropriate clinical tools to assist in identification and diagnosis of the problem. In reality, the patient with mTBI most often presents to the primary care office or the emergency department, neither of which specialize in diagnosis and treatment of mTBI. Yet, if this is where individuals first arrive, this is where we must focus our efforts to improve initial identification.

Review of available clinical tools used consistently for identification and diagnosis of mTBI in primary care and emergency care settings reveals no standardized methods.[14] Assessment of post-mTBI signs and symptoms is often cursory with a focus on a limited set of readily identifiable and/or high-frequency symptoms such as loss of consciousness, headache, and memory loss.[1] Assessing a small set of signs and symptoms does not reflect the full spectrum of possible symptoms or even some of the most common symptoms following mTBI. Research evidence has demonstrated that symptoms can be divided into several categories[11,15,16]: (1) physical, including headaches, fatigue, dizziness, drowsiness, sensitivity to light and noise, nausea, balance problems, visual disturbance (double or blurry vision), vomiting, and numbness/tingling; (2) cognitive, including poor concentration, problems with memory, feeling mentally foggy, and feeling slowed down; (3) emotional, including feeling irritable, greater emotionality, sadness, and nervousness; and (4) sleep problems, including sleeping more than usual, trouble falling asleep, sleeping less than usual.

Furthermore, there are no standardized systems for monitoring patient symptoms over time even when mTBI is identified. Little direction is available to the medical community regarding standardized protocols for identification of mTBI. The guidelines for the management of mTBI published in 1999 by the American Academy of Pediatrics[17] focus primarily on an algorithm for detecting intracranial injury in severely injured children (within 24 hours) who have experienced a loss of consciousness of less than 1 minute. Little attention is given to the nature of the symptom assessment and management processes. Although considered by many practitioners to be a cardinal sign of mTBI, loss of consciousness occurs in less than 1 quarter of individuals with mTBI.[18,19] The American Academy of Pediatrics practice parameter, therefore, excludes over 75% of children with mTBI. In addition to imaging procedures, physicians are guided to observe the patient together with gathering a thorough history and appropriate physical/neurological examination. The practice parameter does not offer guidance on the full spectrum of symptoms that should be assessed or the kinds of questions to be asked regarding the injury itself. The poor understanding of existing management guidelines for sports-related concussions was identified in 2001 by Bazarian,[20] with a low percentage of primary care medical practitioners demonstrating knowledge of existing guidelines for return to play. Interestingly, in a later survey in 2006 of primary care providers in Maine,[21] 70% of the respondents reported that they "routinely use" published guidelines in managing concussions, although they were not asked to demonstrate this knowledge as the Bazarian[20] study required. Overall, the lack of available standardized tools and the lack of knowledge regarding current practices in evaluating and managing mTBI argue strongly for significant improvement in this area.

As might be expected, given the lack of defined methods for identification and diagnosis, treatment of mTBI is often unsystematic and based on limited information with limited treatment foci (eg, headache management). Thus, problems in identification lead to problems in management as the person with mTBI may not be diagnosed for days or weeks after concussion, symptoms go unmanaged with risks of exacerbation associated with physical and cognitive exertion, or at worst re-injury. Increased risks of undetected and untreated mTBI are also evident in school and social functioning arenas. Ponsford[9] demonstrated improvement of post-mTBI functioning in individuals identified and evaluated early in the emergency department, who were provided with injury-specific information and coping strategies. In contrast, the nonintervention group reported a greater number of post-mTBI symptoms, behavioral maladjustment, and attention problems at 3 months.

PROPER IDENTIFICATION OF mTBI: CHALLENGES AND OPPORTUNITIES

There are legitimate reasons why the recognition of mTBI is in its current state. Identification can be challenging, as the symptoms are common and similar to those of other medical and psychiatric conditions such as posttraumatic stress disorder, depression, and headache syndromes.[11] Furthermore, symptom onset or the patient's recognition of symptoms may be somewhat removed from the actual physical injury and not occur for days or, in some cases, weeks afterward.[22] An early and systematic assessment of the injury and its manifestation is, therefore, essential to proper management and reduced morbidity.[23] To facilitate early identification and diagnosis, it is important to distill the essential elements of mTBI. At the most fundamental level, the trigger conditions that would warrant assessment of a possible mTBI requires 2 major factors: (1) evidence of either a direct or an indirect forcible blow to the head with, (2) presence of signs and/or symptoms of an injury to the brain in reasonable temporal relation to the forcible blow.[11]

One challenge to early recognition is determining whether a "difference" from the person's typical functional state has occurred, that is, reliably detecting change from "usual" functioning. Depending on a person's age and premorbid functioning, detecting such change may be difficult. For example, it may be difficult to detect a change in attentional functioning in a child with premorbid attention problems or in a preschool child. Detecting a change in irritability in an adult with premorbid depression may also be a challenge. Direct questioning of the patient or caretaker about any changes from their "usual" state of functioning is essential. It is equally important to inquire about all potential mTBI symptom areas, specifically the 4 categories previously indicated, cognitive, somatic, emotional, and sleep. Symptoms should also be queried and evaluated across the relevant settings where they may arise, such as in school, at home, at work, and during physical and mental activity. Finally, as an injury to the brain takes time to recover, monitoring of symptoms and functional status over time is important to guide treatment. In doing so, the clinician must also detect reliable improvement and return back to the person's "usual" functioning.

Another challenge to early evaluation of an mTBI is determining which key circumstances or situations warrant examination for possible mTBI. There are injuries where mTBI assessment is clearly indicated including those in which loss of consciousness, change in mental status, confusion, or amnesia are observed, and those injuries where mTBI is suspected in the presence of other traumatic injuries. Evaluation for mTBI should be considered with any injury stemming from high-speed activities including motor vehicle, bicycle, or skateboarding accidents; sports and recreation activities; falls especially from a significant distance and particularly for children and older adults; suspected child maltreatment (eg, shaking, hitting, or throwing); exposure to blasts including military personnel returning from war zones; and other injuries to the external parts of the head and/or scalp (eg, lacerations).[24]

Opportunities

With the field in need of better early identification of mTBI, the opportunity exists to improve early identification at the primary care source, facilitate appropriate management on the basis of individualized assessment information, and thereby improve recovery and reduce morbidity. From a public health perspective, a major opportunity exists for improved epidemiologic understanding of mTBI incidence to direct appropriate health and education resources to intervention and prevention efforts.[5] Without adequate recognition and identification of the problem, our accurate understanding of the scope and impact of mTBI will be diminished and allocation of necessary resources will be misdirected. Providing a system of improved identification and diagnosis will increase general knowledge of mTBI and its management within the medical community.

Acute concussion evaluation[25]

Given the need for a standardized tool to aid in identifying mTBI in primary care and emergency medicine settings, our broad goals were to (1) develop a systematic evidence-based clinical protocol (ie, a set of clinical questions) for use when a possible mTBI injury presents to the medical setting; (2) provide direct research evidence for the use of the ACE protocol (Appendix A); and (3) link the assessment information to initial follow-up recommendations for patients and their families. The ACE was developed to address these goals. The ACE provides clinicians with essential information derived from recent literature that is necessary to render an appropriate diagnosis of an mTBI. It is administered as a clinical interview of the patient directly or of a knowledgeable caretaker, spouse, or friend–in person as part of a clinical examination or over the telephone as an initial triage. The ACE is organized according to key areas of inquiry including (1) specific characteristics of the injury including details of the direct or indirect blow to the head, retrograde and anterograde amnesia and loss of consciousness[18,19,26]; (2) a full array of 22 symptoms and 5 signs associated with mTBI,[27] referred to as the ACE symptom checklist; and (3) risk factors that might predict a prolonged recovery such as a history of previous mTBI,[28–30] headaches,[31,32] learning disabilities,[33] or attention-deficit/hyperactivity disorder, and anxiety or depression.[34–36] The presence of these risk factors would prompt the clinician to expect a lengthier recovery period and to counsel the patient about this possibility. The ACE also serves as a tool for monitoring the array of symptoms over time through repeated assessments. Serial assessment can document the progress of recovery or, with little or no progress, prompt referral to a specialist (eg, neuropsychologist or neurologist) for further in depth evaluation.

To inform management of the patient with an mTBI, we developed the ACE care plan.[24] The fundamental concepts driving the set of treatment recommendations in the care plan are maximizing rest and minimizing overexertion of brain. Excessive physical and/or mental activity frequently results in an increase in symptoms (ie, exertional effects) and can be counterproductive to recovery. Student-athletes and persons with demanding school and/or work responsibilities can experience significant cognitive exertional effects with adverse effects on academic and/or work function, and may have prolonged recovery period if not appropriately managed. With these essentials in mind, the ACE care plan was developed via a logical-rational application of these concepts. The care plan offers specific recommendations regarding return to school, work, sports, and return to home life/social activities.

This study presents the psychometric properties of the ACE symptom checklist to establish evidence of reliability and validity. The statistical structure of the symptom checklist and its relationship to injury characteristics and later symptom reporting are examined.

METHODS

Participants

A consecutive series of 354 individuals, all of whom were the parents of children and adolescents with suspected mTBI who called in to a regional concussion clinic, participated in this study. The age range of the injured patients was 3 to 18 years (mean age = 13.4 years, SD = 3.3); the sex distribution was 232 (65.5%) males, 122 females (see Table 1). Patients were referred by physicians (emergency medicine, primary care, sports medicine, and neurologists), athletic trainers, and/or family members. Ethnicity of the sample was, White 65.2%, Black 26.3%, Latino 4.1%, Asian 1.5%, other or undetermined 2.9%. Reported acute injury characteristics were as follows: 31% with loss of consciousness, 32% with retrograde amnesia, and 42% with anterograde amnesia; all reports were irrespective of duration. These 3 injury characteristics were reported by the participants in response to the ACE questions 3 to 5 (eg, Question 3 [see Appendix A], retrograde amnesia, "are there any events just before the injury that the person has no memory of [even brief]?"). The median time interval from the date of injury to the date of first ACE administration was 6 days (range = 0–119 days) with 87% having an interval of 30 days or less. The injuries occurred under the following circumstances: organized sports (50%), recreation (8.2%), fall (16.1%), head struck by object (5.1%), occupant in motor vehicle accident (9.6%), pedestrian motor vehicle accident (5.9%), and assault (5.1%).

TABLE 1 *Age and sex of Acute Concussion Evaluation injury sample*

Age	Total *N*	*N* %	No. of males	%, Males
3–7	24	6.8	12	50
8–12	90	25.4	60	67
13–18	240	67.8	160	67
	354	100	232	65.5

Procedure

The ACE was administered via telephone interview by trained research assistants to individuals making an initial call to a regional clinic for mTBI. The ACE symptom checklist was presented as a 22-item dichotomous (presence/absence) inventory. For each symptom item, respondents were asked whether the patient was exhibiting the symptom "any more than usual." Respondents were also asked about the presence of 5 additional acute signs (see Appendix A) that do not contribute to the ACE symptom checklist total score. These 5 acute signs were not included in the current analysis.

To establish the predictive relationship of the ACE symptom checklist to subsequent symptom reporting in the clinic, parents and patients completed a standard graded symptom checklist, the postconcussion symptom inventory (PCSI),[27,37] adapted for either parent or patient self-report. Symptom severity is rated on the PCSI with anchors ranging from "none" to "severe." Median time between the telephone-based ACE symptom checklist and the completion of the PCSI at the first clinic visit was 7 days.

Measures

Acute Concussion Evaluation symptom checklist

The ACE symptom checklist can be completed via telephone or in-person interview with the patient and/or parent/caretaker if the patient is a child. Symptoms are organized according to the 4 symptom areas (physical, cognitive, emotional, and sleep) that are identified commonly in diagnostic systems such as the International Statistical Classification of Diseases–10th Revision[15,16] and other literature on mTBI.[11,38] Because symptoms can be present prior to the injury (eg, inattention and headaches), the respondent is asked to indicate whether there is evidence of any changes from usual symptom presentation. A total symptom checklist score is calculated by summing the number of symptoms that are reported as present, and subtotals can be calculated for each of the 4 symptom areas. The total score can range from 0 (*no symptoms*) to 22 (*maximum number of symptoms*).

PCSI–parent version

The parent version of the PCSI is an adaptation of the 22-item 7-point Likert scale self-report measure for adults.[27,37] The measure queries common physical, cognitive, and behavioral symptoms seen following a concussion. The instructions were modified to ask the parent respondent to rate the extent to which each symptom is observed in the home setting. Two forms are administered at the first visit: (1) a retrospective preinjury baseline report in which the parent is asked to rate the extent to which any of the symptoms were observed a day or two before the injury, and (2) a postinjury report in which the parent is asked to rate the extent to which any of the symptoms have been observed over the past day or two.

PCSI—self-report versions

The PCSI forms were administered to the patients in a similar manner as the parents (retrospective preinjury baseline report and current postinjury report), to gather self-reports of symptoms. Different age-dependent forms were used according to the developmental level of the child (age = 5–7 years, 8–12 years, and 13–18 years). The reports of the 2 older patient groups are examined in this study. The PCSI for the 8- to 12-year old patients includes 25 items rated on a more age-suited and modified 3-point Likert scale in which the child is asked to rate whether the symptom is present, not at all, a little, or a lot. The PCSI completed by the 13- to 18-year old patients was the standard 22-item, 7-point Likert scale version,[27,37,38] administered as part of the computerized neuropsychological test battery, Immediate Postconcussion Assessment and Cognitive Testing.

Data analyses examined the evidence for reliability, including strength of item-scale membership (item-total correlations) and internal consistency reliability (coefficient α) and evidence for validity, including analyses of content validity, predictive validity (relationship with clinic-based symptom reports), convergent (rank correlation with established symptom questionnaires) and discriminant validity (relationship with pre- and postinjury symptom ratings and injury characteristics), and construct validity (via exploratory factor analysis).

RESULTS

Descriptive statistics

ACE symptom checklist frequencies

The duration of time to complete the injury description/characteristics and symptom checklist of the ACE was sampled in 232 participants with a mean time of 5.5 minutes (SD = 2.1). The frequency with which each symptom was endorsed is presented in Table 2. In general, reported symptom frequency is consistent with the literature, indicating the highest frequency symptoms to be headache (74%), fatigue (60%), and feeling slowed down (48%), whereas the 3 lowest symptoms are vomiting (4.5%), numbness/tingling (9%), and sleeping less often than usual (11%).

TABLE 2 *Acute Concussion Evaluation symptom report frequencies and item-total correlations*

Symptom	Reporting symptom, %	Item-total correlation
Headache	74	0.333
Fatigue	60	0.521
Feeling slowed down	48	0.511
Difficulty concentrating	43	0.490
Difficulty remembering	42	0.415
Dizziness	41	0.424
Feeling drowsy	41	0.442
Feeling mentally foggy	40	0.413
Sleeping more than usual	40	0.369
Irritability	35	0.415
More emotional	34	0.509
Sensitivity to light	28	0.397
Sadness	27	0.425
Sensitivity to noise	27	0.449
Nausea	25	0.412
Balance	22	0.380
Trouble falling asleep	21	0.299
Visual problems	20	0.305
Nervousness	18	0.369
Sleeping less than usual	11	0.163
Numbness/tingling	9	0.186
Vomiting	4.5	0.131

Evidence for reliability

Item-scale membership

The statistical strength of each item's membership with the total symptom score was examined via the item-total correlation statistic. Examination of the item-total correlations, reported in Table 2, indicates that most of the symptoms have a moderate correlation with the total score, indicating adequate scale membership. The 3 symptoms, from the somatic, cognitive, and emotional subdomains, respectively, most highly correlated with the total score were fatigue (0.500), feeling slowed down (0.490), and feeling more emotional (0.522) whereas the 3 symptoms least correlated were vomiting (0.129), sleeping less often than usual (0.158), and numbness/tingling (0.186). These latter 3 are also the symptoms least endorsed.

Internal consistency

Internal consistency reflects the degree to which items in a single scale are measuring the same underlying construct. The typical internal consistency statistic is

Cronbach α,[39] the mean correlation of all possible sets of item-total correlations within a scale. The internal consistency of the 22-item ACE was moderate to high and appropriate for a rating scale, with an α coefficient of 0.82.

Interrater reliability

Measurement variability attributable to examiner error or bias is an important issue for a tool such as the ACE. Although the design of this study did not afford the opportunity to conduct a classic analysis of interrater reliability (ie, having 2 raters rate the same data to establish agreement), we are able to examine possible influences of different "raters" during the clinic intake process. We identified 4 raters who had contributed 35 or more ACE symptom ratings (rater 1, $n = 35$; rater 2, $n = 51$; rater 3, $n = 72$; and rater 4, $n = 36$). Although it was not feasible to have more than 1 rater complete the ACE with the same family, as this would have placed an additional burden on an already stressed family, it was possible to compare overall scores between raters to determine whether there were any systematic differences. Controlling for injury and demographic characteristics (which can affect the ratings), there were no differences between any of the 4 raters (MANCOVA $F_{3,184} = 2.3$; $P > .05$). In addition, we were interested in examining any differential relationships between any of the 4 raters and symptom outcomes in clinic–possibly an indicator of rater variance with respect to outcome. We found equally high correlations between the initial ACE symptom checklist total scores and later parent-report clinic-PCSI scores, regardless of rater (rater 1, $\rho = 0.699$; rater 2, $\rho = 0.592$; rater 3, $\rho = 0.681$; and rater 4, $\rho = 0.689$; $P < .001$). Thus, given our current design, we did not identify any systematic or gross differences in ACE symptom assessment attributable to raters.

Evidence for validity

Validity

Refers to the accuracy with which an instrument measures the intended construct. Evidence supporting the valid interpretation of the ACE symptom checklist total score is based on various sources. In this case, evidence supporting the valid interpretation of the ACE symptom score is based on (*a*) the content of its items, (*b*) the convergence and divergence of the ACE score with those of other measures, and (*c*) the internal structure of the ACE.

Content validity

The ACE was developed with attention to content validity for individual items. To this end, the *symptom items* were identified and defined on the basis of the existing research literature, including the relevant domains (somatic, cognitive, emotional, and sleep) reflected in other postconcussion symptom measures. As previously noted, postconcussion symptom scale by Lovell and Collins (1998)[27] served as the basis for the development of items for the ACE symptom checklist.

Predictive validity

Predictive validity refers to an instrument's ability to detect symptoms or diagnoses, such as those based on clinic-based symptom assessment. The dichotomous ACE symptom checklist total score, obtained at the time of the initial telephone call, correlated significantly with the parent- and child-PCSI 7-point graded symptom rating scores at the first clinic appointment (6-day median interval) as follows: parent postconcussion ratings ($n = 314$; $\rho = 0.679$, $P < .001$); patient (age = 8–12 years) postconcussion ratings ($n = 63$; $\rho = 0.421$, $P = .001$); and patient (age = 13–18 years) postconcussion ratings ($n = 236$; $\rho = 0.587$, $P < .001$).

Convergent and discriminant validity

One method for evaluating the validity of a newly developed instrument is to examine correlations between the new measure (ACE) and existing measures (PCSI) of similar (postinjury) and dissimilar (preinjury) traits. The degree to which the new measure correlates, or converges, with other measures of similar traits is one indicator of validity. At the same time, the new measure should correlate less with other rating scales of dissimilar characteristics, such as the relationship between postinjury symptoms as measured on the ACE and measures of preinjury, nonsymptomatic functioning.

Similarities between the "behaviors" of the ACE symptom checklist items with clinic-based measures were examined. That is, how do reports of individuals via the ACE telephone-based symptom checklist-triage method compare with the symptom reports of individuals in clinic using established graded postconcussion scales? To examine convergence with the symptom frequencies of the ACE symptom checklist method versus the established graded symptom measures, correlational analyses were conducted comparing the rank order of symptom frequency with several samples: (1) the published reports of symptom frequency of 2 external samples using postconcussion scales (22-item PCS;[37] 14-item scale[11]) and (2) the symptom frequencies of the clinic-based parent and patient PCSI in this study's sample. The frequency of the symptom reports was rank ordered for each of the samples. Rank order correlations demonstrated strong relationships with the external samples from both the Lovell sample (Spearman's $\rho = 0.791$, $P < .001$) and the McCrea sample (Spearman's $\rho = 0.763$, $P = .001$).

Similarly, rank order correlations were also highly significant for the internal samples (parent PCSI Spearman's $\rho = 0.957$, $P < .001$; child [age = 8–12 years] PCSI Spearman's $\rho = 0.875$, $P < .001$; and adolescent [age = 13–18 years] PCSI Spearman's $\rho = 0.901$, $P < .001$).

To further examine the divergent validity of the ACE symptom checklist, that is, whether the score is differentially sensitive to postinjury concussion symptoms, ACE symptom checklist total scores were correlated with the parent and patient retrospective preinjury baseline ratings. We posited that these correlations would be significantly lower than correlations between the ACE and parent- and patient-postinjury ratings at the initial office visit as they were rating different functional states (pre- vs postinjury). The z scores were calculated and submitted to a difference test to measure significant differences in strength of association. Our hypothesis was supported with the ACE correlating significantly more strongly with postinjury parent and adolescent patient symptom ratings than with retrospective baseline symptom ratings. The correlation between the ACE score and parent baseline symptoms ratings was significantly lower ($\rho = 0.228$, $n = 320$) than the correlation between the ACE score and parent postinjury ratings ($\rho = 0.679$) ($z = 7.49$; $P < .0001$). The correlation between the ACE and 13- to 18 year-old patient preinjury ratings was ($\rho = 0.246$, $n = 193$) also significantly lower compared with postinjury ratings ($\rho = 0.587$) ($z = 5.19$, $P < .0001$). These significant findings indicate a stronger relationship between the ACE symptom checklist score and the 2 postinjury reports than with baseline reports, providing further evidence of its selective relationship with postconcussive symptoms. The difference in strength of correlations did not reach statistical significance for the 8- to 12-year-old patient reports (difference $P \leq .415$).

Relationship of the ACE to demographics and acute injury characteristics

Demographic variables such as patient age (as a continuous variable) and ethnicity (as a categorical variable) were not significantly related to the ACE symptom checklist total score. Sex differences were found with girls reportedly exhibiting a significantly higher number of overall symptoms (mean = 8.4, SD = 4.7) than boys (mean = 6.4, SD = 4.3; $P < .001$).

An examination of the relationships between ACE symptom checklist and injury characteristics was conducted. Each injury characteristic was entered as a factor in an analysis of variance with ACE symptom checklist total score as a dependent variable. Findings indicate that patients who experienced a loss of consciousness had higher ACE symptom checklist scores ($F_{2,345} = 3.89$, $P = .021$) as did those identified as having experienced anterograde amnesia ($F_{2,342} = 3.44$, $P = .033$), whereas presence of retrograde amnesia was not statistically related to the ACE total symptom score ($F_{2,338} = 1.81$, $P > .05$). The relationship of the time interval between the injury and the ACE symptom checklist report was examined to determine whether shorter time intervals (ie, acute injury) might be related to higher total symptomatology. Correlation of the interval in days since injury with the ACE symptom checklist score was low but significant ($\rho = 0.198$; $P < .001$), indicating a tendency for those with a longer interval to report more symptoms on the ACE. This unexpected positive correlation is likely due to a mixture of injury acuities. Patients in the current sample with relatively long time intervals since injury appeared to have had persisting and possibly worsening symptom profiles. This more chronic subsample combined with the more acute subsample likely altered the findings.

Construct validity: Exploratory factor analysis

Symptom variables can be viewed as unique individual entities that have their own importance and relevance (eg, presence and severity of a headache) as well as a member of a group that shares a common characteristic with other like symptoms (eg, somatic symptoms). Clinically, it can be useful to examine a symptom scale at both levels. Exploration of the shared relationships of symptoms, as they might group into meaningful subscales, can be conducted via factor analysis. Exploratory factor analysis provides additional evidence for the validity of the internal scale structure of the ACE symptom checklist. The common factor analysis method (principal axis factoring) was used as the exploratory method. Orthogonal (varimax) and oblique (promax) rotational methods were applied to examine the resultant factor patterns, allowing for examination of solutions with noncorrelated (orthogonal) and correlated (oblique) factors.[40] One important purpose of the factor analyses in this study was to examine the consistency of the scale's structure with the previously reported factor structures of postconcussion symptom scales,[38,41] a means of validating the constructs underlying the ACE symptom checklist.

Initial examination of the communality estimates (ie, the proportion of a variable's variance accounted for by the common factors) revealed low-to-moderate values ($h^2 = 0.3–0.6$) for most symptoms but very low values for 2 symptoms regardless of the number of factors extracted. The communalities for vomiting (eg, $h^2 = 0.087$ in a 4-factor model) and numbness/tingling (eg, $h^2 = 0.065$), indicate less than 10% of variance accounted for by the common factors, which suggests that they are not strongly associated with the scale structure. These symptoms also happen to be reported at a very low frequency, which likely affects their relationship to the scale as a whole. Because of the low general relationship with the

TABLE 3 *Factor loadings for 4-factor solution of Acute Concussion Evaluation symptom checklist**

ACE† symptom	Somatic	Emotional	Cognitive	Sleep
Sensitivity to light	0.634			
Sensitivity to noise	0.514			
Nausea	0.507			
Dizziness	0.495			
Headaches	0.409			
Drowsiness	0.381			
Balance problems	0.372			
Fatigue	0.353	0.336		
More emotional		0.635		
Sadness		0.336		
Irritability		0.515		
Nervousness		0.485		
Difficulty remembering			0.638	
Feeling mentally foggy			0.615	
Difficulty concentrating			0.595	
Feeling slowed down			0.448	
Sleeping less than usual				0.638
Trouble falling asleep				0.421
Sleeping more than usual		0.330		0.638
Variance accounted for	24.4%	8.5%	7.9%	6.8%

*Factor loading threshold = 0.3; Factor rotation method (varimax).
†ACE indicates Acute Concussion Evaluation.

rest of the symptoms, factor solutions were calculated with (22 items) and without (20 items) these 2 symptoms. Factor solutions of 2 to 6 factors were explored on the basis of theoretical and statistical considerations with particular interest in the 3- and 4-factor solutions, given the identification of distinct cognitive, somatic, emotional, and sleep factors in the general literature. Thus, factor solutions based on eigenvalues greater than 1.0 (a traditional statistic used in selecting the number of factors to retain in exploratory factor analysis) was not used in isolation. The criterion for inclusion of a variable on a factor was set at a loading greater than 0.30.

Several consistent findings were evident regardless of the number of factors extracted in the solution or the rotational method chosen. A 4-symptom cognitive factor (difficulty remembering, difficulty concentrating, feeling mentally foggy, and feeling slowed down) and a 4-symptom emotional factor (sadness, irritability, more emotional, and nervousness) were produced invariably. Variations of a somatic factor also were evident consisting of headaches, nausea, sensitivity to light and noise, balance problems, dizziness, feeling fatigued, visual problems, and drowsiness, although some items fractionated to small 2-item factors (eg, nausea and vomiting) in some solutions. A sleep factor was present to varying degrees depending on the factor model with "sleeping more than usual," "sleeping less than usual," and "trouble falling asleep" loading on this factor most often. Thus, in summarizing the various solutions, on the basis of statistical, practical, and theoretical considerations, a 4-factor model was determined to be generally representative of the ACE symptom checklist. Table 3 presents the factor loadings for the 4-factor principal factor solution with varimax rotation, to provide independence of the factors. Note that the factor solution accounts for only 48% of the variance, a modest overall common variance, likely reflecting the relatively higher unique variance of the symptom items, consistent with the low-to-moderate communalities. Thus, the factor analysis provides some reasonable support for 3 to 4 subscales, consistent with the literature, although interpretation of the individual symptoms has statistical support as well.

DISCUSSION

Lack of appropriate recognition and diagnosis of injury presents one of the greatest barriers to providing services to individuals who have sustained an mTBI. Without proper identification, individualized treatment cannot be initiated, and patients may be at increased risk for exacerbated symptoms, slow or incomplete recovery, or further injury. The ACE, a structured front-end clinical protocol based on empirical literature, was developed to facilitate early diagnosis of mTBI in primary care physician/clinician and emergency medicine settings. The components of the ACE are based on accumulated research-based evidence highlighting key injury characteristics, a full range of early signs and symptoms, exertion effects, risk factors for prolonged recovery, and critical signs of possible neurological deterioration.

We present the first psychometric evidence in support of the reliability and validity of the ACE, a clinical protocol designed to assist clinical identification and diagnosis of mTBI. The ACE symptom checklist, a dichotomous inventory of 22 symptoms selected from the literature,[27,37] demonstrated appropriate scale membership for most items with the exception of 2 low-frequency items—vomiting and numbness/tingling. Appropriate evidence of reliable internal scale structure via internal consistency was also demonstrated. The validity of the ACE, that is, evidence of its meaningfulness in a clinical setting, was demonstrated in several ways. First, the items on the ACE symptom checklist operate in a similar manner as established postconcussion symptom scales, demonstrating a similar ranking of symptoms. Furthermore, the ACE total symptom score predicted parent and patient postconcussion graded symptom reports, and less so preinjury baseline symptom reports, providing some evidence of convergent and divergent validity. Finally, the meaningfulness of the symptom subscales as they relate to the existing constructs in the literature and constellations in practice was demonstrated via factor analysis, with cognitive, emotional, somatic, and sleep factors subscales generated. Given a modest degree of common variance accounted for by the 4-factor solution, however, the symptom subscales should not be overly emphasized. There was no systematic relationship between the ACE symptom total score and patient age or ethnic group membership. There were a greater number of symptoms reported for girls than for boys, and higher symptom scores were reported in the presence of loss of consciousness and anterograde amnesia but not retrograde amnesia. Overall, the ACE symptom checklist exhibits reasonably strong psychometric properties as an initial tool in the assessment of mTBI.

The limitations of the ACE must also be appreciated. First, the mTBI diagnosis can be quite complex at times.[11] The ACE was developed as an initial method of identifying mTBI, not as a comprehensive evaluation tool. Although the clinical protocol is useful in further defining the injury and its characteristics, it has limited utility as a lone instrument. The ACE may be most useful as an instrument to assist the early identification of patients in need of further evaluation or follow-up. In many cases, particularly those injuries whose symptoms persist beyond several days, the ACE can be used as an initial triage tool, with referral for more in-depth evaluation of neuropsychological, psychiatric, and medical issues. In addition, certain circumstances of mTBI require referral for neuropsychological evaluation such as return to play, in sports-related mTBI where quantitative evidence of recovery of neurocognitive functioning is an essential component in addition to symptom resolution. Furthermore, when individuals are experiencing problems at work or school with concentration, memory, or speed of processing/performance, neuropsychological testing can be very useful in identifying specific issues for treatment and management. Persisting physical symptoms such as headache and sleep disturbance also require further medical and/or behavioral evaluation to guide treatment. Emotional issues such as anxiety or depression can also persist to affect adversely the individual's functioning and requires active psychiatric evaluation and possible treatment.

Additional research with the ACE is warranted to further define its psychometric characteristics as well as its utility with mTBI. Two aspects of reliability warrant continued research including (1) the stability of the ACE symptom checklist reports via test-retest reliability and (2) interrater reliability to establish the possible effect of examiner bias or error on measurement variability of the ACE. Further research also is warranted on the serial use of the ACE symptom checklist as a tracking tool, and relationship of patterns/types of symptom resolution relative to injury characteristics, sex, age, and treatment response (eg, compliance with ACE care plan recommendations). This study did not address issues associated with the types of symptoms (somatic, cognitive, emotional, and sleep) as they relate to age, sex, and length of recovery. Further study of these issues will assist clinicians' use of the ACE as a clinical tool. Finally, more in depth analysis of the convergent and discriminant validity of the ACE symptom checklist would be important to examine its differential sensitivity to features specific to mTBI. Specifically, it will be important to compare the ACE symptoms with other measures intended to assess related but different conditions such as mood disorder, posttraumatic stress disorder, nonneurologic medical illnesses, and/or chronic pain.

In using the ACE and its assessment of injury characteristics, symptoms, and risk factors for prolonged recovery, it is important that the care provider appreciate the need for referral to specialists to evaluate and manage the mTBI. For patients with active signs/symptoms persisting beyond 3 to 5 days with little-to-no improvement, referral to a specialist should be seriously considered, especially when school, work, or social activity are adversely affected. Follow-up—focused neuropsychological evaluation, in particular, should be strongly considered as it provides important information regarding the cognitive and behavioral issues affecting patient functioning. In the case of acute mTBI, a focused evaluation of key cognitive functions—attention/concentration, working memory, new learning and memory storage/retrieval, processing speed, and reaction time–should be the initial approach. Comprehensive neuropsychological evaluation is generally not necessary in the acute phase unless significant premorbid issues are present that require clarification and differentiation with respect to the mTBI-related issues. In addition to the common cognitive and/or behavioral/emotional sequelae, referral to specialist should be considered with persisting headache and sleep-related symptoms.

The ACE provides a structured clinical protocol designed to improve the initial identification and diagnosis as well as early treatment and management of individuals with possible mTBI. Initial evidence for its psychometric properties is presented to provide clinicians with information regarding its statistical basis. For further information regarding mTBI, its management, and the use of the ACE and ACE care plan, the reader is referred to the recent publication entitled *Heads Up: Brain Injury in Your Practice* by the Centers for Disease Control and Prevention.[24] The comprehensive set of mTBI diagnostic and management information, including the ACE and the associated ACE care plan, may help realize the goal of improving services to individuals with mTBI.

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Appendix A

ACUTE CONCUSSION EVALUATION (ACE)
PHYSICIAN/CLINICIAN OFFICE VERSION

Gerard Gioia, PhD[1] & Micky Collins, PhD[2]
[1]Children's National Medical Center
[2]University of Pittsburgh Medical Center

Patient Name___________________________________
DOB: ______________ Age:_____________________
Date:_______________ ID/MR#___________________

A. Injury Characteristics **Date/Time of Injury**_____________________________**Reporter: __Patient __Parent __Spouse __Other**________

1. Injury Description ____

____

1a. Is there evidence of a forcible blow to the head (direct or indirect)? __Yes __No __Unknown
1b. Is there evidence of intracranial injury or skull fracture? __Yes __No __Unknown
1c. Location of Impact: __Frontal __Lft Temporal __Rt Temporal __Lft Parietal __Rt Parietal __Occipital __Neck __Indirect Force

2. Cause: __MVC __Pedestrian-MVC __Fall __Assault __Sports (*specify*)___________________Other__________________________________

3. Amnesia Before (Retrograde) Are there any events just BEFORE the injury that you/ person has no memory of (even brief)? __ Yes __No Duration

4. Amnesia After (Anterograde) Are there any events just AFTER the injury that you/ person has no memory of (even brief)? __ Yes __No Duration

5. **Loss of Consciousness:** Did you/ person lose consciousness? __ Yes __No Duration

6. **EARLY SIGNS:** __Appears dazed or stunned __Is confused about events __Answers questions slowly __Repeats Questions __Forgetful (recent info)

7. Seizures: Were seizures observed? No__ Yes___ Detail____

B. Symptom Check List* Since the injury, has the person experienced any of these symptoms any more than usual today or in the past day?
Indicate presence of each symptom (0=No, 1=Yes). ***Lovell & Collins, 1998 JHTR***

PHYSICAL (10)		COGNITIVE (4)		SLEEP (4)	
Headache	0 1	Feeling mentally foggy	0 1	Drowsiness	0 1
Nausea	0 1	Feeling slowed down	0 1	Sleeping less than usual	0 1 N/A
Vomiting	0 1	Difficulty concentrating	0 1	Sleeping more than usual	0 1 N/A
Balance problems	0 1	Difficulty remembering	0 1	Trouble falling asleep	0 1 N/A
Dizziness	0 1	**COGNITIVE Total (0-4)** _____		**SLEEP Total (0-4)** _____	
Visual problems	0 1	**EMOTIONAL (4)**			
Fatigue	0 1	Irritability	0 1		
Sensitivity to light	0 1	Sadness	0 1		
Sensitivity to noise	0 1	More emotional	0 1		
Numbness/Tingling	0 1	Nervousness	0 1		
PHYSICAL Total (0-10) _____		**EMOTIONAL Total (0-4)** _____			
(Add Physical, Cognitive, Emotion, Sleep totals) Total Symptom Score (0-22)			_____		

Exertion: Do these symptoms worsen with:
Physical Activity __Yes __No __N/A
Cognitive Activity __Yes __No __N/A

Overall Rating: How different is the person acting compared to his/her usual self? (circle)

Normal 0 1 2 3 4 5 6 Very Different

C. Risk Factors for Protracted Recovery *(check all that apply)*

Concussion History? Y ___ N___	√	**Headache History?** Y ___ N___	√	**Developmental History**	√	**Psychiatric History**
Previous # 1 2 3 4 5		Prior treatment for headache		Learning disabilities		Anxiety
Longest symptom duration Days__ Weeks__ Months__ Years__		History of migraine headache __ Personal __ Family__________________ __________________		Attention-Deficit/ Hyperactivity Disorder		Depression
						Sleep disorder
If multiple concussions, less force caused reinjury? Yes__ No__				Other developmental disorder____________		Other psychiatric disorder ____________

List other comorbid medical disorders or medication usage (e.g., hypothyroid, seizures)_______________________________________

____

D. RED FLAGS for acute emergency management: Refer to the emergency department with sudden onset of any of the following:

- **Headaches that worsen**
- **Seizures**
- **Focal neurologic signs**
- **Looks very drowsy/ can't be awakened**
- **Repeated vomiting**
- **Slurred speech**
- **Can't recognize people or places**
- **Increasing confusion or irritability**
- **Weakness or numbness in arms/legs**
- **Neck pain**
- **Unusual behavioral change**
- **Change in state of consciousness**

E. Diagnosis (ICD): __Concussion w/o LOC 850.0 __Concussion w/ LOC 850.1 __Concussion (Unspecified) 850.9 __Other (854) _____________
__No diagnosis

F. Follow-Up Action Plan **Complete *ACE Care Plan* and provide copy to patient/family.**

___ **No Follow-Up Needed**
___ **Physician/Clinician Office Monitoring**: Date of next follow-up __________________
___ **Referral:**
  ___ Neuropsychological Testing
  ___ Physician: Neurosurgery____ Neurology____ Sports Medicine____ Physiatrist____ Psychiatrist____ Other__________________________
  ___ Emergency Department

ACE Completed by:_______________________________ **MD RN NP PhD ATC**

This form is part of the "Heads Up: Brain Injury in Your Practice" tool kit developed by the Centers for Disease Control and Prevention (CDC).

A concussion (or mild traumatic brain injury (MTBI)) is a complex pathophysiologic process affecting the brain, induced by traumatic biomechanical forces secondary to direct or indirect forces to the head. Disturbance of brain function is related to neurometabolic dysfunction, rather than structural injury, and is typically associated with normal structural neuroimaging findings (i.e., CT scan, MRI). Concussion may or may not involve a loss of consciousness (LOC). Concussion results in a constellation of physical, cognitive, emotional, and sleep-related symptoms. Symptoms may last from several minutes to days, weeks, months or even longer in some cases.

ACE Instructions

The ACE is intended to provide an evidence-based clinical protocol to conduct an initial evaluation and diagnosis of patients (both children and adults) with known or suspected MTBI. The research evidence documenting the importance of these components in the evaluation of an MTBI is provided in the reference list.

A. Injury Characteristics:

1. Obtain **description of the injury** – how injury occurred, type of force, location on the head or body (if force transmitted to head). Different biomechanics of injury may result in differential symptom patterns (e.g., occipital blow may result in visual changes, balance difficulties).
2. Indicate the **cause of injury**. Greater forces associated with the trauma are likely to result in more severe presentation of symptoms.

3/4. **Amnesia:** Amnesia is defined as the failure to form new memories. Determine whether amnesia has occurred and attempt to determine length of time of memory dysfunction – before (retrograde) and after (anterograde) injury. Even seconds to minutes of memory loss can be predictive of outcome. Recent research has indicated that amnesia may be up to 4-10 times more predictive of symptoms and cognitive deficits following concussion than is LOC (less than 1 minute).[1]

5. **Loss of consciousness (LOC)** – If occurs, determine length of LOC.
6. **Early signs.** If present, ask the individuals who know the patient (parent, spouse, friend, etc) about specific signs of the concussion that may have been observed. These signs are typically observed early after the injury.
7. Inquire whether **seizures** were observed or not.

B. Symptom Checklist: [2]

1. Ask patient (and/or parent, if child) to report presence of the four categories of symptoms since injury. It is important to assess all listed symptoms as different parts of the brain control different functions. One or all symptoms may be present depending upon mechanisms of injury.[3] Record "1" for Yes or "0" for No for their presence or absence, respectively.
2. For all symptoms, indicate presence of symptoms as experienced within the past 24 hours. Since symptoms can be present premorbidly/at baseline (e.g., inattention, headaches, sleep, sadness), it is important to assess change from their usual presentation.
3. **Scoring**: Sum total number of symptoms present per area, and sum all four areas into Total Symptom Score (score range 0-22). (Note: most sleep symptoms are only applicable after a night has passed since the injury. Drowsiness may be present on the day of injury.) If symptoms are new and present, there is no lower limit symptom score. Any score > 0 indicates positive symptom history.
4. **Exertion:** Inquire whether any symptoms worsen with physical (e.g., running, climbing stairs, bike riding) and/or cognitive (e.g., academic studies, multi-tasking at work, reading or other tasks requiring focused concentration) exertion. Clinicians should be aware that symptoms will typically worsen or re-emerge with exertion, indicating incomplete recovery. Over-exertion may protract recovery.
5. **Overall Rating:** Determine how different the person is acting from their usual self. Circle "0" (Normal) to "6" (Very Different).

C. Risk Factors for Protracted Recovery: Assess the following risk factors as possible complicating factors in the recovery process.

1. **Concussion history:** Assess the number and date(s) of prior concussions, the duration of symptoms for each injury, and whether less biomechanical force resulted in re-injury. Research indicates that cognitive and symptom effects of concussion may be cumulative, especially if there is minimal duration of time between injuries and less biomechanical force results in subsequent concussion (which may indicate incomplete recovery from initial trauma).[4-8]
2. **Headache history:** Assess personal and/or family history of diagnosis/treatment for headaches. Research indicates headache (migraine in particular) can result in protracted recovery from concussion.[8-11]
3. **Developmental history**: Assess history of learning disabilities, Attention-Deficit/Hyperactivity Disorder or other developmental disorders. Research indicates that there is the possibility of a longer period of recovery with these conditions.[12]
4. **Psychiatric history**: Assess for history of depression/mood disorder, anxiety, and/or sleep disorder.[13-16]

D. Red Flags: The patient should be carefully observed over the first 24-48 hours for these serious signs. Red flags are to be assessed as possible signs of deteriorating neurological functioning. Any positive report should prompt strong consideration of referral for emergency medical evaluation (e.g. CT Scan to rule out intracranial bleed or other structural pathology).[17]

E. Diagnosis: The following ICD diagnostic codes may be applicable.

850.0 (Concussion, with no loss of consciousness) – Positive injury description with evidence of forcible direct/ indirect blow to the head (A1a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); no evidence of LOC (A5), skull fracture or intracranial injury (A1b).

850.1 (Concussion, with brief loss of consciousness < 1 hour) – Positive injury description with evidence of forcible direct/ indirect blow to the head (A1a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); positive evidence of LOC (A5), skull fracture or intracranial injury (A1b).

850.9 (Concussion, unspecified) – Positive injury description with evidence of forcible direct/ indirect blow to the head (A1a); plus evidence of active symptoms (B) of any type and number related to the trauma (Total Symptom Score >0); unclear/unknown injury details; unclear evidence of LOC (A5), no skull fracture or intracranial injury.

Other Diagnoses – If the patient presents with a positive injury description and associated symptoms, but additional evidence of intracranial injury (A 1b) such as from neuroimaging, a moderate TBI and the diagnostic category of 854 (Intracranial injury) should be considered.

F. Follow-Up Action Plan: Develop a follow-up plan of action for symptomatic patients. The physician/clinician may decide to (1) monitor the patient in the office or (2) refer them to a specialist. Serial evaluation of the concussion is critical as symptoms may resolve, worsen, or ebb and flow depending upon many factors (e.g., cognitive/physical exertion, comorbidities). Referral to a specialist can be particularly valuable to help manage certain aspects of the patient's condition. (Physician/Clinician should also complete the ACE Care Plan included in this tool kit.)

1. **Physician/Clinician serial monitoring –** Particularly appropriate if number and severity of symptoms are steadily decreasing over time and/or fully resolve within 3-5 days. If steady reduction is not evident, referral to a specialist is warranted.
2. **Referral to a specialist –** Appropriate if symptom reduction is not evident in 3-5 days, or sooner if symptom profile is concerning in type/severity.
   - Neuropsychological Testing can provide valuable information to help assess a patient's brain function and impairment and assist with treatment planning, such as return to play decisions.
   - Physician Evaluation is particularly relevant for medical evaluation and management of concussion. It is also critical for evaluating and managing focal neurologic, sensory, vestibular, and motor concerns. It may be useful for medication management (e.g., headaches, sleep disturbance, depression) if post-concussive problems persist.