Effect of Mild Head Injury on Postural Stability in Athletes

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Objective: Athletic trainers and team physicians are often faced with the dilemma of when to return athletes to participation following mild head injury. Unfortunately, clinicians rarely have quantitative information on which to base their decisions. The purpose of this investigation was to identify postural stability changes in athletes with acute mild head injury.

Design and Setting: High school and college male athletes were prescreened for postural stability before the start of their season. Subjects suffering injury during the season returned for testing on days 1, 3, 5, and 10 following injury, and 1 month postseason. Control subjects were selected for comparisons.

Subjects: Ten prescreened subjects (age = 17.4 ± 2.2 yr; ht = 183.8 ± 8.1 cm; wt = 87.7 ± 17.3 kg) returned for testing following an injury. Ten matched control subjects (age = 18.6 ± 2.6 yr; ht = 185.7 ± 6.7 cm; wt = 84.5 ± 19.5 kg) were selected for comparisons. Additionally, nine subjects (eight male and one female) (age = 19.9 ± 4.2 yr; ht = 182.3 ± 10.9 cm; wt = 89.6 ± 25.2 kg) who had sustained a mild head injury from other varsity sports teams were recruited. Nine matched controls (age = 22.1 ± 3.3 yr; ht = 181.0 ± 9.9 cm; wt = 84.9 ± 25.6 kg) were again utilized.

Measurements: Sway index and center of balance were measured using the Chattecx Balance System during three eye conditions and three surface conditions for all subjects.

Results: Repeated measures analyses of variance (ANOVA) for each prescreened subject's sway index revealed significant differences between injured subjects and control subjects on day 1 postinjury as compared with the prescreening and/or subsequent tests. The analysis for sway index and center of balance inclusive of all 19 subjects with mild head injury and all 19 control subjects demonstrated increased postural sway compared with control subjects on day 1 postinjury during all platform conditions, and on day 3 during the foam platform condition. The analysis for center of balance using the same subjects revealed that injured subjects maintained their center of balance farther away on day 1 postinjury compared with subsequent tests ($p < .05$).

Conclusions: These findings suggest that computerized dynamic posturography is a useful tool in objectively assessing postural stability in subjects with mild head injuries. Subjects with mild head injury appear to demonstrate impaired postural stability 1 to 3 days following injury. This information should aid clinicians in determining when an athlete can safely return to participation.

Key Words: concussion, balance, postural sway

Returning athletes to competition following mild head injury (MHI) often creates a dilemma for athletic trainers and team physicians. These very important return-to-play decisions are too often based on subjective information gathered from an anxious athlete rather than from sound objective data. Athletes are often returned to activity with doubt still lingering in the mind of the clinician making the decision.

Mild head injury is becoming an increasingly important topic of discussion within the sports medicine community. The National Athletic Trainers' Association's Research and Education Foundation (NATA-REF) held a Mild Brain Injury Summit Roundtable in 1994. Goals of the summit included identifying potential risks for returning to activity following mild head injury, developing more widely accepted guidelines for treatment, and emphasizing the need for research and education in this area.[25]

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 mild head injury in contact sports is well documented.[3,5,6,9,28] Gerberich[9] estimated that approximately 250,000 head injuries occur annually in high school football alone and that 20% of all high school football players suffer a concussion every season. Athletic trainers and team physicians are often faced with a difficult decision related to returning these athletes to play, while having little or no quantitative information on which to base the decision. Determination of the severity of injury is sometimes difficult, especially when there is no loss of consciousness or amnesia. Returning an athlete to competition too early has the potential to become a very costly decision–one that could lead to death. According to Cantu[7] many decisions are based simply on the judgment of a physician or athletic trainer.

Changes in simple motor skills[13,15] and postural control[2,14] accompany mild head injury. However, tests used to assess such injuries are criticized for their lack of sensitivity and objectivity. The areas of the brain that are disrupted as a result of a concussion are responsible for the maintenance of equi-

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librium.[1,2,12,18-20,29] Other studies[10,11,17] reveal that concussion diminishes cerebral reserve despite apparent recovery and places individuals at risk for more prolonged disability after a second such injury.

Romberg's tests of sensory modality function are frequently used to test "balance" following a head injury. Despite their wide use, there is more to posture control than just balance and sensory modality,[21-24,27,30] especially when assessing people with head injury.[2,14] The purpose of this study was to identify changes in postural stability in athletes with acute mild head injury and to develop a recovery curve based on quantitative measures for determining readiness to return to activity.

METHODS

Seventy college or high school football players between the ages of 15 and 25 years were prescreened during the preseason and first 2 weeks of their season. Players were recruited from all positions but were excluded from participation if they had a history of any severe visual, vestibular, or balance disorders. Athletes having sustained a MHI within the 6 months before testing were also excluded from the study. Ten subjects (age = 17.4 ± 2.2 yr; ht = 183.8 ± 8.1 cm; wt = 87.7 ± 17.3 kg) suffered a mild head injury and returned for testing on days 1, 3, 5, and 10 following injury, and one month postseason. A group of prescreened matched control subjects (age = 18.6 ± 2.6 yr; ht = 185.7 ± 6.7 cm; wt = 84.5 ± 19.5 kg) was selected to compare group differences.

Additionally, we recruited 8 male and 1 female subjects (age = 19.9 ± 4.2 yr; ht = 182.3 ± 10.9 cm; wt = 89.6 ± 25.2 kg) who sustained MHI from other varsity sports teams and a local health center's emergency room. These subjects and a group of matched controls (age = 22.1 ± 3.3 yr; ht = 181.0 ± 9.9 cm; wt = 84.9 ± 25.6 kg) were assessed under the same conditions as prescreened subjects on days 1, 3, 5, and 10 postinjury, and 1 month postseason.

A questionnaire that included the Galveston Orientation and Amnesia Test (GOAT)[17] and a list of 15 possible postconcussion symptoms (eg, headache, disequilibrium, blurred vision, nausea, etc) was also administered to the injured subjects within the first 8 hours following injury.

Measuring Device

We measured postural sway using the Chattecx Balance System (Chattanooga Group, Inc., Chattanooga, TN). This instrument measures vertical reaction forces using four electronic pressure transducers placed under the medial and lateral aspects of the heel and forefoot (Fig 1). The distribution of pressure over the forefoot plates shows fluctuations in weight distribution that reflect the amount of postural sway and the direction of postural sway in the forward/backward and left/right directions. Computer analysis calculates the center of balance (COB), which is the average X and Y coordinates plotted using the "normal" COB (where X = 0 and Y = 0) as a reference point.[8] The Pythagorean formula was used to calculate the distance in centimeters of the subject's COB from the "normal" COB.

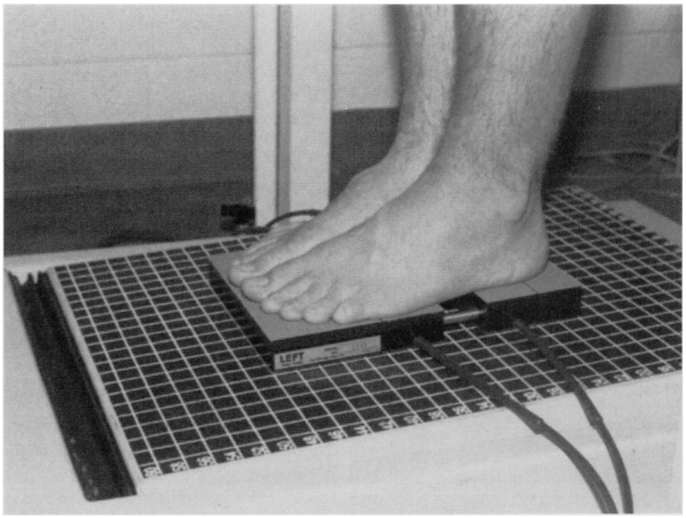


Fig 1. Chattecx Balance System allows for assessment of postural sway using four electronic pressure transducers placed under the medial and lateral aspects of the heel and forefoot.

Deviation from the COB in any direction represents postural sway, measured by the sway index (SI). Sway index (in centimeters) reflects the degree of scatter of data about the subject's center of balance. The force platform measurements are interfaced with software that filters data collected at 100 Hz so that they can be sampled and analyzed at approximately 15 Hz. Extraneous high-frequency sway oscillations are virtually eliminated using this technique. Each subject's COB and SI were measured as a representation of postural sway under the nine testing conditions (Table 1). Byl and Sinnott[4] investigated intratester and intertester reliability of the instrument and reported correlation coefficients of .92 and .90, respectively.

Protocol

Although subjects received no visual feedback during conditions 1 through 9, we provided a practice trial before testing that allowed them to observe their postural sway on the monitor in all four directions. We explained that the goal was to remain in an upright position, while attempting to minimize sway. Shoes and/or socks were removed before testing. The force plates were adjusted to fit the subjects' feet. The force plates were placed together, which allowed the subjects to assume the Romberg position (Fig 2a).

The first nine testing conditions involved 20-second Romberg tests while standing on the force transducers under

Table 1. Balance Testing Conditions Used to Isolate Sensory Modalities

1. Eyes open, normal stable platform
2. Blindfolded, normal stable platform
3. Visual-conflict dome, normal stable platform
4. Eyes open, foam-padded stable platform
5. Blindfolded, foam-padded stable platform
6. Visual-conflict dome, foam-padded stable platform
7. Eyes open, normal plantar/dorsiflexion dynamic platform
8. Blindfolded, normal plantar/dorsiflexion dynamic platform
9. Visual-conflict dome, normal plantar/dorsiflexion dynamic platform

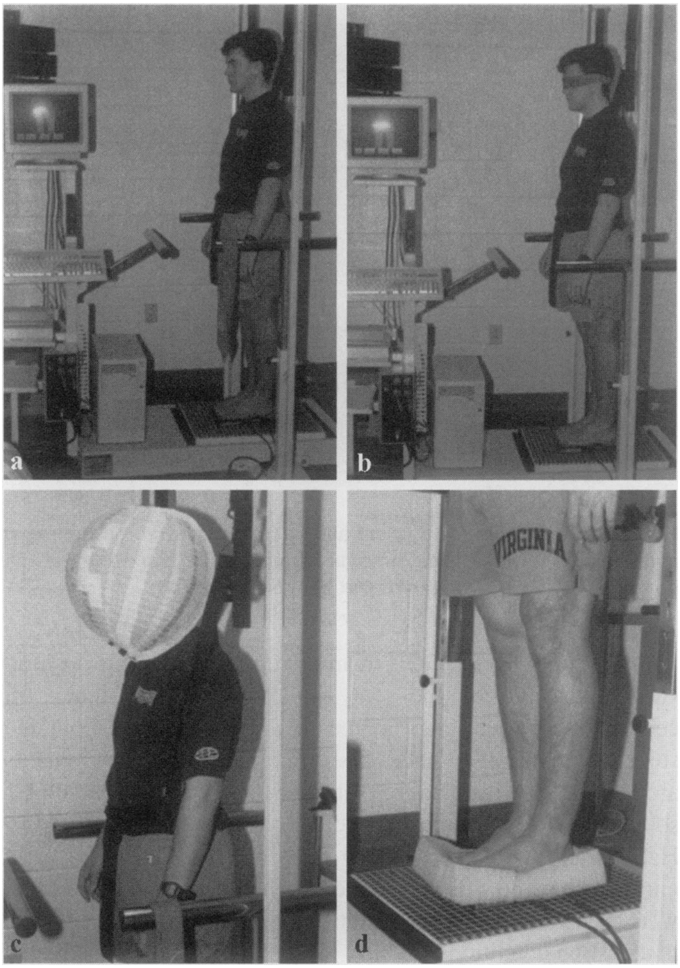


Fig 2. a) Subject tested with eyes open on a normal, stable platform; b) Subject tested with eyes blindfolded; c) Subject tested wearing visual-conflict dome; d) Subject tested on a foam platform.

varying degrees of sensory input disruption. We instructed subjects to remain as motionless as possible as they performed two trials for each condition. We used the better of the two scores for data analysis. The testing conditions were randomly administered to avoid a learning effect.

The technique uses combinations of three visual and three support-surface conditions (Table 1). Altered visual conditions include the use of a blindfold (Fig 2b) for eliminating visual input and a visual-conflict dome (Fig 2c) for producing inaccurate vestibular and visual input.[30] During the visual-conflict conditions, we instructed the subjects to stare directly at the "X" placed on the inside of the dome, approximately 10 cm from the face. Under normal visual conditions, we asked the subjects to focus on an "X" placed on a wall approximately 3 m in front of their faces. The altered support surface conditions included the use of a compliant section of medium-density foam placed between the force transducers and the feet to reduce accuracy of proprioceptive feedback (Fig 2d). Angular perturbations of the Balance System's platform were also used for three of the conditions. This produces a plantar flexion/dorsiflexion movement pattern, which also alters proprioceptive feedback about the joints of the ankle, knee, and hip.

Data Analysis

Two separate, mixed-model (1 between, 3 within), repeated measures analyses of variance (ANOVA) for sway index and center of balance were used to determine if significant differences existed for the two data sets. These analyses determined if significant differences existed across *groups* (between) and *day, eye condition, and platform condition* (within) for both measures of stability. The goal was to determine if changes in the dependent variables SI and COB with time (days following injury) and with alterations to sensory input (visual, vestibular, somatosensory) were dependent on group.

RESULTS

Descriptive statistics for subject characteristics are presented in Tables 2 and 3. Of the 19 MHI subjects, all but three suffered football-related injuries. Selection of the matched control subjects was based on a combination of baseline sway measures, sex, age, height, weight, and activity level. Level of significance ($p < .05$) was set a priori for all statistics.

Prescreened MHI and Control Subjects

The ANOVA for SI revealed a significant interaction for group by day by platform, F(10,180) = 4.24 (Fig 3). Additional significant two-way interactions were found for group by day, F(5,90) = 7.09; day by eyes, F(10,180) = 1.87; day by platform, F(10,180) = 10.65; and eyes by platform, F(4,72) = 75.76. Tukey post hoc analysis revealed that sway index differences >.30 cm represented significantly more postural sway, as shown in Figure 3. Significant main effects were revealed for day, eyes, and platform. Tukey post hoc analysis, however, indicated that while there were group differences on day 1 postinjury, there were no group differences after day 1. Similarly, while MHI subjects' sway measures significantly increased preinjury to postinjury, their performance returned to baseline around day 3 or day 5 postinjury. The ANOVA for COB revealed no significant group interactions ($p > .05$).

Combined Prescreened and Nonprescreened MHI and Control Subjects

The ANOVA for SI revealed a significant interaction for group by day by platform, F(8,288) = 3.36 (Fig 4). Additional

Table 2. Descriptive Statistics for Characteristics of Prescreened Subjects (n = 10) with Mild Head Injury (MHI) and Prescreened Control Subjects (n = 10)

Variable	MHI	Control
Age (yr)	17.4 ± 2.2	18.6 ± 2.6
Height (cm)	183.8 ± 8.1	185.7 ± 6.7
Weight (kg)	87.7 ± 17.3	84.5 ± 19.5
GOAT Score*	94.5 ± 6.4	N/A‡
No. Postconcussion Sympt.†	5.60 ± 1.9	N/A

* Galveston Orientation & Amnesia Test = 10-item, 100-point questionnaire testing for amnesia administered immediately following injury[17]
† Number of postconcussion symptoms present during first 24 hours postinjury (15 possible)
‡ N/A, not applicable

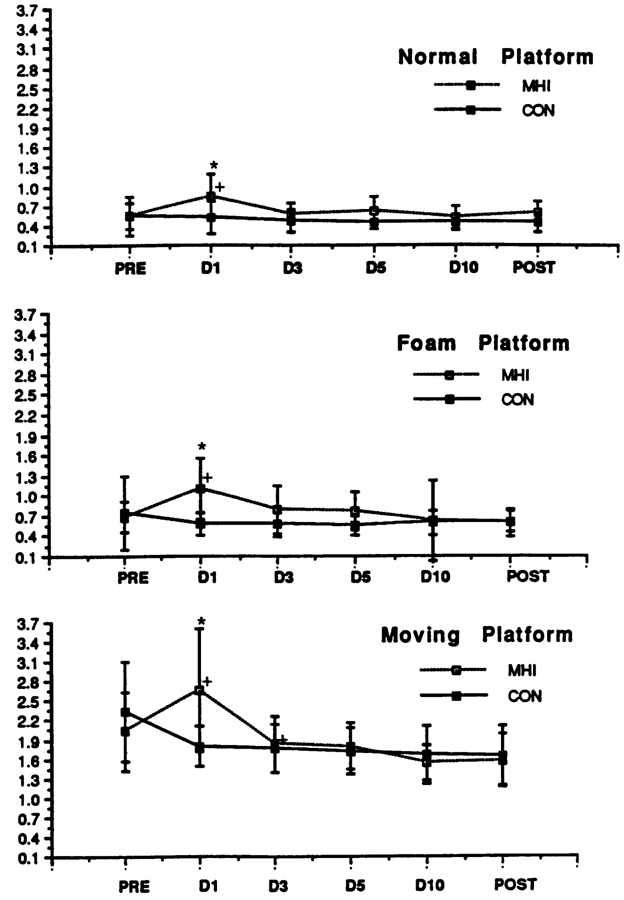
Table 3. Descriptive Statistics for Characteristics of Nonprescreened Subjects (n = 9) with Mild Head Injury (MHI) and Nonprescreened Control Subjects (n = 9)

Variable	MHI	Control
Age (yr)	19.9 ± 4.2	22.1 ± 3.3
Height (cm)	182.3 ± 10.9	181.0 ± 9.9
Weight (kg)	89.6 ± 25.2	84.8 ± 25.6
GOAT Score*	91.2 ± 7.7	N/A‡
No. Postconcussion Sympt.†	6.1 ± 1.4	N/A

* Galveston Orientation & Amnesia Test = 10-item, 100-point questionnaire testing for amnesia administered immediately following injury[17]

† Number of postconcussion symptoms present during first 24 hours postinjury (15 possible)

‡ N/A, not applicable

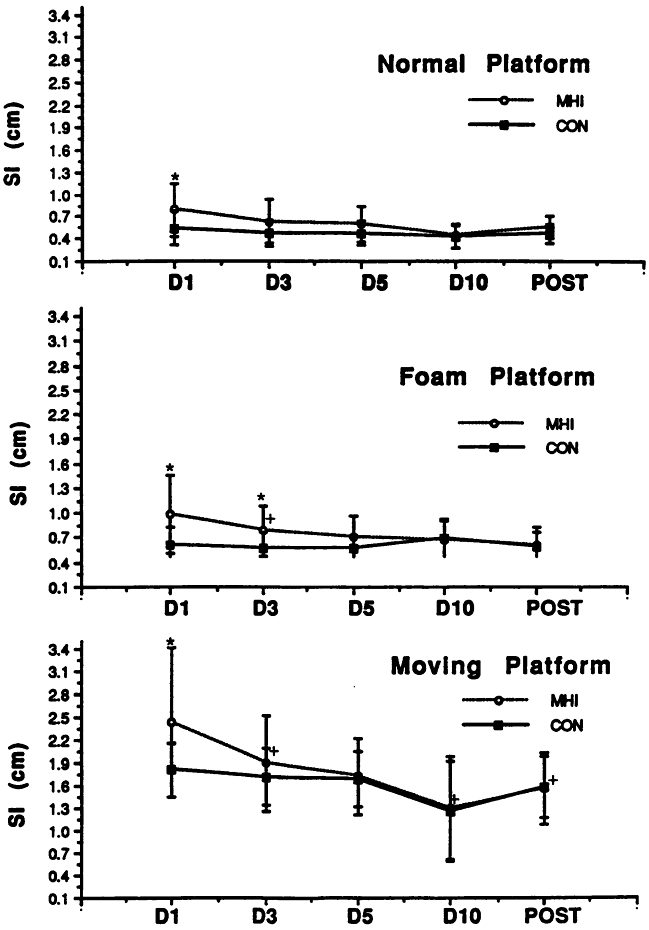


\+ significantly different from preceding test Tukey HSD = .30, p<.05

* significantly different from other group

Fig 3. Sway Index means (± SD) for prescreened subjects with mild head injury (MHI) and control subjects (CON) across each testing session (preseason, day 1 postinjury through day 10 postinjury, and postseason).

significant two-way interactions were found for group by day, F(4,144) = 6.74; day by eyes, F(8,288) = 23.92; day by platform, F(8,288) = 25.85; and eyes by platform, F(4,144) = 62.32. The ANOVA for COB revealed a significant interaction for group by day, F(4,144) = 3.06 (Fig 5).



\+ significantly different from preceding test Tukey HSD = .21, p<.05

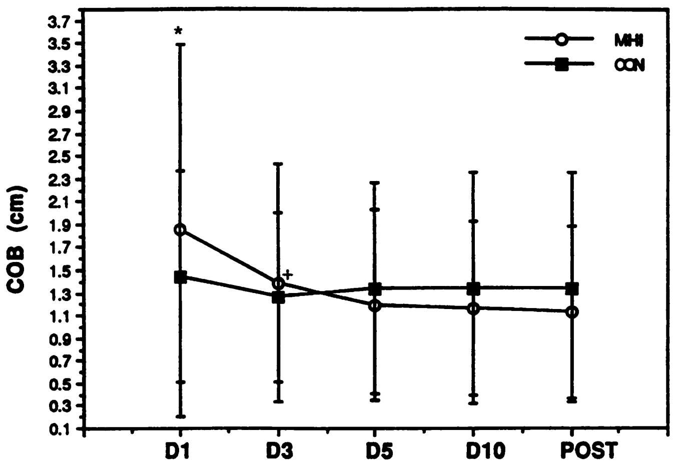
* significantly different from other group

Fig 4. Sway Index means (± SD) for all subjects with mild head injury (MHI) and all control subjects (CON) across each testing session (day 1 postinjury through day 10 postinjury and postseason).

DISCUSSION

The most important finding in this study is that athletes may have sensory integration problems during the first few days following mild head injury. The overall results of our study indicate that athletes with acute mild head injury demonstrate significantly more postural sway up to 3 days following injury. Additionally, athletes with mild head injury demonstrate increased postural sway up to 3 days postinjury as compared with matched control subjects. The results suggest that injured athletes return to baseline approximately day 3 to day 5 following injury and eventually mimic the improved scores of control subjects about day 10 following injury (Figs 3 & 4). Furthermore, the differences between MHI and control subjects are most evident when sensory input is altered through the inclusion of foam padding on the force transducers or when the platform is perturbed in a plantar flexion/dorsiflexion direction (Figs 3 & 4). Finally, although GOAT scores for injured subjects averaged only 5.50 and 8.78 points lower than noninjured subjects (Tables 2 and 3), differences in balance between the injured and noninjured subjects were more obvious. Thus, the decision to return athletes to participation based solely on cognitive tests such as the GOAT may not be as accurate.

Our study is unique in that it studied the effect of *acute* mild head injury on postural stability. Unfortunately, there are very



* significantly different from other group Tukey HSD = 48, p<.05
\+ significantly different from preceding test

Fig 5. Center of balance (± SD) for all subjects with mild head injury (MHI) and all control subjects (CON) across each testing session (day 1 postinjury through day 10 postinjury and postseason).

few studies with which our study can be compared. As such, our findings of this study will be compared with findings of more severe and chronic head injuries that are reported in the literature.

Sway Index

Our findings for prescreened subjects (Fig 3) and combined subjects (Fig 4) are the most intriguing. The results suggest that MHI subjects sway significantly more than control subjects on day 1 following injury. This difference is greater during conditions where somatosensory input is altered. For example, the moving platform produced greater differences between the two groups than the foam platform, whereas the foam platform produced greater differences than the normal platform. MHI subjects also swayed significantly more on day 1 following injury than they swayed at preseason or on subsequent tests after day 1.

The set of data combining prescreened subjects with nonprescreened subjects increased the sample from 10 to 19 and revealed significant group differences at day 3 that were not evident in the original set of prescreened subjects. The advantage of combining the data is that doubling the number of subjects improves the statistical power; thus, smaller differences between groups may be considered significant. The disadvantage of combining these subjects is that baseline preseason measures taken on 10 of the subjects are eliminated for comparison purposes. Nevertheless, the differences between MHI subjects and control subjects can be seen for as long as 3 days following injury on a foam platform (Fig 4). MHI subjects gradually regained stability around day 5 postinjury, at which time they demonstrated a trend similar to control subjects.

The increased postural sway we found during conditions where somatosensory input was confounded suggests that MHI subjects experience sensory modality interaction problems up to 3 days postinjury. In uninjured people, the vestibular, visual, and somatosensory systems work together to control postural stability. In people with mild head injury there appears to be a communication or interaction problem that prevents the vestibular and/or visual systems from compensating for altered somatosensory (proprioceptive) feedback during the foam and moving platform conditions. Newton[26] and Shumway-Cook and Horak[30] state that sway patterns are based on the assumption that stability scores reflect the interaction of sensory systems. If a subject has difficulty balancing under conditions in which sensory modalities have been altered, it can be hypothesized that the subject is unable to ignore altered environmental conditions and therefore selects a motor response based on the altered environmental cues. This has the potential to cause problems in athletes who encounter situations during activity that alter sensory input to one or more systems.

Although SI increased when the eyes were closed or a visual-conflict dome was worn, the increases were equal for both MHI and control subjects regardless of day. Therefore, it is difficult to discriminate between visual and vestibular deficits. Since the eyes-closed condition and the visual-conflict-dome condition both eliminate visual cues, it is not surprising that there is no difference between these two conditions in the absence of a pure vestibular lesion. This supports the theory that MHI subjects may experience mild visual and/or vestibular deficiencies. We believe that differences between MHI and controls are not revealed when vision is either eliminated (eyes closed) or conflicted (visual-conflict dome) due to the compensatory nature of somatosensory input. Finally, all nonprescreened subjects (regardless of group) swayed significantly more with their eyes closed and when wearing a visual-conflict dome than with their eyes open. These increased sway measures become even more apparent when somatosensory input is altered (foam and moving platform). These findings are consistent with those of Lehmann et al,[16] who found no significant differences in sway measured with the eyes closed and while wearing the visual-conflict dome. They did, however, report that the differences among eyes-open, eyes-closed, and visual-conflict conditions were greater in traumatically brain injured (TBI) subjects as opposed to able-bodied subjects. They attribute the differences to TBI patients' relying more on visual cues from the environment than able-bodied subjects. Our study did not reveal these same group-by-eye interactions. Therefore, MHI subjects evidently do not rely as much on visual cues as TBI subjects. A better explanation might be that TBI patients, unlike MHI patients, do not have adequate somatosensory input to compensate for visual or vestibular deficits.

Our findings on altered platform surfaces are also consistent with those of Lehmann et al,[16] who reported that the difference between standing on a solid support and standing on foam is greater in the TBI population than in the able-bodied population. Our MHI subjects swayed significantly more than control subjects on day 1 postinjury (all three support surfaces) and on day 3 postinjury (on the foam surface) (Fig 4). Furthermore, the differences between groups increased as somatosensory input became more confounded (moving > foam > normal).

Center of Balance

The set of data inclusive of all 19 MHI subjects and all 19 control subjects best represents COB changes following head injury. Our results suggest that MHI subjects maintain their COB significantly farther away from their base of support (normal COB) on day 1 following injury than do control subjects (Fig 5). Additionally, MHI subjects appear to recover on day 3 following injury, since they are able to position themselves significantly closer to their ideal COB compared to day 1.

The COB results are consistent with those of Ingersoll and Armstrong.[14] They reported that head-injured subjects (injury > 1 year old) maintained their center of pressure at a greater distance from the center of their base of support and made fewer postural corrections. The differences reported were particularly evident when one or more of the sensory modalities were conflicted or eliminated. This is also consistent with our findings. The fact that MHI subjects returned to baseline levels on both SI and COB by 1 month postseason contradicts the findings of Ingersoll and Armstrong,[14] who suggested that head-injured patients could maintain their center of pressure at distances farther away from their base of support up to 9 years postinjury. A possible reason for this discrepancy is that they used several grades of head-injured patients (mild, moderate, severe) as compared with the mildly impaired athletes used in our study.

CONCLUSION

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. Our findings also suggest that the effect of mild head injury on postural stability lasts longer than just 1 day postinjury and that balance deficits may be present in the absense of amnesia and/or other postconcussion symptoms.

Unfortunately, most clinicians do not have postural stability systems available. However, these findings can still be helpful in making decisions related to safely returning athletes to participation following a mild head injury. First and foremost, athletes sustaining a MHI should not be permitted to return to activity until all postconcussive symptoms have resolved. An athlete returning to contact sports before meeting these standards may be at risk for suffering second-impact syndrome. Unfortunately, most of the measures taken before making this decision are very subjective. Therefore, without the luxury of having a stability system, clinicians should consider holding athletes out of participation for at least 3 days following a MHI (assuming all other signs and symptoms have resolved). Clinicians should seriously consider whether or not they might be placing athletes at risk by returning them earlier than 3 days postinjury.

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REFERENCES

1. Adams J. The neuropathology of head injuries. In: Vinken P, Bruyn G, eds. *Handbook of Clinical Neurology: Injuries of the Brain and Skull.* Amsterdam: North-Holland Publishing Co; 1975:35-65.
2. Arcan M, Brull M, Najenson T, Solzi P. FGP assessment of postural disorders during the process of rehabilitation. *Scand J Rehabil Med.* 1977;9:165-168.
3. Bruce D, Schut L, Sutton L. Brain and cervical spine injuries occurring during organized sports activities in children and adolescents. *Prim Care.* 1982;11:175-194.
4. Byl N, Sinnott P. Variations in balance and body sway in middle-aged adults. *Spine.* 1991;16:325-330.
5. Cantu R. Cerebral concussion in sports: management and prevention. *Sports Med.* 1992;14:64-74.
6. Cantu R. Minor head injuries in sports. *Adolesc Med.* 1991;2:141-154.
7. Cantu R. When to return to contact sports after cerebral concussion. *Sports Med Dig.* 1988;10:1-2.
8. Chattanooga Group, Inc. *The Balance System: Clinical Desk Reference.* Chattanooga, TN: Chattecx Corporation: 1992:4-36.
9. Gerberich S, Priest J, Boen J, Staub C, Maxwell R. Concussion incidences and severity in secondary school varsity football players. *Am J Public Health.* 1983;73:1370-1375.
10. Gronwall D, Wrightson P. Cumulative effect of concussion. *Lancet.* Nov 22, 1975;995-997.
11. Gronwall D, Wrightson P. Delayed recovery of intellectual function after minor head injury. *Lancet.* Sep 14, 1974;605-609.
12. Guyton A. *Textbook of Medical Physiology.* 8th ed. Philadelphia, PA: WB Saunders Co; 1986:610-615.
13. Haaland K, Temkin N, Randahl G, Dikmen S. Recovery of simple motor skills after head injury. *J Clin Exp Neuropsychol.* 1994;16:448-456.
14. Ingersoll C, Armstrong C. The effects of closed-head injury on postural sway. *Med Sci Sports Exerc.* 1992;24:739-742.
15. Klonoff P, Costa L, Snow W. Predictors and indicators of quality of life in patients with closed-head injury. *J Clin Exp Neuropsychol.* 1986;8: 469-485.
16. Lehmann J, Boswell S, Price R, Burleigh A, deLateur B, Jaffe K, and Hertling D. Quantitative evaluation of sway as an indicator of functional balance in post-traumatic brain injury. *Arch Phys Med Rehabil.* 1990;71: 955-962.
17. Levin H. Position paper on mild brain injury. *Proceedings of the Mild Brain Injury in Sports Summit.* Dallas, TX: National Athletic Trainers' Association, Inc; 1994:53-61.
18. Mauritz K, Dichgans J, Hufschmidt A. Quantitative analysis of stance in late cortical cerebellar atrophy of the anterior lobe and other forms of cerebellar ataxia. *Brain.* 1979;102:461-482.
19. McIntosh T, Vink R. Biomechanical and pathophysiologic mechanisms in experimental mild to moderate traumatic brain injury. In: Hoff J, Anderson T, Cole T, eds. *Mild to Moderate Head Injury.* Boston, MA: Blackwell Scientific Publications; 1989:35-45.
20. Mitchell S, Lewis M. Tendon-jerk and muscle-jerk in disease and especially in posterior sclerosis. *Am J Med Sci.* 1886;92:363-372.
21. Nashner L. Adaptation of human movement to altered environments. *Trends Neurosci.* 1982;5:358-361.

22. Nashner L. Adapting reflexes controlling the human posture. *Explor Brain Res.* 1976;26:59–72.

23. Nashner L, Berthoz A. Visual contribution to rapid motor responses during postural control. *Brain Res.* 1978;150:403–407.

24. Nashner L, Black F, Wall C. Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. *J Neurosci.* 1982;2:536–544.

25. National Athletic Trainers' Association Research & Education Foundation. Executive summary: mild brain injury summit roundtable. *Proceedings of the Mild Brain Injury in Sports Summit.* Dallas, TX: National Athletic Trainers' Association, Inc; 1994:2–5.

26. Newton R. Recovery of balance abilities in individuals with traumatic brain injuries. *Balance: Proceedings of the American Physical Therapy Association Forum.* Nashville, TN: APTA; Jun 13–15, 1989:69–72.

27. Norre M. Sensory interaction testing in platform posturography. *Laryngol Otol.* 1993;107:496–501.

28. Ommaya A, Ommaya A, Salazar A. A spectrum of mild brain injuries in sports. *Proceedings of the Mild Brain Injury in Sports Summit.* Dallas, TX: National Athletic Trainers' Association, Inc; 1994:72–80.

29. Saunders R, Harbaugh R. The second impact in catastrophic contact-sports head injury. *J Am Med Assoc.* 1984;252:538–539.

30. Shumway-Cook A, Horak F. Assessing the influence of sensory interaction on balance. *Phys Ther.* 1986;66:1548–1550.