Alternative approaches to the assessment of mild head injury in athletes

By: KEVIN GUSKIEWICZ, BRYAN RIEMANN, DAVID PERRIN, and LEWIS NASHNER

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Abstract:

Objectives: Athletic trainers and team physicians are often faced with decisions concerning the severity and timing of an athletes return to play following mild head injury (MHI). These decisions can be the most difficult ones facing clinicians because of the limited amount of quantitative information indicating injury severity. Several authors have published guidelines for return to play following MHI, however these guidelines are based on limited scientific data. The purpose of this paper was to examine the effects of MHI on two objective measures, postural stability and cognitive function, to determine their usefulness in MHI assessment. The data gathered from these two measures has the potential to establish recovery curves based on objective data.

Methods: Eleven Division I collegiate athletes who sustained a MHI and eleven matched control subjects were assessed for postural stability and cognitive function at four intervals following injury. Postural stability was assessed using the Sensory Organization Test on the NeuroCom Smart Balance Master. Cognitive functioning was measured through the use of four neuropsychological tests: Stroop Test, Trail Making Test, Digits Span and Hopkins Verbal Learning Test. Separate mixed model repeated measures ANOVAs were calculated for the composite score and three ratio (vestibular, visual and somatosensory) scores from the Sensory Organization Test and the scores from the neuropsychological test to reveal significant differences between groups and across days postinjury.

Results: A significant group by day interaction for overall postural stability(composite score) revealed that MHI athletes displayed increased postural instability for the first few days following MHI ($p<.05$). Analysis of the ratio scores revealed a significant interaction for the visual ratio. No significant group differences were revealed for any of the neuropsychological tests ($p<.05$), however significant day differences were revealed($p<.05$).

Conclusions: The results from this study indicate that athletes demonstrate decreased stability until 3 days postinjury. It appears this deficit is related to a sensory interaction problem, whereby the injured athlete fails to use their visual system effectively. These findings suggest that measures of postural stability may provide clinicians with a useful clinical tool for determining when an athlete may safely return to competition, although these findings need to be confirmed in larger groups of athletes.

Article:

Deciding when athletes can safely return to competition following a mild head injury (MHI) is one of the greatest challenges facing athletic trainers and team physicians. The complexity of the brain and the few objective signs often manifested at the time of injury make the assessment of MHI uniquely challenging. Clinicians are often solely dependent on subjective symptoms, most of which are underreported by anxious athletes, rather than the evidence of sound objective data. In addition to being underreported, subjective signs and symptoms may resolve immediately after injury, although underlying pathology may still remain undetected (2,8,10,23,41).

MHI is produced by acceleration/deceleration of the freely moving head which produces unconsciousness or diminished consciousness for a period of no longer than 20 min, a Glasgow Coma Scale (GCS) score greater than 12, and negative neuroimaging at the time of physician examination. In addition, posttraumatic amnesia (PTA) may be present, but lasts less than 24 h (6,28,42). Practitioners often use the term“concussion” to describe mild head injury, and depending on which concussion grading scale is used, most grade 1 and grade 2 concussions can be classified as a mild head injury. The Committee of Head Injury Nomenclature of the Congress of Neurological Surgeons adopted a formal definition of concussion in 1966. Concussion is defined by this body as a clinical syndrome characterized by immediate and transient post-traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to brain stem involvement (14).

Despite the considerable amount of protective equipment available to athletes today, the head and brain are still susceptible to injury during athletic competition. A high incidence of MHI in contact sports is well documented (7,9,10,16,41, 43). Although American football is generally recognized as the sport most often associated with concussions, research reports moderate to high incidences of concussion in basketball, softball, soccer, baseball, boxing, rugby, and ice hockey (25,41).

Several grading scales and return-to-play guidelines have been proposed (8,13,38), yet there is still great debate as to when athletes sustaining MHI can safely return to participation. The Sports Medicine Committee for the Colorado Medical Society (CMS)(13) recommends that athletes sustaining a grade I concussion return to participation only if the athlete is asymptomatic during rest and exertion for at least 20 min. The CMS recommends that following a grade II concussion, the athlete be removed from participation and evaluated frequently over the next 24 h for signs of evolving intracranial pathology. Return to play after a grade III concussion is allowed only if the athlete has been asymptomatic at rest and exertion for at least 2 wk, according to the CMS guidelines. The recommendations of Cantu (8-10) for return to play are similar to the CMS guidelines. Although both of these guidelines are useful, they are based on a collection of clinical observations rather than on experimentally based research findings. Therefore, the purpose of this paper is to investigate the effect of mild head injury on postural stability and cognitive function in athletes. This preliminary investigation may provide alternative methods for obtaining objective information by which clinicians can assess mild head injury and begin establishing a recovery curve based on measures of postural stability and cognitive function.

ALTERNATIVE METHODS OF ASSESSMENT

The literature has revealed deficiencies in cognitive functions such as attention span, memory, concentration, and information processing as a result of MHI (6,15,18,19,26,27,28,30,42). Additionally, it has been reported that the areas of the brain which are disrupted as a result of MHI are responsible for the maintenance of equilibrium (1,4,21,22,31-33,44). As a result of these findings, cognitive and postural measures have been proposed as means through which head injury can be objectively assessed (3,6,15,18,19,20,24,27,30). Traditionally clinicians have utilized the Romberg test for assessing disequilibrium in head-injured athletes, but only recently has computerized posturography become available to offer a more objective and challenging assessment. Likewise, clinicians have used verbal concentration tests such as serial 7's and questions of orientation and amnesia such as those on the Galveston Orientation and Amnesia Test (GOAT) (28) to assess MHI, but only recently have they begun to consider the utilization of neuropsychological tests used in clinical populations.

METHODS

Twenty-two subjects participated in this study (16 males and 6 females). Eleven Division I collegiate athletes (age = 18.6 ± 2.0 yr; height = 70.4 ± 3.1 cm; weight = 77.8 ± 17.1 kg) who suffered a mild head injury during either practice or competition were assessed on day 1, 3, 5, and 10 postinjury. Additionally, 11 matched control subjects (age = 20.2 ± 1.3 yr; height = 69.7 ± 2.3 cm; weight = 78.0 ± 16.4 kg) were recruited from the intramural sports program and assessed according to the same schedule. Subjects who had sustained a MHI during the previous year or who presented with a vestibular deficit or musculoskeletal injury that affected their equilibrium were excluded from the study. All subjects were informed of the procedures and inherent risks of the investigation. They were asked to read and sign an informed consent form in accordance with the University of North Carolina's Institutional Review Board. In addition to the postural stability and cognitive assessments, any current signs and symptoms associated with MHI were recorded.

Postural Stability Assessment

Postural stability was measured through the use of the Sensory Organization Test (SOT) on the NeuroCom Smart Balance Master System (NeuroCom International, Inc., Clackamas, OR) (Fig. 1). This system, like other force plate systems, measures vertical reaction forces produced from the body's center of gravity moving around a fixed base of support. The advantage of using the SOT is that clinicians can easily isolate sensory modalities providing afferent information to the postural control system. Under normal circumstances a person balances with the aid of information from the visual, vestibular, and somatosensory systems. If one system is deficient the other systems should compensate for the deficiency.

Figure 1-The NeuroCom Smart Balance Master (NeuroCom International Inc., Clackamas, OR) allows for sensory organization testing (SOT) using a dual force plate system. Both the support surface and visual surround tilt(sway referencing) to alter sensory conditions.

The SOT is designed to systematically disrupt the sensory selection process by altering the orientation information available to the somatosensory and/or visual inputs while measuring a subject's ability to maintain equilibrium. The test protocol consists of three 20-s trials under three different visual conditions (eyes open, eyes closed, sway referenced) and two different surface conditions (fixed, sway referenced) (Fig. 2). Subjects are asked to stand as motionless as possible for each of the 20-s trials in a normal stance with their feet at a shoulder's width apart.

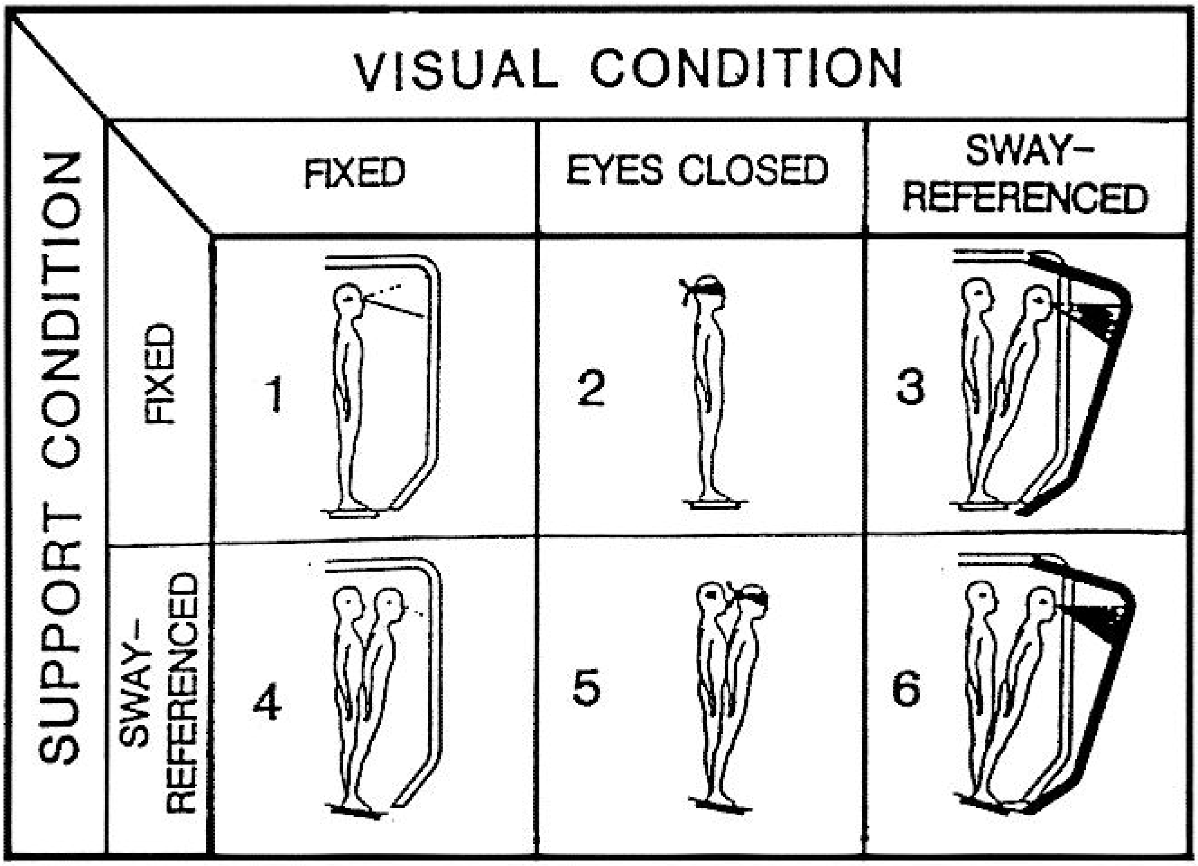


Figure 2-The six testing conditions used during the sensory organizational test. The first three involve a fixed platform for the three visual conditions (eyes open, eyes closed, sway referenced) and the last three involve a sway-referenced platform for the same three visual conditions.

The term sway referencing involves the tilting of the support surface and/or visual surround to directly follow the athlete's center of gravity(COG) sway such that the orientation of the surface remains constant in relation to the COG angle. By using this technique, the somatosensory and/or visual systems report that the subject's orientation to gravity is constant when in fact it is changing, requiring the subject to ignore the inaccurate information from the sway referenced sense(s). An overall composite equilibrium score describing a person's overall level of performance during all of the trials in the SOT is calculated, with higher scores being indicative of better balance performance. The composite score is the average of the following 14 scores: the condition 1 average score, the condition 2 average score, and the three equilibrium scores from each of the trials in conditions 3-6. The equilibrium scores from each of the trials represents a nondimensional percentage comparing the subject's peak amplitude of anterior/posterior sway to the theoretical anterior/posterior limit of stability.

Additionally, relative differences between the equilibrium scores of various conditions are calculated using ratios to reveal specific information about each of the sensory modalities involved with maintaining balance. For example, a vestibular ratio is computed by using scores attained in condition 5 (eyes closed, sway referenced platform) and condition 1 (eyes open, fixed platform). This ratio indicates the relative reduction in postural stability when visual and somatosensory inputs are simultaneously disrupted. These ratios are useful in identifying sensory integration problems.

Cognitive Assessment

Cognitive function was assessed on each of the subjects utilizing the following four neuropsychological tests. These tests were selected because of their ability to assess various aspects of cognitive function often depressed following MHI. The tests were given using standard administration and scoring procedures in a quiet, controlled environment.

Trail Making Test A (Reitan Neuropsychological Laboratory, Tucson, AZ). Subjects completing this test are asked to sequentially trace a list of 25 numbers on a piece of paper as fast as possible using a pen. This task assessed orientation, concentration, visuospatial capacity, and problem-solving abilities. The time required for successful completion is recorded, adding 1 s for each sequential error committed.

Wechsler Digit Span Test (WDST) (Psychological Corporation, San Antonio, TX). The WDST consists of a two-part protocol and is used to examine a patient's concentration and immediate memory recall. During both parts of the test subjects are presented with a series of numbers and asked to repeat the digits in either the same order (Digits Forward) for the first part or in the reverse order (Digits Backward) for the second part. The number of successful trials for each part is recorded as the total score (Digits Total).

Stroop Test (Stoelting Co., Wood Dale, IL). The Stroop Test is designed to assess cognitive flexibility and attention span by examining a subject's ability to separate word and color-naming stimuli through the use of three separate subtests. Each subtest contains 100 items presented in five columns of 20 items. Subjects have 45 s to complete each subtest, with a total score calculated from the sum of each subtest. During the first subtest, subjects are asked to read aloud the words RED, GREEN, or BLUE written in black ink. For the second subtest the subject is asked to identify aloud the colors red, green, or blue printed in “XXXX”. Finally, the third subtest involves the words on page one blended with the colors on page two; however, in no case does the word match with the print color. Subjects are asked to read the color of print instead of the actual word.

Hopkins Verbal Learning Test (The Johns Hopkins University, Baltimore, MD). Each form of the HVLT consists of a 12-item word list composed of four words from three semantic categories used for assessing verbal memory. The subject is instructed to listen carefully and memorize the word list. The subject then recalls as many words as possible in any order. The examiner records the number of correct responses and the same procedure is repeated for two more trials. After the third trial, the subject is read 24 words and is asked to identify words contained in the original list. The number of incorrect responses is subtracted from the overall recall score.

DATA ANALYSIS

Separate mixed model (1 between, 1 within), repeated measures analyses of variance (ANOVA) were calculated for the overall composite score, each of the three ratio scores, and each of the neuropsychological tests. These analyses determined if significant differences existed across groups (between) and days postinjury (within) for each of the dependent variables.

RESULTS

Descriptive statistics representing the number of subjects experiencing signs and symptoms associated with MHI are presented in Table 1. Of the 11 MHI subjects, all but 4 had lingering symptoms lasting up to 3 days postinjury, and only one subject complained of a headache lasting longer than 3 days. Selection of the matched control subjects was based on a combination of sex, age, height, and weight. Level of significance($P < 0.05$) was set a priori for all statistics.

	Day of Injury	day 1 Postinjury	day 3 Postinjury
Loss of consciousness	6		
Confusion	5	1	1
Disorientation	7	1	
Anterograde amnesia	2		
Retrograde amnesia	4		
Neck pain	3	3	1
Headache	10	8	5
Blurry vision	6	2	
Photophobia	2		
Dizziness	9	3	
Fatigue	6	3	1
Sleepiness	2		
Irritability	1		
Disequilibrium	4		
Nausea/vomiting	1		
Tinnitus	2		

TABLE 1. Descriptive statistics representing the number of total subjects experiencing signs and symptoms following injury (n = 11).

The ANOVA for Composite Score on the Smart Balance System revealed a significant interaction for group by day, $F(3,60) = 3.46$, $P = 0.02$). Tukey post-hoc analysis revealed that Composite Score differences> 6.83 represented significantly increased postural instability (Fig. 3). MHI subjects demonstrated increased postural instability on day 1 postinjury in comparison to the control day 1 scores as well as their own day 3 postinjury scores. While differences between control subjects and MHI subjects were not significant on day 3 and 5 postinjury, it appears that recovery was still occurring.

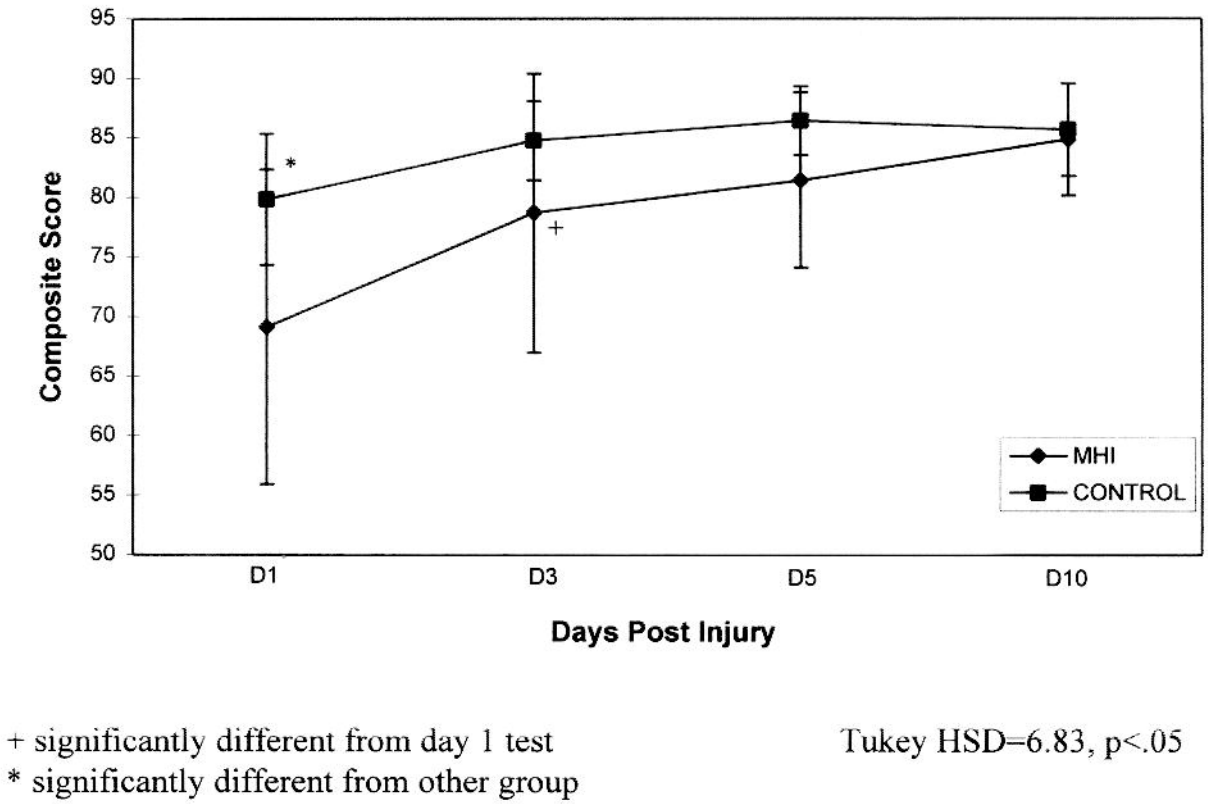
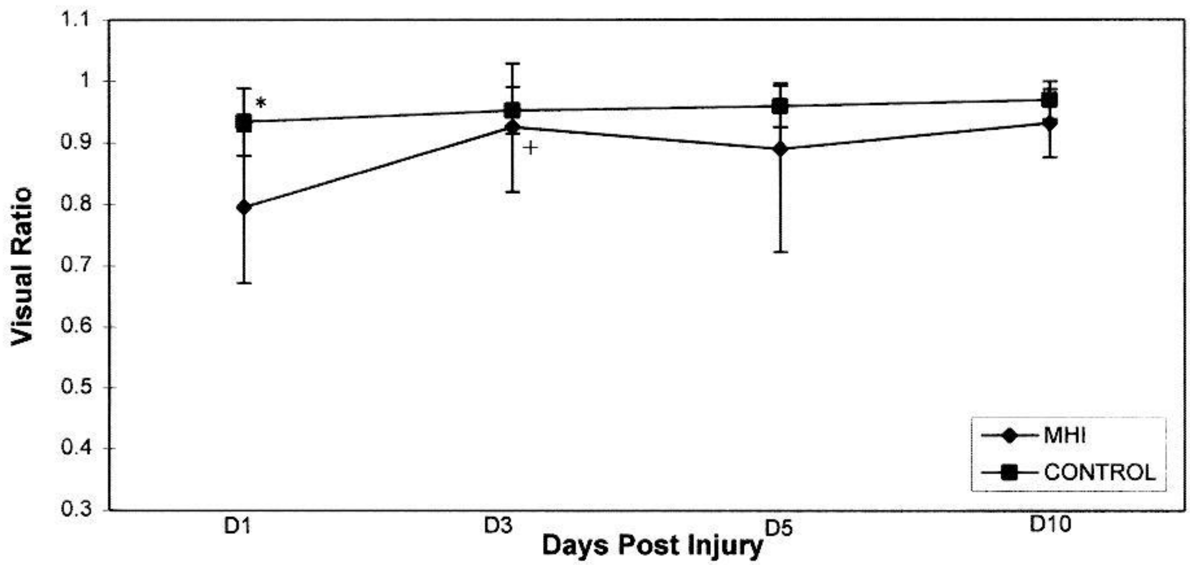


Figure 3-Composite Score means (±SD) on the NeuroCom Smart Balance Master for 11 mild head-injured and 11 control subjects for each testing session (day 1 postinjury through day 10 postinjury).

An additional analysis of the ratio scores (visual, vestibular, and somatosensory) revealed a significant group by day interaction for the visual ratio, $F(3, 60) = 4.10$, $P = 0.01$), suggesting that postural stability deficits in mild head-injured athletes could be linked to a sensory organization problem. Figures 4-6 present the mean scores for the three ratios across the four postinjury test sessions. Ratio scores are calculated by dividing the equilibrium score of one sensory condition by the equilibrium score of another condition. Post-hoc analysis for the visual ratio revealed that differences of > 0.07 between MHI and control subjects were significant. Therefore, MHI subjects demonstrated a low visual ratio on day 1 postinjury in comparison to their matched control subjects and their own day 3 postinjury ratio.



+ significantly different from day 1 test

Tukey HSD=.07, p<.05

* significantly different from other group

Figure 4-Visual Ratio score means (±SD) on the NeuroCom Smart Balance Master for 11 mild head-injured and 11 control subjects for each testing session (day 1 postinjury through day 10 postinjury).

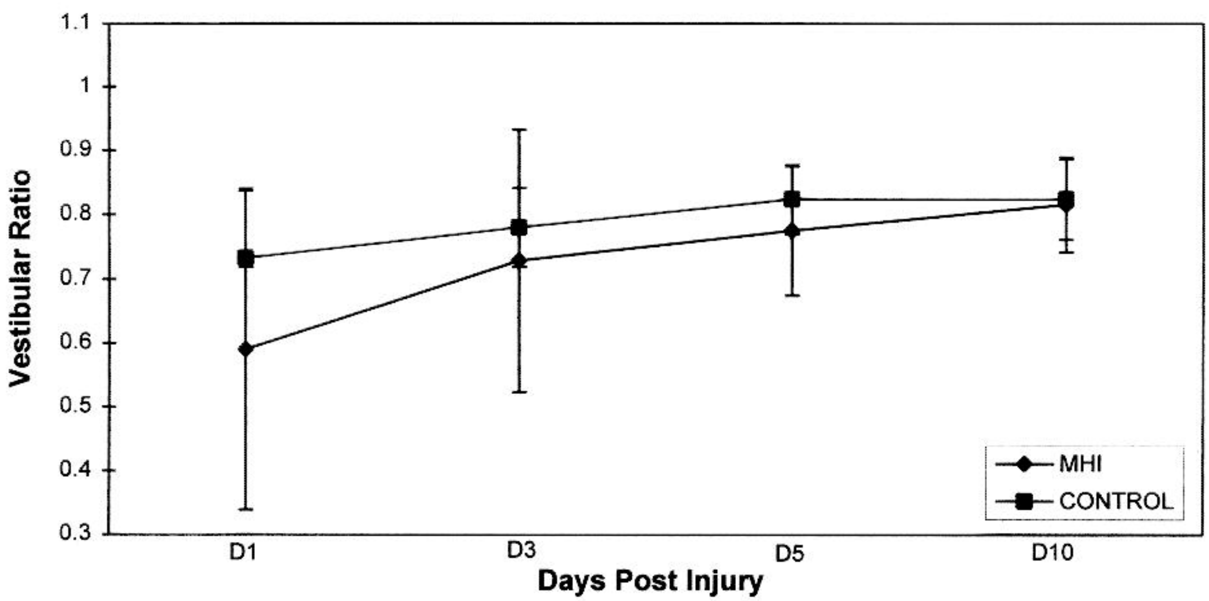


Figure 5-Vestibular Ratio score means (±SD) on the NeuroCom Smart Balance Master for 11 mild head-injured and 11 control subjects for each testing session (day 1 postinjury through day 10 postinjury).

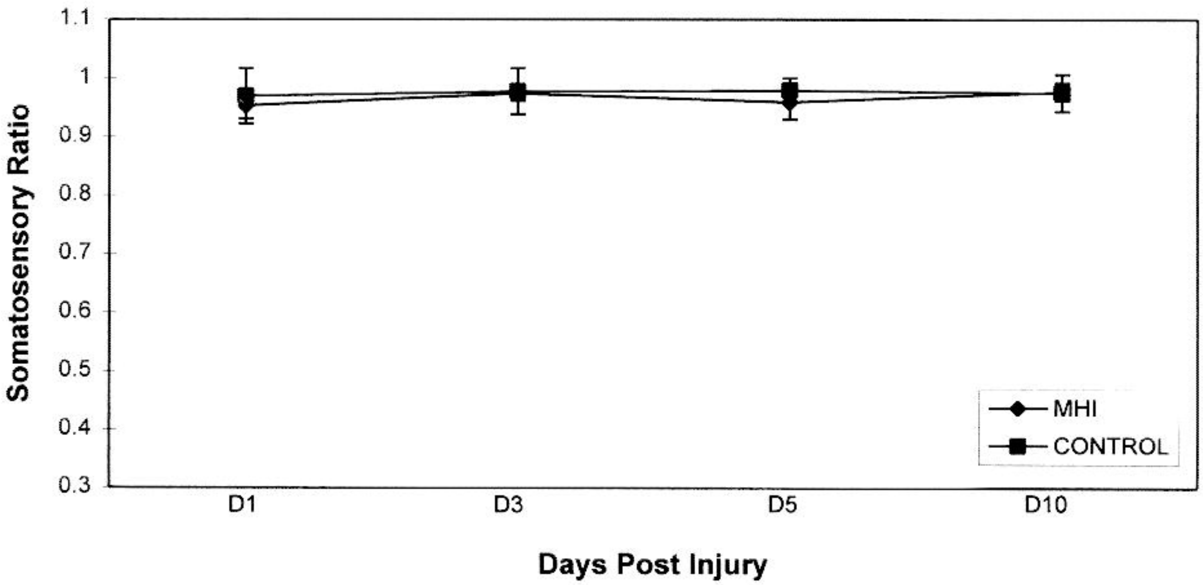


Figure 6-Somatosensory Ratio score means (±SD) on the NeuroCom Smart Balance Master for 11 mild head-injury and 11 control subjects for each testing session (day 1 postinjury through day 10 postinjury).

Group comparisons of the day 1 postinjury neuropsychological test scores are presented in Table 2. For all tests, except the Trail Making A, the higher the score the better the performance. The repeated measures ANOVA for the respective neuropsychological tests revealed significant main effects for day ($P < 0.05$) on all tests except Digits Forward ($P > 0.05$). Post-hoc analysis revealed that all subjects generally improved progressively during days 1, 3, and 5, thus revealing the practice effect reported by Oliaro et al.(40). No significant differences between groups($P > 0.05$) and no significant group by day interactions($P > 0.05$) were revealed, suggesting that MHI subjects learned at the same rate as control subjects on the neuropsychological tests.

	MHI Subjects		Control Subjects			
	M	SD	M	SD	Group (*P* Value)	Group × Day (*P* Value)
Stroop total	222.89	32.96	248.63	30.27	0.124	0.166
Stroop page 3	43.89	10.41	50.73	8.13	0.066	0.904
Trail Making A	28.90	9.19	21.76	5.67	0.089	0.182
Digits Total	18.78	2.33	19.55	2.62	0.711	0.318
Digits Backward	8.33	1.58	8.91	1.76	0.618	0.261
Digits Forward	10.44	.88	10.63	1.29	0.768	0.093
HVLT	41.67	6.02	40.73	2.83	0.889	0.697

Mean (M), standard deviation (SD), and *P* values from repeated measures ANOVA.

TABLE 2. Comparisons of neuropsychological tests for day 1 postinjury by group.

DISCUSSION

The most important finding of our ongoing research is that athletes may have sensory interaction problems during the first few days following MHI. The overall postural stability results indicate that athletes with acute MHI demonstrate decreased stability until approximately 3 d after the injury. While differences between control subjects and MHI subjects were not significant on day 3 and day 5 postinjury, it appears that recovery was still occurring, and with additional subjects included it is speculated that significant differences may be revealed. The athletes eventually recovered to mimic the scores of their matched control subjects at day 10 postinjury. It appears that this deficit is related to a sensory interaction problem, whereby the injured athletes fail to use their visual system effectively. The integration of visual and vestibular information is essential for the maintenance of equilibrium under certain altered conditions similar to those performed during the SOT (34-37,39). If subjects have difficulty balancing under conditions in which sensory modalities have been altered, it can be hypothesized that they are unable to ignore altered environmental conditions and therefore select a motor response based on the altered environmental cues. This has the potential to cause problems and perhaps predispose athletes to further injury when encountered with activities that alter sensory input to either one or more systems.

The visual and vestibular ratios in Figures 4 and 5 suggest that the postinjury stability problems demonstrated by composite scores occurred primarily under the sensory conflict conditions involving unstable (sway referenced) surface conditions and either normal or absent vision (conditions 4 and 5). The statistical significance of the visual ratio and insignificance of the vestibular ratio on the first postinjury day was possibly due to individual differences in patterns of instability among the MHI subjects. Individual differences in the expression of sensory interaction problems may be a characteristic feature of MHI. Previous studies of patients with histories of mild traumatic head injuries also reported significant abnormalities among individuals in sensory organization testing involving primarily the unstable or altered surface conditions (12,20).

In contrast to the visual and vestibular ratios, the somatosensory ratios in Figure 6 (eyes closed vs eyes open on a fixed surface) showed no postinjury effects. This suggests that proprioceptive inputs derived from a fixed support surface are sufficiently powerful to overcome the postinjury deficits in visual and vestibular interactions. Similar results have also been reported in populations of patients with balance disorders of vestibular origin (5,29). This observation suggests that the classic Romberg test of eyes open and eyes closed balance is insensitive in many cases of vestibular disorder and MHI.

Two recent controlled prospective studies identified objective criteria based on sensory organization testing for identifying patients with exaggerated symptoms of unsteadiness (11,17). None of the patterns of unsteadiness observed in our study were consistent with the criteria that suggest symptom exaggeration.

These results affirm our earlier work that found significant differences between MHI athletes and control subjects on day 1 postinjury as compared to preseason and/or subsequent tests using the Chattecx Balance System (20). This earlier study, which utilized a foam and dome test on a force plate system, did not allow for specific isolation of sensory modalities. Therefore, we could only speculate that there was an overall balance deficit due to sensory interaction problems. Unfortunately we did not have preseason measures on all subjects in the current study; therefore, we eliminated this data point in the analysis. The current findings also concur with those of Ingersoll and Armstrong (24), who reported that head-injured subjects (injury >1 yr old) maintained their center of pressure at a greater distance from their base of support and made fewer postural corrections. The differences reported were also particularly evident when one or more of the sensory modalities were conflicted or eliminated.

Surprisingly, the mild head-injured athletes in this study did not display significantly poorer performance than uninjured controls on any of the neuropsychological tests. Our findings suggest that the Trail Making A, HVLT, Stroop, and Digit Span tests are not sensitive enough to reveal cognitive deficits in athletes sustaining MHI. These results contradict previous studies which reported neuropsychological deficits following MHI in a clinical population (6,15,18,19,27,28,42). The extent to which MHI failed to cause cognitive deficits in our sample could be attributed to several factors. First, although the definition of MHI used in our study is the same as that used in most of the other studies, the subject characteristics are somewhat different. With the exception of Barth et al. (6) and Alves et al. (3), none of the other studies involved a young athletic population, whereby the learning curve might be accelerated and thus the tests might not be sensitive enough to discriminate between injured and uninjured subjects. Furthermore, the battery of tests used by Barth et al. (6) was different from that used in the current study, although many of the same cognitive abilities(i.e., concentration, problem solving, short-term memory, and attention span) were assessed.

Barth et al. (6) utilized the Paced Auditory Serial Addition Task (PASAT) and revealed significantly different learning curves between MHI football players and student control subjects. Our previously conducted pilot study which included 10 MHI subjects and 10 matched control subjects did not reveal significant differences between MHI and control subjects on the PASAT, and it was therefore eliminated from our current test battery. It should be noted that the neuropsychological tests in the current study were selected from a larger test battery used by the Pittsburgh Steelers Football Club under the direction of the team's consulting neurosurgeon and neuropsychologist. This abbreviated battery has been proposed for use by several other professional and collegiate sports teams due to the ease of administration on the sideline. Finally, we realize that this is a small data set of 11 MHI subjects and 11 control subjects. Although we found no significant differences between MHI athletes and uninjured control subjects in this data set, it will be interesting to see if the trend continues following the inclusion of additional MHI subjects.

Additionally the recovery of signs and symptoms reported at each testing session (Table 1) appears to coincide with the recovery curve for postural stability. While the signs and symptoms may not always be accurately reported, if used in conjunction with objective postural stability measures they can provide clinicians with a more detailed portrayal of the injury.

CONCLUSIONS

Our findings suggest there is potential to develop an objective clinical assessment of MHI in terms of initial severity as well as residual impairment through postural stability measures. The effect of MHI on postural stability appears to persist longer than just 1 day postinjury, and balance deficits may be present in the absence of amnesia and/or other postconcussion symptoms. The effect of these postural stability deficits on risk for reinjury either to the brain or other body parts remains unknown at this time.

Preliminary research studying the effect of acute MHI in athletes on postural stability suggests that objective and quantifiable measures of the injury can be identified. Our results reveal a recovery curve that should be considered, as opposed to simply using subjective symptoms and return-to-play guidelines which are based only on a collection of clinical observations. These measures may be even more valuable when managing injuries which involved momentary loss of consciousness but reveal no lingering signs or symptoms. It appears that sensory feedback from the visual, vestibular, and somatosensory systems in MHI subjects is not properly processed during the first few days following injury. If computerized posturography is available, it can provide the clinician with a reliable and valid instrument for obtaining objective data. Unfortunately, most clinicians do not have the use of a high-tech postural stability system. Our findings, however, can still be helpful in making decisions related to safely returning athletes to participation following an MHI.

First and foremost, we would suggest that athletes sustaining an MHI never be permitted to return to activity until all postconcussive symptoms have resolved. Based on our findings, athletes whose symptoms resolve quickly following injury should at the very least, be held from competition for 3 d following any episode that suggests they sustained an MHI. Clinicians should seriously consider whether or not they might be placing an athlete at risk by returning them earlier than 3 d postinjury. Finally, clinicians should realize that postural stability is only one small piece of a very large puzzle in the assessment of MHI. MHI may not necessarily affect the postural control system in every case, nor does postural instability manifest itself in a consistent manner in every head-injured athlete. It would be extremely beneficial if clinicians were to perform baseline preseason postural stability assessments so comparisons could be made with postinjury results. While postural stability can lend objective information, a thorough evaluation and re-evaluation inclusive of additional neurological tests should always be performed.

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