BALANCE DEFICITS AFTER SPORTS-RELATED CONCUSSION IN INDIVIDUALS REPORTING POSTTRAUMATIC HEADACHE

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OBJECTIVE: Posttraumatic headache (PTH) may affect neurocognition after sports-related concussion. To our knowledge, no studies have examined how PTH affects balance after concussion using dynamic posturography. The purpose of this study is to compare balance after concussion between athletes reporting PTH and athletes not reporting PTH.

METHODS: We conducted a retrospective, repeated-measures design with participants grouped by presence of postinjury report of headache. Balance testing was conducted on 108 concussed collegiate athletes (age, 18.83 ± 1.27 yr; height, 180.92 ± 10.01 cm; mass, 83.29 ± 19.62 kg). Presence of PTH during the first postinjury test session (group) and test time (baseline, postinjury) served as the independent variables. The composite equilibrium score and the somatosensory, vestibular, and visual ratio scores served as dependent variables. A 2 × 2 mixed model analysis of variance was used to analyze each outcome measure.

RESULTS: Significant decreases in all four measures assessed were noted after concussion compared with preseason baseline measures ($P < 0.05$). Significant group by test-time interactions were observed, suggesting that composite equilibrium ($F_{1106} = 6.6089$; $P = 0.012$) and vestibular ratio ($F_{1106} = 7.156$; $P = 0.009$) scores are affected by the presence of PTH. Athletes reporting PTH also demonstrated worse visual ratio scores compared with individuals not experiencing PTH ($F_{1106} = 4.26$; $P = 0.041$). No other significant findings were observed for the somatosensory ratio score.

CONCLUSION: Current literature proposes that PTH is associated with cognitive deficits. Our study indicates that PTH may also contribute to increased balance deficits. We believe the deficits may be a result of increased sensory organization challenges after injury. Clinicians should be mindful of these findings when managing concussed athletes reporting headache.

KEY WORDS: Migraine, Mild traumatic brain injury, Postural stability

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Sports-related concussion results in a variety of symptoms and neurocognitive deficits after injury. Headache is one of the more common symptoms, occurring in 40 to 86% of concussed individuals, and may often be overlooked after a possible concussive injury (10, 11, 20). Decreases in neuropsychological performance and increases in symptom presence and severity in individuals reporting posttraumatic headache (PTH) and characteristics of posttraumatic migraine after a concussive injury have been reported in the literature (2, 21, 28). These findings are important to clinicians, as PTH may exacerbate neurocognitive impairment after injury. The headache literature also identifies neuropsychological deficits in individuals experiencing various headache disorders (18, 25, 36).

Various forms of headache, particularly migraine, have been associated with balance disorders throughout the balance literature. Both vertigo and generic postural instability are common problems for individuals experiencing headache disorders. Vestibular disturbance is one of the most commonly reported in the literature (9, 17, 30, 35). Research has also

revealed the presence of balance deficits after sport-related concussion (10, 12, 27, 29). Concussion-related balance deficits tend to be greatest at 24 hours after injury and typically resolve approximately 3 days after injury (12). Research has identified vestibular and visual system deficiencies in individuals with global postural control deficits (7, 12, 31).

Although studies have discussed neurocognitive deficits, to our knowledge, no other study has examined balance assessed by dynamic posturography in individuals reporting headache after concussive injury. Although it has been previously established that athletes reporting PTH experience increased presence and severity of symptoms (2, 21, 28), the purpose of this study was to compare balance deficits between individuals not reporting PTH and individuals reporting PTH after a concussive injury.

PATIENTS AND METHODS

One hundred and eight concussed male and female collegiate athletes served as subjects for this study (age, 18.83 ± 1.27 yr; height, 180.92 ± 10.01 cm; mass, 83.29 ± 19.62 kg). The study was approved by the university's institutional review board and was fully explained to participants before their participation in the study. Written informed consent was obtained from each subject before the collection of any data.

Subjects were stratified into one of two groups based on their self-report of headache on a symptom checklist during the first postinjury test session. Subjects reporting headache on a symptom checklist were placed in the PTH group (n = 82) and subjects not reporting headache were placed in the non-PTH group (n = 26). The PTH group consisted of 60 men and 22 women and the non-PTH group consisted of 15 men and 11 women. The subjects' balance scores were obtained during a preseason baseline session and the first postinjury evaluation session.

Balance Assessment

Balance was measured using the Sensory Organization Test (SOT) (NeuroCom International, Clackamas, OR) (1, 5, 10, 12, 16, 22, 23, 26, 34). The SOT protocol consists of six different 20-second conditions performed three times each. The six conditions of the SOT are designed to evaluate an individual's balance by disrupting the somatosensory, vestibular, and visual systems to determine how the individual responds and compensates in the altered environments. The SOT accomplishes this by moving the visual surround (walls) and surface (floor) while the subject's eyes are either open or closed, depending on the condition. The amount of sway is directly proportional to the movement of the center of gravity as measured by the SOT force platform (sway referencing set at +1). *Figure 1* depicts the six SOT conditions. Using these conditions, an overall composite equilibrium score, as well as somatosensory, vestibular, and visual ratio scores, were obtained. The composite score represents the weighted average of the scores of all of the sensory conditions. A higher score represents better performance or less postural sway. The vestibular ratio score is calculated as the ratio of Condition 5 equilibrium score to Condition 1 equilibrium score. The visual ratio score represents the ratio of Condition 4 to Condition 1, and the somatosensory ratio score represents the ratio of Condition 2 to Condition 1. The first condition is regarded as a reference in which all sensory modalities are available and unaltered. Higher ratio scores indicate the subject's increased ability to maintain balance under conditions in which the vestibular (Condition 5), visual (Condition 4), and somatosensory (Condition 2) systems are required to compensate for the alteration of other systems. The composite equilibrium score and the three ratio scores served as dependent variables in our study. These four measures were compared at baseline, after injury, and across the two test times. Baseline means and standard deviations, which were not significantly different between the groups, are listed in *Table 1*. The following values were recorded: composite, $t_{106} = 1.80$ and $P = 0.072$; vestibular, $t_{106} = 0.528$ and $P = 0.598$; visual, $t_{106} = 1.00$ and $P = 0.318$; and somatosensory: $t_{106} = -694$ and $P = 0.489$.

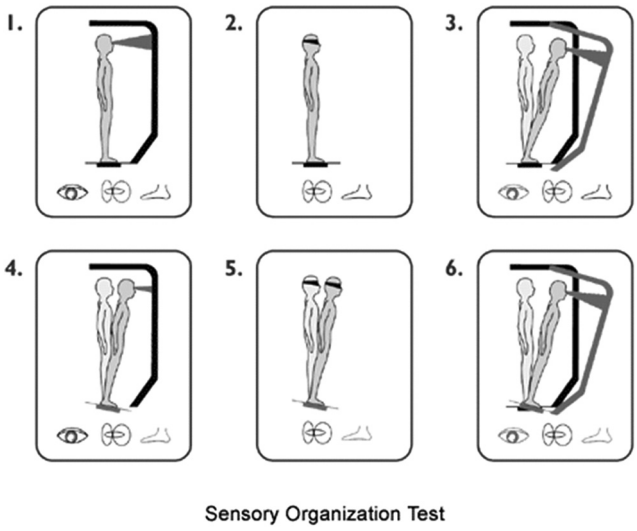

FIGURE 1. *Six conditions of the Sensory Organization Test (SOT). (Reproduced courtesy of NeuroCom International, Inc., Clackamas, OR).*

Data Analyses

To address our purpose, we performed separate 2 × 2 mixed model analyses of variance for each of the four dependent measures of interest. Test-time (preseason baseline and postinjury) and group (PTH and non-PTH) served as our independent variables for each of our analyses. Our alpha level was set a priori to a P value less than 0.05. All statistical analyses were performed using SPSS 13.0 software (SPSS, Inc., Chicago, IL).

RESULTS

Regardless of headache group classification (i.e., PTH or non-PTH), we noted a significant decrease in all four measures assessed in this study after injury compared with preseason baseline measures ($P < 0.05$). This finding was driven largely by the PTH group, as the non-PTH group did not exhibit significant changes in these measures and the PTH group made up a larger portion of the sample. The mean time to the first follow-up evaluation was 1.44 ± 0.90 days for the PTH group and the mean time to the follow-up evaluation for the non-PTH group was 1.81 ± 1.1 days. The baseline and postinjury means and standard deviations are listed in *Table 1* and depicted in *Figures 2* through *5*.

We observed a significant group by test-time interaction for the overall composite balance equilibrium score ($F_{1106} = 6.6089$; $P = 0.012$). The postural stability of our injured athletes after concus-

TABLE 1. Means and standard deviations of Sensory Organization Test scores[a]

Outcome measure	Baseline		Postinjury	
	Non-PTH	PTH	Non-PTH	PTH
Composite[b,c,d]	82.22 ± 5.16	79.88 ± 5.90	82.02 ± 6.97	72.67 ± 14.23
Vestibular[b,c,d]	0.76 ± 0.09	0.75 ± 0.10	0.77 ± 0.11	0.63 ± 0.23
Visual[c,d]	0.91 ± 0.07	0.89 ± 0.08	0.91 ± 0.08	0.83 ± 0.18
Somatosensory[d]	0.97 ± 0.02	0.97 ± 0.03	0.95 ± 0.03	0.95 ± 0.06

[a] PTH, posttraumatic headache.
[b] Significant group by test-time interaction ($P < 0.05$).
[c] Significant group main effect ($P < 0.05$).
[d] Significant time main effect ($P < 0.05$).

sion was influenced by whether or not they were experiencing a headache after injury. On average, PTH athletes demonstrated a seven-point decline on the composite equilibrium score after injury compared with individuals not experiencing PTH (*Fig. 2*).

A significant group by test-time interaction was also observed for the vestibular ratio measure ($F_{1106} = 7.156$; $P = 0.009$). The ability of individuals to accurately use information from the vestibular system was influenced by whether or not they experienced headache after injury. Contributing to these findings is the significant departure from baseline performance, as the vestibular ratio score seemed to be more impaired (approximately 13%) in the PTH group than in individuals not reporting PTH (*Fig. 3*). Individuals with PTH also demonstrated worse visual ratio scores compared with individuals not experiencing PTH ($F_{1106} = 4.26$; $P = 0.041$). The group by test-time interaction was not significant ($P = 0.086$) but suggests a trend similar to that of the other variables and a departure of postinjury visual ratio scores from preseason baseline measures (*Fig. 4*). No other significant findings were observed for the somatosensory ratio score (*Fig. 5*).

DISCUSSION

Our most important finding is that concussed athletes with PTH experience greater declines in balance than concussed athletes without PTH. As maintaining postural stability is an important activity of daily living, understanding the effect of PTH on balance impairments is of important clinical applicability not only for evaluating concussed athletes but also for managing a safe return to activity. Feedback given by the vestibular, visual, and somatosensory systems gives rise to the various central nervous system commands needed to generate the appropriate response to environmental changes to maintain balance. These sensory systems, as well as the integration of these systems, have been documented to be affected by both concussion and headache (12, 17, 27, 30, 35). Our study displays

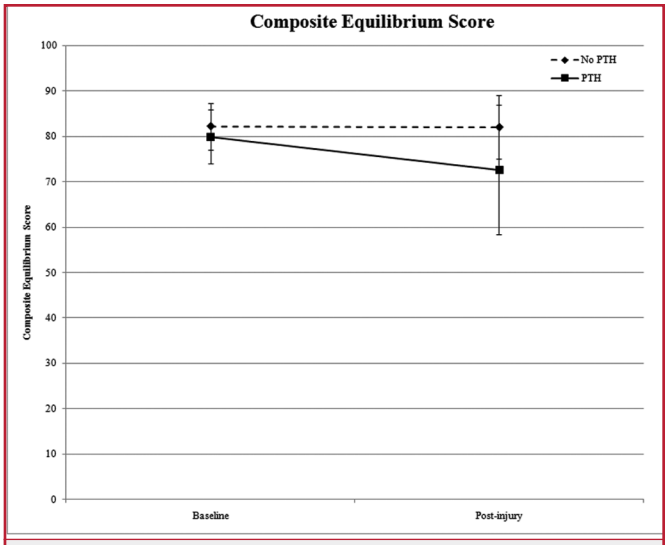

FIGURE 2. *SOT overall composite equilibrium score. A significant group by test-time interaction indicating that athletes with posttraumatic headache (PTH) performed worse after concussion compared with preseason baseline than athletes not reporting headache after injury ($P < 0.05$).*

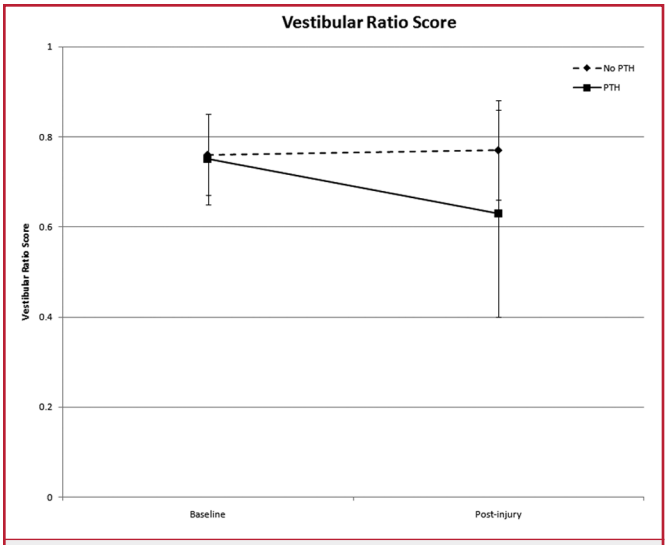

FIGURE 3. *SOT vestibular ratio score. A significant group by test-time interaction indicating that athletes with PTH had more difficulty using the vestibular system to maintain balance after concussion compared with preseason baseline than athletes not reporting headache after injury ($P < 0.05$).*

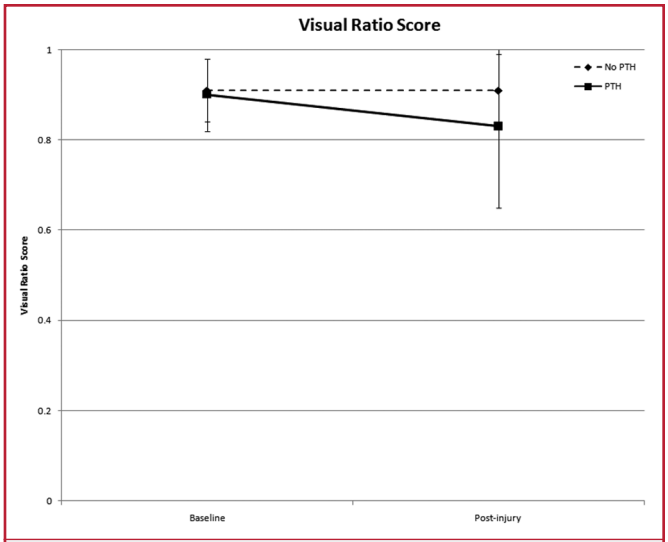

FIGURE 4. *SOT visual ratio score. A significant main effect of group suggested that athletes with PTH had more difficulty using visual information to maintain balance after concussion compared with preseason baseline than athletes not reporting headache after injury ($P < 0.05$).*

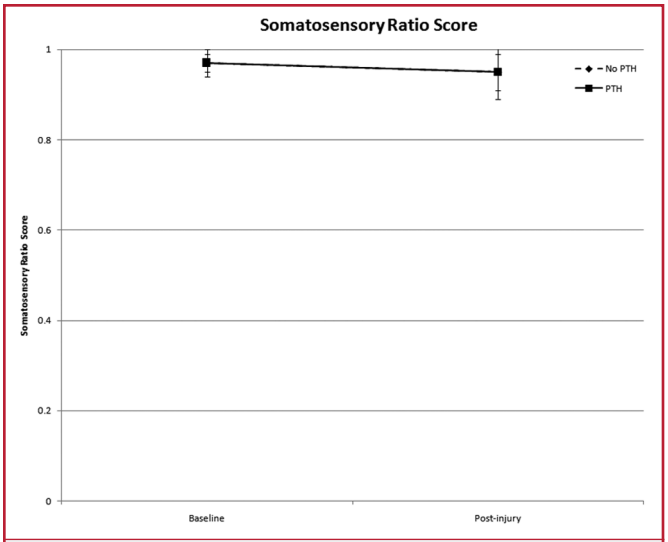

FIGURE 5. *SOT somatosensory ratio score. A significant main effect of time suggested that athletes in general had more difficulty using somatosensory information to maintain balance after concussion compared with preseason baseline measures ($P < 0.05$).*

increased deficits related to both the vestibular and visual systems and overall balance in individuals reporting PTH after concussion.

Headache studies have documented an increase in postural sway and other postural control deficits in individuals experiencing both tension-type headache and migraine. One of the hypothesized explanations for this deficit in individuals with tension-type headache is cervical area muscular involvement, as some studies have shown cervical proprioceptive input to contribute to postural control (8). Oftentimes, concussive injuries result in concomitant neck pain, or nuchal and paravertebral muscle contraction, which may result in abnormal proprioceptive feedback (19, 31). Considering that both headache and concussion often contribute to muscular issues in the cervical region, this may partially explain the decreased overall balance performance in individuals reporting PTH. Individuals experiencing migraine headaches have also been reported to have these increased balance deficits (9, 17, 30, 33, 35). The mechanism is different for those with migraine than for those with tension-type headache. The deficit is often a result of vestibulocerebellar dysfunction and has been found to be of a central origin (14). Given that many individuals reporting headache after concussion also report symptoms consistent with those of a migraine headache, perhaps these deficits are more pronounced with PTH as a result of overlap from headache, symptoms, and the concussive injury altering the integration of visual, vestibular, and somatosensory input.

The vestibular disturbances accompanied by tension-type headaches may be attributable to cervical muscular issues, as vestibular, visual, and neck proprioceptive information work together to achieve body and space orientation (30). Concussion has been shown to inhibit an individual's ability to appropriately use feedback from the vestibular system when visual and somatosensory inputs are disrupted. This disruption creates an increased challenge for individuals attempting to ignore altered environmental information. A healthy individual would be able to compensate; however, concussed individuals are often unable to ignore these altered environmental conditions and select an "incorrect" motor response as a result (12, 15). Our study found that individuals reporting PTH experience significantly decreased postinjury vestibular ratio scores, indicating a significantly greater reduction in balance when inputs from both the visual and somatosensory inputs are disrupted.

It is not unusual that we also observed a significantly lower postinjury visual ratio score in the group reporting PTH. In those experiencing migraine, it has been hypothesized that the close connections between the vestibular nuclei and the oculomotor nuclei resulting in the vestibular processing problem may also be causing issues with visual integration (4, 6, 32). This mechanism may explain the problems with the visual system in our athletes with PTH.

No group differences were found with respect to the somatosensory system. In our experience, this is the system least affected by concussion. This system appears to remain the least affected even in the presence of PTH. Studies have suggested that both peripheral and central deficits may be the causative factors in postural stability deficits after concussion (19). There are also known attention and concentration deficits after concussion that may play a role in these deficits, specifically, 1 to 2 days after injury (3, 12, 22, 27). When considering that these deficits are often significantly worse in individuals experiencing PTH (2, 21, 28), balance deficits in individuals reporting PTH may be of clinical concern. One study using the Balance Error Scoring System, a sideline clinical balance

assessment battery, found no significant differences in errors performed by athletes; however, a trend for declining scores was reported (28).

As with any study, ours is not without limitations. We used a self-report symptom checklist to determine the presence of headache, which may have introduced a recall bias. Our groups were not evenly balanced; however, we believe our sample represents the concussed population, where as many as 86% of concussed individuals report headache after injury (13). An additional limitation is that neither history of headache disorders and previous concussion presence of baseline headache, were included in this study; however, previous work has suggested that there is no association with previous concussion and presence of headache immediately after concussion (28). We also did not examine migraine characteristics or other specific headache types. With these limitations in mind, future research should obtain more information on headache after concussion as well as the presence of posttraumatic migraine characteristics and the effects these characteristics may have on balance and recovery after sport-related concussion. It should also be noted that in cases of statistical nonsignificance, these measures resulted in large standard deviations; however, this is common among concussed individuals, as concussion is such an individualized injury.

Our overall findings may best be explained by the changes of interpretation of sensory cues underlying postural control as a result of the concussion and the headache in combination altering the muscular proprioceptive feedback. This may result in changes in normal sensory cues and create a reorganization pattern of the remaining sensory cues. Our study provides several clinical implications. First and foremost, PTH is the most common symptom of concussion and has recently been identified as a possible contributor to increased neurological deficits after injury (2, 21, 28). Recent studies have displayed increased symptom presence, severity, and decreases in neuropsychological performance in individuals reporting PTH after concussion. These deficits are magnified with increasing headache severity and the presence of posttraumatic migraine characteristics (2, 21, 28). Our study adds to this body of literature, suggesting increased postural stability deficits and decreased ability to ignore altered environmental conditions in individuals reporting PTH. Many clinicians do not have access to highly advanced assessment tools, but 85% of certified athletic trainers use a graded symptom checklist as part of their concussion management protocol (24). In the absence of these advanced measures, the presence of symptoms may provide clinicians important information regarding a concussive injury. Clinicians should consider headache (in the presence or absence of other symptoms) after concussion as a sign that the athlete is not ready to return to play.

CONCLUSION

Clinicians should be mindful of the possible increased cognitive and balance deficits in the presence of posttraumatic headache. Most aspects of sport and physical activity place competing demands on the cognitive system and require complex sensory modality interaction. These demands and complex interactions may predispose an athlete experiencing headache after injury to further injury. Clinicians and athletes should be aware that headache after a sudden movement of the head or body, or even a direct blow to the head, is a serious symptom and should be treated as such. Our study also reinforces the need for preseason baseline assessment, as understanding what is normal gives insight into how impaired an individual may be after injury. The most important implication of our study is that completely asymptomatic return to play is essential, as even the presence of headache may indicate a decrease in an individual's overall ability to maintain balance.

REFERENCES

1. Broglio SP, Tomporowski PD, Ferrara MS: Balance performance with a cognitive task: A dual-task testing paradigm. **Med Sci Sports Exerc** 37:689–695, 2005.
2. Collins MW, Field M, Lovell MR, Iverson G, Johnston KM, Maroon J, Fu FH: Relationship between postconcussion headache and neuropsychological test performance in high school athletes. **Am J Sports Med** 31:168–173, 2003.
3. Collins MW, Grindel SH, Lovell MR, Dede DE, Moser DJ, Phalin BR, Nogle S, Wasik M, Cordry D, Daugherty KM, Sears SF, Nicolette G, Indelicato P, McKeag DB: Relationship between concussion and neuropsychological performance in college football players. **JAMA** 282:964–970, 1999.
4. Cutrer FM, Baloh RW: Migraine-associated dizziness. **Headache** 32:300–304, 1992.
5. Ford-Smith CD, Wyman JF, Elswick RK Jr, Fernandez T, Newton RA: Test-retest reliability of the sensory organization test in noninstitutionalized older adults. **Arch Phys Med Rehabil** 76:77–81, 1995.
6. Furman JM, Marcus DA, Balaban CD: Migrainous vertigo: Development of a pathogenetic model and structured diagnostic interview. **Curr Opin Neurol** 16:5–13, 2003.
7. Geurts AC, Ribbers GM, Knoop JA, van Limbeek J: Identification of static and dynamic postural instability following traumatic brain injury. **Arch Phys Med Rehabil** 77:639–644, 1996.
8. Giacomini PG, Alessandrini M, Evangelista M, Napolitano B, Lanciani R, Camaioni D: Impaired postural control in patients affected by tension-type headache. **Eur J Pain** 8:579–583, 2004.
9. Guidetti G, Bergamini G, Pini LA, Galetti G, Sternieri E: Dizziness and headache. **Acta Otorhinolaryngol Belg** 38:140–147, 1984.
10. Guskiewicz KM: Assessment of postural stability following sport-related concussion. **Curr Sports Med Rep** 2:24–30, 2003.
11. Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Cantu RC, Randolph C, Jordan BD: Association between recurrent concussion and late-life cognitive impairment in retired professional football players. **Neurosurgery** 57:719–726, 2005.
12. Guskiewicz KM, Ross SE, Marshall SW: Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. **J Athl Train** 36:263–273, 2001.
13. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr: Epidemiology of concussion in collegiate and high school football players. **Am J Sports Med** 28:643–650, 2000.
14. Harno H, Hirvonen T, Kaunisto MA, Aalto H, Levo H, Isotalo E, Kallela M, Kaprio J, Palotie A, Wessman M, Färkkilä M: Subclinical vestibulocerebellar dysfunction in migraine with and without aura. **Neurology** 61:1748–1752, 2003.
15. Horstmann GA, Dietz V: The contribution of vestibular input to the stabilization of human posture: A new experimental approach. **Neurosci Lett** 95: 179–184, 1988.
16. Hu MH, Hung YC, Huang YL, Peng CD, Shen SS: Validity of force platform measures for stance stability under varying sensory conditions. **Proc Natl Sci Counc Repub China B** 20:78–86, 1996.
17. Kuritzky A, Ziegler DK, Hassanein R: Vertigo, motion sickness and migraine. **Headache** 21:227–231, 1981.

18. Lake AE III, Branca B, Lutz TE, Saper JR: Headache level during neuropsychological testing and test performance in patients with chronic posttraumatic headache. **J Head Trauma Rehabil** 14:70–80, 1999.
19. Mallinson AI, Longridge NS: Dizziness from whiplash and head injury: Differences between whiplash and head injury. **Am J Otol** 19:814–818, 1998.
20. McCrory PR, Ariens T, Berkovic SF: The nature and duration of acute concussive symptoms in Australian football. **Clin J Sport Med** 10:235–238, 2000.
21. Mihalik JP, Stump J, Collins MW, Lovell MR, Field M, Maroon JC: Posttraumatic migraine characteristics in athletes following sports-related concussion. **J Neurosurg** 102:850–855, 2005.
22. Mrazik M, Ferrara MS, Peterson CL, Elliott RE, Courson RW, Clanton MD, Hynd GW: Injury severity and neuropsychological and balance outcomes of four college athletes. **Brain Inj** 14:921–931, 2000.
23. Nashner LM, Peters JF: Dynamic posturography in the diagnosis and management of dizziness and balance disorders. **Neurol Clin** 8:331–349, 1990.
24. Notebaert AJ, Guskiewicz KM: Current trends in athletic training practice for concussion assessment and management. **J Athl Train** 40:320–325, 2005.
25. O'Bryant SE, Marcus DA, Rains JC, Penzien DB: Neuropsychology of migraine: Present status and future directions. **Expert Rev Neurother** 5:363–370, 2005.
26. Patel AV, Mihalik JP, Notebaert AJ, Guskiewicz KM, Prentice WE: Neuropsychological performance, postural stability, and symptoms after dehydration. **J Athl Train** 42:66–75, 2007.
27. Peterson CL, Ferrara MS, Mrazik M, Piland S, Elliott R: Evaluation of neuropsychological domain scores and postural stability following cerebral concussion in sports. **Clin J Sport Med** 13:230–237, 2003.
28. Register-Mihalik J, Guskiewicz KM, Mann JD, Shields EW: The effects of headache on clinical measures of neurocognitive function. **Clin J Sport Med** 17:282–288, 2007.
29. Riemann BL, Guskiewicz KM: Effects of mild head injury on postural stability as measured through clinical balance testing. **J Athl Train** 35:19–25, 2000.
30. Rossi C, Alberti A, Sarchielli P, Mazzotta G, Capocchi G, Faralli M, Ricci G, Molini E, Altissimi G: Balance disorders in headache patients: Evaluation by computerized static stabilometry. **Acta Neurol Scand** 111:407–413, 2005.
31. Rubin AM, Woolley SM, Dailey VM, Goebel JA: Postural stability following mild head or whiplash injuries. **Am J Otol** 16:216–221, 1995.
32. Savundra PA, Carroll JD, Davies RA, Luxon LM: Migraine-associated vertigo. **Cephalalgia** 17:487, 505–510, 1997.
33. Solomon S: John Graham Senior Clinicians Award Lecture. Posttraumatic migraine. **Headache** 38:772–778, 1998.
34. Tang PF, Moore S, Woollacott MH: Correlation between two clinical balance measures in older adults: Functional mobility and sensory organization test. **J Gerontol A Biol Sci Med Sci** 53:M140–M146, 1998.
35. Toglia JU, Thomas D, Kuritzky A: Common migraine and vestibular function: Electronystagmographic study and pathogenesis. **Ann Otol Rhinol Laryngol** 90:267–271, 1981.
36. Tsushima WT, Tsushima VG: Relation between headaches and neuropsychological functioning among head injury patients. **Headache** 33:139–142, 1993.

COMMENTS

This article reports a retrospective analysis of 108 concussed collegiate athletes' baseline and postinjury balance performance using the Sensory Organization Test. Register-Mihalik et al. compare balance deficits in those reporting versus those not reporting symptoms of posttraumatic headache (PTH). The finding that balance deficits are significantly worse in concussed patients with coexisting PTH than in concussed patients without PTH is important for neurosurgeons and others involved in decisions on return to play. It suggests that the presence of PTH, which can be readily assessed, may serve as a marker for concomitant balance deficits.

Register-Mihalik et al. have provided a detailed description of the numerous issues involved with the maintenance of postural stability and how they can be affected after mild traumatic brain injury (MTBI). The role of the vestibular system in symptomatology and our prior belief that it can be primarily involved in concussive head injury is borne out by these observations in athletes. In addition, in experimental models, we know that, clinically and pathologically, both axonal and neuronal injury in MTBI can be expressed in the brainstem. Undoubtedly, the clinical expression of symptoms after MTBI in athletes is complex and multifactorial. However, this research sheds light on the interaction of these several systems that contribute to reversible neurocognitive impairment after MTBI, which may become repetitive, especially in athletes.

Despite its potential clinical utility, the underlying pathophysiological basis of this association is not well understood, and many questions remain. Preconcussion risk factors are likely to be contributory and should be investigated. In addition, the role of PTH severity needs to be elucidated. Register-Mihalik et al. focused on the symptoms and signs during the first 3 days after injury. Further description of the temporal dynamics of the relationship between PTH and balance would be useful. Ultimately, it will be important to determine whether PTH itself is disruptive to visual, vestibular, and/or somatosensory pathways or whether PTH serves as a marker of some other etiological factor. In the meantime, the authors have made an important contribution to the clinical evaluation of concussed athletes.

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In this provocative study, Register-Mihalik et al. evaluated the relationship between postinjury headache and balance. They believe that, as for headache and cognition, a relationship exists with balance that may dictate decision making on return to play. As they note, there are significant limitations with this work, including a lack of detail related to headache character, past headache history if any, other potentially related symptoms (i.e., visual symptoms), and a large variance in the collected data. They postulate a number of physiological mechanisms that might correlate headache with balance dysfunction, including cervical musculature pain. However, these are speculative correlations only. Perhaps the main value of this report is to provide the impetus for additional, more detailed studies of the relationship between described postinjury symptoms and balance.

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Headache after concussion is a pervasive symptom and can present confusing scenarios to the clinician who is often faced with making difficult return-to-play decisions. Although our current knowledge regarding postconcussion headache is limited, prior studies have demonstrated a neurocognitive component that can be measured with careful neuropsychological evaluation. In this study, Register-Mihalik et al. add to our understanding of PTH and rightly espouse a multifaceted evaluation of the concussed athlete. I am hopeful that these researchers will continue this line of investigation in the future.

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Register-Mihalik et al. evaluated how headache after concussion influenced balance. This study is important because of its originality and also because it further validates the importance of including balance testing in the battery of baseline and postconcussive injury testing in athletes. Balance information is very helpful in communicating with both the athlete and the coaching staff when one has to explain why that athlete should not participate in their sport. It is a

physical sign and symptom that can be measured and presented with other symptoms such as headache, "feeling in a fog," feeling tired, difficulty concentrating, and so on. Balance testing is an excellent complement to computerized neuropsychometric testing, and standard assessment of Concussion and Post Concussion Symptom Scale information. We use the Balance Error Scoring System at our institution and find the information quite valuable.

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Overall this study describes deficits in standardized balance assessments in patients experiencing headache as a postconcussive symptom. This is an important finding because it relates a readily available clinical parameter (subjective report of postconcussive headache) to an objective physiological measure (the Sensory Organization Test). The interpretation does not overreach the data, and the conclusions of the study have potential significance. One of the strengths of the study is the capacity for within-subject analyses when results from baseline and postinjury symptoms and balance testing are compared. Given the concern in the literature for athletes minimizing or underreporting symptoms after concussion, it would be interesting to look at the subset of individuals not reporting postconcussive headache but showing evidence of impairments on the Sensory Organization Test and/or the correlation between deficits in sensory organization and neuropsychological impairments. Furthermore, recent studies have raised the possibility of reversible white matter dysfunction as a mechanism of underlying neurological impairment after concussion. Wilde et al. (2) reported increased fractional anisotropy in the corpus callosum that correlated with postconcussive symptoms. One may speculate that integration of multiple sensory/postural stimuli may be dependent on normal connectivity between different brain structures that modulate sensation/posture. Vagnozzi et al. (1) showed evidence of neurometabolic dysfunction (reduced *N*-acetylaspartate) using magnetic resonance spectroscopy with a voxel at the frontal gray-white matter junction that recovers over time, but recovery is prolonged if a second concussion is sustained before resolution of the initial neurometabolic deficit. Future areas for investigation could include within-subject administration of the Sensory Organization Test, standardized symptom checklists, and noninvasive neuroimaging measures of functional connectivity.

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1. Vagnozzi R, Signoretti S, Tavazzi B, Floris R, Ludovici A, Marziali S, Tarascio G, Amorini AM, Di Pietro V, Delfini T, Lazzarino G: Temporal window of metabolic brain vulnerability to concussion: A pilot ^{1}H-magnetic resonance spectroscopic study in concussed athletes. **Neurosurgery** (in press).
2. Wilde EA, McCauley SR, Hunter JV, Bigler ED, Chu Z, Wang ZJ, Hanten GR, Troyanskaya M, Yallampalli R, Li X, Chia J, Levin HS: Diffusion tensor imaging of acute mild traumatic brain injury in adolescents. **Neurology** 70:948–955, 2008.

IN-TRAINING LIAISONS

The Congress of Neurological Surgeons exists for the purpose of promoting public welfare through the advancement of neurosurgery by a commitment to excellence in education and by a dedication to research and scientific knowledge.

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Inherent in this commitment is a critical charge to serve the needs of the in-training individuals. Considering the importance of this vital group within the neurosurgical community, the Journal has established a position within its board structure termed In-training Liaison. The individuals holding this position will act as spokespersons especially addressing the needs and concerns of individuals in in-training positions globally, as they relate to journal content and perspective.

The current individuals holding this position are:
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