Which On-Field Signs/Symptoms Predict Protracted Recovery From Sport-Related Concussion Among High School Football Players?

Brian C. Lau,*† MD, Anthony P. Kontos,‡ PhD, Michael W. Collins,‡ PhD, Anne Mucha,§ PT, and Mark R. Lovell,‡ PhD

Investigation performed at University of Pittsburgh Medical Center, Center for Sports Medicine, Pittsburgh, Pennsylvania

Background: There has been increasing attention and understanding of sport-related concussions. Recent studies show that neurocognitive testing and symptom clusters may predict protracted recovery in concussed athletes. On-field signs and symptoms have not been examined empirically as possible predictors of protracted recovery.

Purpose: This study was undertaken to determine which on-field signs and symptoms were predictive of a protracted (≥21 days) versus rapid (≤7 days) recovery after a sports-related concussion. On-field signs and symptoms included confusion, loss of consciousness, posttraumatic amnesia, retrograde amnesia, imbalance, dizziness, visual problems, personality changes, fatigue, sensitivity to light/noise, numbness, and vomiting.

Study Design: Cohort study (prognosis); Level of evidence, 2.

Methods: The sample included 107 male high school football athletes who completed computerized neurocognitive testing within an average 2.4 days after injury, and who were followed until returned to play as determined by neuropsychologists using international clinical concussion management guidelines. Athletes were then grouped into rapid (≤7 days, n = 62) or protracted (≥21 days, n = 36) recovery time groups. The presence of on-field signs and symptoms was determined at the time of injury by trained sports medicine professionals (ie, ATC [certified athletic trainer], team physician). A series of odds ratios with χ^2 analyses and subsequent logistic regression were used to determine which on-field signs and symptoms were associated with an increased risk for a protracted recovery.

Results: Dizziness at the time of injury was associated with a 6.34 odds ratio (95% confidence interval = 1.34-29.91, χ^2 = 5.44, *P* = .02) of a protracted recovery from concussion. Surprisingly, the remaining on-field signs and symptoms were not associated with an increased risk of protracted recovery in the current study.

Conclusion: Assessment of on-field dizziness may help identify high school athletes at risk for a protracted recovery. Such information will improve prognostic information and allow clinicians to manage and treat concussion more effectively in these at-risk athletes.

Keywords: concussion; mild traumatic brain injury (mTBI); signs/symptoms; neurocognitive testing; recovery time; prognosis

Researchers estimate that each year approximately 3.2 million concussions occur in the United States, with 136 000 in high school–aged individuals alone.[32] Estimates of the length of recovery after a concussion vary widely, from a few days to several weeks.[7,9,10,18,28,33] A prospective, observational study on recovery times after a sport-related concussion in high school athletes showed that 50% of athletes at 1 week and 83% at 3 weeks had recovered and returned to play, leaving 17% with protracted recovery times lasting greater than 3 weeks.[7] Recently, researchers have attempted to identify predictors of athletes who will have a protracted recovery.[15,22,23] This type of prognostic information is important because it allows clinicians to be more confident in management decisions regarding return to play and, in the case of the student athlete,

*Address correspondence to Brian C. Lau, MD, 337 Spahr Street, Apt 2, Pittsburgh, PA 15232 (e-mail: blau10@gmail.com).

†University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania.

‡University of Pittsburgh Medical Center, Department of Orthopaedic Surgery, Sports Medicine Concussion Program, Pittsburgh, Pennsylvania.

§University of Pittsburgh Medical Center, Centers for Rehab Services, Pittsburgh, Pennsylvania.

One or more of the authors has declared the following potential conflict of interest or source of funding: Drs Lovell and Collins are codevelopers of the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) software used in this study and are co-owners of ImPACT Applications, the company that distributes the ImPACT program. As such, they have a financial interest in the company.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546511410655

appropriate return to the classroom. Moreover, concrete information on predictors and risk factors for protracted recovery after a concussion may assist in developing focused treatments to expedite recovery time. Several factors, including poorer performance on neurocognitive reaction time and visual memory and the presence of migraine/somatic (eg, headache, dizziness) cluster symptoms subacutely (2-3 days after injury), have been reported as potential predictors of a protracted recovery.[15,22,23] Surprisingly, on-field signs and symptoms at the time of injury have not been studied as possible predictors of prognosis (ie, recovery time) after a sports-related concussion.

On-Field Signs and Symptoms

On-field signs and symptoms have been used by researchers to identify high school and collegiate athletes with poorer presentation at initial follow-up.[6] Patients were placed into 2 groups based on presentation at follow-up within 5 days of injury as good or poor presentation. Poor presentation was defined as a decline in memory of 10 or more points on computerized neuropsychological tests along with at least a 10-point increase on the Post-Concussion Symptom Scale (PCSS). Analysis revealed that athletes with poor presentation at 2 to 3 days after injury were 10 times more likely to experience retrograde amnesia and 4 times more likely to experience posttraumatic amnesia (PTA).[6] The researchers, however, did not examine the effects of on-field signs and symptoms on athletes' recovery times after concussion.

Traditionally, on-field loss of consciousness (LOC) played a major role in the on-field assessment and management of concussion[23]; however, researchers have questioned its importance in the diagnosis and prognosis of concussion.[24,26,31] As such, researchers turned to other measures such as retrograde amnesia and PTA to assess concussion.[6] Researchers reported that the presence of both retrograde amnesia and PTA was useful in diagnosing concussion.[6] More recently, researchers have focused on imbalance and dizziness in relation to concussion outcomes.[12,34,36,38]

Traditionally, balance involves the interplay of 3 distinct central nervous systems: visual, proprioceptive (somatosensory), and vestibular.[29] Impairment in any 1 of these systems may lead to imbalance. Balance is typically assessed by clinicians using practical, observational rating tests such as Romberg test,[21] tandem walking, and heel-to-toe testing and the Balance Error Scoring System (BESS)[38] or Clinical Tests of Sensory Interaction and Balance (CTSIB).[5] Balance can also be measured using more accurate, but less practical, biomechanics assessments involving accelerometers, force plates, and video analyses.[12,34] In contrast, dizziness is a self-reported symptom that may involve vertigo (ie, illusion of movement), presyncopal lightheadedness (ie, feeling of impending faint), or psychophysiologic symptoms (eg, space phobia).[29] Researchers utilizing the BESS and biomechanical force-plate testing report that imbalance after a concussion resolves within 3 to 7 days after injury.[12,34,36] A study of mild traumatic brain injury (mTBI) identified dizziness along with headache as the most common and persistent complaints after injury.[42] In summary, several on-field signs and symptoms are present during the diagnosis and recovery from a concussion (eg, LOC, retrograde amnesia, PTA, balance, and dizziness) but their effectiveness as markers of protracted recovery from a sport-related concussion have yet to be examined.

Purpose of the Study

The purpose of this study was to examine, using a series of univariate nonparametric tests (ie, χ^2 with odds ratios [ORs]), which on-field signs and symptoms were associated with an increased risk of a protracted recovery after a sport-related concussion in high school athletes. The factors associated with protracted recovery identified in these initial analyses were then examined using a subsequent logistic regression (LR) to determine which among the factors were most predictive of protracted recovery. The on-field signs and symptoms included the following: confusion, headache, LOC, PTA, retrograde amnesia, imbalance, dizziness, visual problems, personality changes, fatigue, sensitivity to light/noise, numbness, and vomiting. On the basis of previous research,[6] we hypothesized that the presence of on-field retrograde amnesia, PTA, and dizziness[42] would predict protracted recovery from concussion. Recent reports that the presence of LOC has a limited role in concussion[26] and recovery of balance typically occurs within 3 to 7 days[12,34,36] led us to hypothesize that LOC and imbalance would not predict protracted recovery from concussion.

METHODS

Design

The study involved a 5-year prospective cohort design. The independent variables were on-field signs and symptoms including confusion, headache, LOC, PTA, retrograde amnesia, balance problems, dizziness, visual problems, personality changes, fatigue, sensitivity to light/noise, numbness, and vomiting. The dependent variable was recovery time to return to play (RTP).

Participants

The participants consisted of male high school football players from the state of Pennsylvania who incurred a sport-related concussion during the preseason or regular season between 2002 and 2006. All athletes participated in the Pennsylvania Interscholastic Athletic Association, which strictly enforces all their rules regarding the number of preseason practices, scrimmages, and games each team may undertake every season. Preseason games begin 2 weeks before regular season play and 1 scrimmage is permitted at the end of each preseason week. During the preseason, each team typically has 3 practices per day. Teams are allowed 3 contact practices per week during the regular

TABLE 1
Participant Demographics[a]

	Total Sample (N = 107)	Rapid Recovery (≤7 Days, N = 62)	Protracted Recovery (≥21 Days, N = 36)
Mean age, y	16.02 (SD = 1.22)	16.01 (SD = 1.27)	15.83 (SD = 1.38)
Mean days to recovery	13.26 (SD = 9.05)	4.31 (SD = 1.74)	29.61 (SD = 6.65)
Mean days evaluation	2.24 (SD = 1.93)	2.11 (SD = 1.46)	2.94 (SD = 2.88)
Previous concussion	29 (27.1%)	16 (25.8%)	11 (30.56%)
History of headache	11 (10.3%)	5 (8.06%)	6 (16.67%)
History of migraine	11 (10.3%)	3 (4.84%)	3 (8.33%)
History of ADHD	4 (3.74%)	0 (0%)	3 (8.33%)
History of any learning disorder	2 (1.87%)	2 (3.23%)	0 (0%)

[a]Percentages represent the percentage with each group (total, rapid, or protracted). Previous concussion refers to patients with a history of at least 1 prior concussion; 29 athletes had at least 1 prior concussion, of whom 16 reported only 1 previous concussion and 13 reported 2 or more. SD, standard deviation; ADHD, attention deficit hyperactivity disorder.

season. All teams play a total of 9 regular season games (11 total games in preseason and regular season). This study only included athletes who had suffered concussions during preseason and regular season football activity, practices, and games and did not include athletes who were injured in postseason playoffs. Under agreement with each school's athletic trainer, all athletes regardless of perceived severity were referred to the sports concussion program and not permitted to RTP unless cleared by specialists.

The players ranged in age from 13 to 19 years with an average age of 16.02 years (standard deviation [SD] = 1.22 years). Inclusion criteria for the study were: (1) diagnosed concussion by trained medical personnel (ie, athletic trainers, team physician); (2) documented, observed on-field signs and symptoms by trained sports medicine staff at the time of injury; and (3) evaluation and follow-up by clinical members of the research team until RTP. Exclusion criteria included current or history of the following: (1) brain surgery, (2) substance abuse, or (3) other neurologic disorder (seizures, meningitis, psychiatric diagnosis, alcohol abuse). Additionally, patients were excluded from the sample if they were not cleared to RTP, lost to follow-up, or did not return to football before the end of data collection (the end of 2006 regular season).

During the course of the study, 176 athletes suffered concussions and were consented and followed. A total of 69 athletes did not RTP, were lost to follow-up, or did not return to football before end of data collection and were excluded. Unfortunately, the individual reason for this level of exclusion was not recorded. Among the remaining 107 potential participants, a total of 62 athletes met criteria for rapid (≤7 days) and 36 for protracted (≥21 days) recovery, for a total sample of 98. Nine participants fell between 7 and 21 days. A summary of participant characteristics is presented in Table 1.

Measures

Concussion. A concussion was defined as a complex pathophysiologic process affecting the brain, induced by direct or indirect traumatic biomechanical forces.[31] In practice, athletes were diagnosed with a concussion by a member of the team's sports medicine staff (ie, athletic trainer, team physician) who was present at the time of injury. The basis for initial diagnosis of concussion was on-field presentation of 1 or more of the following signs and symptoms after a direct or indirect impact to the head: (1) confusion, (2) headache, (3) LOC, (4) PTA, (5) retrograde amnesia, (6) balance problems, (7) dizziness, (8) visual problems, (9) personality changes, (10) fatigue, (11) sensitivity to light/noise, (12) numbness, and (13) vomiting.

On-Field Signs and Symptoms. On-field signs and symptoms of concussion were observed and recorded at the time of injury by members of the sports medicine staff (ie, athletic trainer, team physician). Before the study, the researchers trained the sports medicine staffs of each participating institution to identify the presence of the on-field signs and symptoms described above. Balance was tested through Romberg, tandem walking, and heel-to-toe testing. Dizziness was assessed through direct questioning and self-report by the athlete.

Neurocognitive Performance and Symptom Reports. The Immediate Post-concussion Assessment and Cognitive Test (ImPACT), which includes the 22-item PCSS, was used to assess postinjury neurocognitive performance on 4 composite scores (verbal and visual memory, motor processing speed, and reaction time) and total concussion symptoms and to inform subsequent RTP decisions. The validity and reliability of the ImPACT test have been reported.[‖]

Determination of Recovery Time and RTP. Recovery time was defined as the period between day of injury and clearance to RTP. Return to play was determined by resolution of symptoms and return of preinjury cognitive function under the care of clinical neuropsychologists who specialize in sport-related concussion using established international consensus protocols.[2,30,31] After RTP was determined, neuropsychologists communicated findings to team personnel, athletic trainers, physicians, and coaches.

[‖]References 16-18, 22, 25, 27, 33, 35, 37, 41.

Participants were returned to play (ie, recovered) when they met the following 4 criteria:

1. Athletes had to be asymptomatic at both rest and after exertion protocols.[2,30,31] Graded exertional protocol requires athletes to be symptom-free at rest and with progressively more strenuous activity (ie, walking, jogging, wind sprints). All physical exertion was monitored by sports medicine staff, and athletes were not returned to play until they were evaluated by clinical staff and met the RTP criteria at both rest and after physical exertion.
2. The athlete's total score on the PCSS[27] was less than 7. The 22 symptoms within the PCSS are not specific to concussion, and athletes may report symptoms at the time of baseline. Iverson et al[17] reported that the mean PCSS score for noninjured high school males was 5.8 despite never having suffered a concussion and that 76% scored 6 or less, with a large portion scoring 0 (40.5%). Therefore a threshold of 7 was used for this study. Regardless of their PCSS score, no athlete was returned to play if they were experiencing any symptoms or dysfunction that was attributable to their injury.
3. The athlete must not have had 2 ImPACT neurocognitive composite scores that were statistically lower (ie, reliable change estimate) than their baseline performance or age-normative data.[17] The study by Iverson et al[17] showed that uninjured athletes with 1 neurocognitive composite score below baseline were not uncommon, but only 3.6% of uninjured athletes had 2 scores below baseline. Reliable change estimates were based on Iverson's observations for significance at 80% confidence intervals: 9 points for verbal memory composite, 14 points for visual memory composite, 0.06 seconds for the reaction time composite, and 3 points for the processing speed composite.[17]
4. Lastly, all of the athlete's neurocognitive composite scores must have been above the tenth percentile for his age, which broadly represents the normal range. The only exception was if a patient's baseline before was below the tenth percentile. It is important to note that the majority (84%) of the total sample completed baseline neurocognitive testing, with 79.31% and 83.87% of the rapid and protracted groups, respectively. If baseline testing was not available, participants were compared with published age-matched normative data.

Based on the above criteria, athletes were grouped into rapid ($\leq$7 days, n = 58) or protracted recovery ($\geq$21 days, n = 31) groups. The mean recovery time in days for the rapid and protracted groups was 4.31 (SD = 1.74) and 29.61 (SD = 6.65) after correction for outliers, respectively.

Procedures

The university's Institutional Research Board approved the current study's protocol. The researchers then obtained written informed parental consent and participant assent from the participants. During the course of the study, concussed athletes were identified by members of each team's sports medicine staff. The sports medicine staff also assessed and recorded the presence of the on-field signs and symptoms at the time of injury. Concussed athletes were then referred to a team of clinical neuropsychologists specializing in sport-related concussion management. All athletes at participating schools during the time frame of this study were referred to concussion specialists from a single group throughout recovery regardless of perceived "severity." All athletes required clearance from the team of clinical neuropsychologists based on the recovery criteria discussed earlier to RTP. After clearance to RTP, decisions were communicated to team personnel to use this information. Thus, players were highly motivated to follow up. Participants completed the postconcussion ImPACT test and symptom report on average 2.4 days (SD = 2.12) after an injury. The rapid and protracted recovery were tested on average 2.11 (SD = 1.46) and 2.94 (SD = 2.88) days after injury, respectively. Athletes were deemed "recovered" when they met all RTP guidelines as described above. After RTP, athletes were grouped into rapid ($\leq$7 days) and protracted ($\geq$21 days) recovery based on time from injury until clearance to RTP. Although this method did not include the full range of recovery times, we chose to use 7 days and 21 days because we believed it would provide a clearer picture of specific predictors of the extremes of recovery.

Statistical Analysis

Descriptive data were used to describe the prevalence of each sign and symptom at time of injury. Fisher exact tests were conducted to assess differences between rapid and protracted recovery groups on potential confounding variables including preinjury history of migraine, headache, attention deficit disorder/attention deficit hyperactivity disorder (ADD/ADHD), learning disorder, and at least 1 previous concussion. A series of ORs with χ^2 analyses were used to identify which on-field signs/symptoms associated with a protracted recovery from concussion. The factors associated with protracted recovery using an exploratory $P < .20$ level identified in the initial OR analyses were then examined using a subsequent LR to determine which among the identified factors were predictive of protracted recovery. Statistical significance for all analyses was set at $P < .05$. Statistical Package for the Social Sciences (SPSS) version 18.0 (SPSS Inc, Chicago, Illinois) was used for all analyses conducted for this study.

RESULTS

The most common sign or symptom observed at the time of injury was headache (94.9%, n = 93). The least common sign or symptom was LOC, with only 13.3% (n = 13) reporting this symptom. A summary of total frequencies and frequencies for the protracted and rapid recovery groups for each sign and symptom is provided in Table 2.

The results of the Fisher exact test indicate no significant differences between protracted and rapid recovery

TABLE 2
Frequencies of On-Field Sign/Symptoms and as Predictors of Protracted Recovery[a]

On-Field Sign/Symptom	N	Rapid Recovery	Protracted Recovery	χ^2	*P*	Odds Ratio	95% Confidence Interval
Dizziness[b]	87	45	34	6.97	.01	6.42	1.39-29.7
Headache	100	58	35	0.64	.43	2.41	0.26-22.47
Posttraumatic amnesia	36	14	11	1.29	.26	1.72	0.67-4.42
Sensitivity light/noise	53	24	18	1.19	.28	1.58	0.70-3.63
Visual problems	60	25	35	0.62	.43	1.40	0.61-3.2
Retrograde amnesia	29	15	10	0.12	.73	1.18	0.46-3.00
Confusion	71	41	25	0.11	.74	1.16	0.48-2.82
Fatigue	66	31	19	0.04	.85	1.08	0.48-2.47
Balance problems	55	31	16	0.28	.60	0.80	0.35-1.83
Personality changes	26	17	7	0.86	.35	0.63	0.23-1.6
Vomiting[b]	15	11	2	2.73	.10	0.28	0.06-1.37
Numbness	20	15	5	1.34	.25	0.52	0.17-1.59
Loss of consciousness[b]	13	11	2	2.73	.10	0.28	0.06-1.37

[a]The total number of participants in rapid and protracted groups was 107. The N column represents the number of patients among the total sample (107) for whom the corresponding sign/symptom was present. Rapid (n = 62) and protracted (n = 36) columns represent the number of participants in each group to present with the corresponding sign/symptom. Markers of injury are not mutually exclusive.
[b]Statistically fit exploratory $P < .2$ for further evaluation in logistic regression.

groups on preinjury history of headache ($P = .20$), migraine ($P = .66$), ADD/ADHD ($P = .47$), learning disability ($P = .53$), and at least 1 previous concussion ($P = .64$). The results of a series of ORs for the risk of a protracted recovery associated with the presence of on-field specific signs and symptoms supported only 1 significant relationship. Athletes with dizziness at time of injury were (OR = 6.4, 95% confidence interval [CI] = 1.39-29.70, $\chi^2 = 6.97$, $P = .01$) more likely to experience a protracted recovery than those with no dizziness. Surprisingly, PTA (OR = 1.72, 95% CI = 0.67-4.42, $\chi^2 = 1.29$, $P = .26$), retrograde amnesia (OR = 1.18, 95% CI = 0.46-3.00, $\chi^2 = 0.12$, $P = .73$), and imbalance (OR = 0.28, 95% CI= 0.35-1.83, $\chi^2 = 0.60$, $P = 0.80$) were not significant risk factors for protracted recovery. A summary of the ORs is presented in Table 2. Based on the results of the ORs, we identified on-field signs/symptoms that were associated with protracted recovery at an exploratory $P < .20$ level but that were not covariant with each other for inclusion in a subsequent direct LR. Using these criteria, we identified 3 variables—dizziness, LOC, and vomiting—to be included in the LR. The results of the direct LR model with the 3 predictors was significant χ^2 (3, 94) = 11.77, $P = .008$, indicating that the predictors reliably distinguished between rapid and protracted recovery groups. The variance in recovery time accounted for by the 3-factor model was low, with Nagelkerke $R^2 = .16$. Table 3 depicts the regression coefficients, Wald statistics, ORs, and 95% CIs for each of the predictors from the model. As is evident in Table 3, only dizziness was a significant ($P = .02$) predictor of recovery time.

TABLE 3
Summary of the Results of the Logistic Regression for Dizziness, Loss of Consciousness, and Vomiting on Recovery From Concussion

					95% CI for OR	
Variables	β	Wald χ^2	OR	*P*	Lower	Upper
Dizziness	1.85	5.44	6.34	.02	1.34	29.91
LOC	−1.31	2.53	0.27	.11	0.54	1.35
Vomiting	−0.86	1.45	0.42	.23	0.10	1.72

[a]CI, confidence interval; OR, odds ratio; LOC, loss of consciousness.

DISCUSSION

Summary of Results

The current study explored on-field signs and symptoms as predictors for a protracted (≥21 days) versus a rapid (≤7 days) recovery in concussed high school football student-athletes followed until full recovery and RTP. Return to play was defined as resolution of symptoms under international graded exertional protocol and return of cognitive functioning with ImPACT testing. The findings in the current study indicated that on-field dizziness was associated with an OR of 6.34× increased risk of a protracted recovery. It should be noted that mean days to recovery for rapid and protracted groups were 4.31 and 29.61, respectively. The remainder of the on-field signs and symptoms (confusion, LOC, PTA, retrograde amnesia, imbalance, visual problems, personality changes, sensitivity to light/noise, numbness, or vomiting) were not significant predictors of protracted recovery in the current study. Given the current findings, the role of dizziness in prognosis for concussion is discussed in the following sections.

Dizziness as an Onfield Predictor of Protracted Recovery. The significance of dizziness as a sign or symptom of concussion has been reported previously by researchers.[3,14,39,40] In 1 study, researchers reported a 17.5% prevalence of dizziness during emergency room evaluation among mTBI patients.[8] A similarly designed study also showed that dizziness adversely affected Glasgow Outcome Scale-Extended (GOSE; a measure of patients' social activities and family relationships) at 1, 2, 4, and 8 weeks after mTBI.[42] Chamelian and Feinstein[4] reported that dizziness in adults (mean age, 33.6 years) was an independent predictor of failure to return to work at 6 months after mTBI. The finding in the current study lends further support to the importance of dizziness as a predictor of recovery time and may be the first to do so in sport-related concussion. In addition, the prevalence of dizziness in the current study was higher than previously reported with 81.3% (n = 87) of all concussed high school athletes, and 94.4% (n = 34) of the protracted recovery group reporting on-field dizziness.

Dizziness Versus Balance. Dizziness and balance are often linked together as subjective and objective impairments of similar nervous system functioning, respectively. The result of the current study, however, suggested that dizziness and balance did not predict recovery in a similar fashion. In fact, dizziness was the only significant risk factor for protracted recovery (OR = 6.34; P =.02), whereas balance was not a significant risk factor. This finding highlights the importance of assessing dizziness separately from balance at the time of injury to inform prognostic outcome after concussion.

As mentioned earlier, dizziness can be the result of multiple organic reasons including disturbances in vestibular (ie, vertigo), visual, or cardiovascular (ie, syncope) systems.[29] The athletes in the current study did not complete objective balance, vestibular, visual, or cardiovascular testing at the time of injury. As such, the role of these individual systems in the dizziness reported by the participants in the current study is unknown. Moreover, the subjectively reported imbalance in the current study may not reflect the results obtained if objective balance assessments were used. On-field objective tests that directly assess dizziness and the involved components of each system are warranted to determine the cause of dizziness after concussion.

At present there is no consensus measure of dizziness. Dizziness is typically measured using postural/balance testing, self-report dizziness questionnaires, or both.[29] The finding in the current study suggested that only dizziness, and not imbalance, was a risk factor for protracted recovery. As such, we believe that postural/balance testing and dizziness tests should be looked at individually. It is important to indicate that postural/balance testing should not be used as a proxy for dizziness. Instead, clinicians and researchers should use questionnaires that assess dizziness including the University of California Los Angeles Dizziness Questionnaire (UCLA-DQ),[13] Dizziness Handicap Inventory (DHI),[19] and Dizziness Beliefs Scale (DBS)[43] may be appropriate.[29] Each of these measures has been validated to measure dizziness frequency, intensity, and effect on daily activities and quality of life; self-perceived dizziness-associated disability and handicap; and its ability to predict the degree of handicap for patients with dizziness, respectively.[13,19,20,43,44] Such measures would augment postconcussion assessment in addition to neurocognitive tests, symptom reports, and postural/balance tests. Additionally, follow-up vestibular assessments should be used to further delineate the cause of dizziness and inform subsequent therapy and treatment of this symptom. Finally, a recent finding found that patients who had at least 2 rehabilitation visits for persistent dizziness after a concussion showed improvement in their DHI scores.[1] It is possible that on-field identification of dizziness may lead to earlier implementation of vestibular rehabilitation and other modalities to treat dizziness, which may expedite recovery from concussion.

Imbalance, Amnesia, and LOC. The finding of the current study suggested that imbalance as determined by Romberg, tandem walking, and heel-to-toe testing was not predictive of protracted recovery. This finding is analogous to those reported in recent studies of imbalance after concussion. Researchers utilizing the BESS with concurrent biomechanical force-plate testing reported that imbalance after a concussion resolved within 3 to 7 days after injury.[12,34,36] Similarly, in the current study retrograde amnesia and PTA were also not predictive of protracted recovery from concussion. A possible explanation why imbalance and amnesia were not predictive of protracted recovery is that such deficits may be part of the normal acute response to a concussion and resolve relatively quickly with little lasting effects. It is important to note that in the current study, LOC was not a significant predictor of protracted recovery from concussion. A possible explanation for this finding is that LOC may represent the brain's defensive mechanism to prevent detrimental or lasting consequences by reducing energy demands and brain function at time of injury. Regardless of the underlying reason, in the current study brief LOC had limited utility as an on-field sign/symptom. It is important to note that the current sample did not include athletes with prolonged (>1 minute) LOC. Therefore, the current findings should not be applied to prolonged LOC at time of injury.

Limitations

The current study was limited by several factors. The sample comprised only male high school football players. Therefore, the results cannot be generalized to older athletes, females, or other sports. Although the history of previous concussions were recorded and shown not to be significant between groups, it is possible that these numbers may underrepresent the actual number of athletes with a previous concussion. As such, in this study a history of previous concussion may have an unseen effect on recovery. On-field predictors were assessed and reported by sports medicine staff using brief screening tests and questions with potentially concussed athletes on the sidelines. As such, report bias and other errors in such measures might have affected the results. In this study, participants were assessed for balance using Romberg, tandem walking, and heel-to-toe tests. Postural/balance tests specific for sports-related concussion such as the BESS were not used. The BESS test may be more effective for use with the current population. Further details of sport-specific balance tests may be referenced in a review by Guskiewicz.[11] This was a homogeneous sample of athletes who received clinical on-field, postinjury management, and RTP was based on international clinical protocols including neurocognitive testing and symptom reports. As care was individualized, there were no precise assessment intervals or a specific number of assessments to determine RTP. As a result there was variability in the assessment intervals regarding RTP decisions. Typically, neurocognitive and symptom assessments were conducted within 72 hours after injury, then approximately 1, 2, and 3 weeks after injury, and as needed until RTP. Hence, some patients that were returned to play after 21 days may have actually recovered earlier but did not follow-up until the 21-day testing period. Although all athletes required clearance to RTP by the concussion clinicians before the conclusion of the football season, students who did not return to football or graduated resulted in participant attrition and consequently a portion of the sample was lost to follow-up.

Conclusion and Future Research

The results of the current study support 2 distinct findings. First, the results indicated that the presence of on-field dizziness was a robust predictor for protracted recovery in sport-related concussions. Second, the results suggested that other on-field signs and symptoms were not significant predictors of protracted recovery from concussion. The latter finding should be interpreted cautiously as previous research has supported retrograde amnesia and PTA as predictors of poor concussion outcomes (although not protracted recovery times, per se).[6] Moreover, sensitive balance testing (eg, BESS,[36] CTSIB[5]) for sport-related concussion was not used in this study, and therefore the findings regarding imbalance must also be interpreted cautiously. Nonetheless, if additional, prospective studies confirm our finding that dizziness may indicate protracted recovery, it would indicate the need for direct assessment of dizziness at time of injury to inform both prognosis and potential therapies to enhance recovery. As such, we believe that clinicians and researchers should consider using separate, specific tests for dizziness (eg, DHI), in addition to traditional postural/balance tests (eg, BESS, CTSIB) in future studies, rather than relying on postural/balance tests as indicators of dizziness.

REFERENCES

1. Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther*. 2010;34(2):87-93.
2. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. *Br J Sports Med*. 2002;36:6-10.
3. Binder LM. A review of mild head trauma, part II: clinical implication. *J Clin Exp Neuropsychol*. 1997;19:432-457.
4. Chamelian L, Feinstein A. Outcome after mild to moderate traumatic brain innjury: the role of dizziness. *Arch Phys Med Rehabil*. 2004;85:1662-1666.
5. Cohen H, Blatchly CA, Gombash LL. A study of the Clinical Test of Sensory Interaction and Balance. *Phys Ther*. 1993;73:346-351.
6. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sports Med*. 2003;13(4):222-229.
7. Collins MW, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: at three-year prospective cohort study. *Neurosurgery*. 2006;58(2):275-286.
8. De Kruijk JR, Leffers P, Menheere PP, Meerhoff S, Rutten J, Twijnstra A. Prediction of post-traumatic complaints after mild traumatic brain injury: early symptoms and biochemical markers. *J Neurol Neurosurg Psychiatry*. 2002;73(6):727-732.
9. Erlanger D, Saliba E, Barth J, Almquist J, Webright W, Freeman J. Monitoring resolution of postconcussion symptoms in athletes: preliminary results of a web-based neuropsychological test protocol. *J Athl Train*. 2001;36:280-287.
10. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;142:546-553.
11. Guskiewicz KM. Balance assessment in the management of sport-related concussion. *Clin Sports Med*. 2011;30(1):89-102.
12. Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athl Train*. 2001;36:263-273.
13. Honrubia V, Bell TS, Harris MR, Baloh RW, Fisher LM. Quantitative evaluation of dizziness characteristics and impact on quality of life. *Am J Otol*. 1996;17:595-602.
14. Ingebrigtsen T, Waterloo K, Marup-Jensen S, Attner E, Romner B. Quantification of post-concussion symptoms 3 months after minor head injury in 100 consecutive patients. *J Neurol*. 1998;245:609-612.
15. Iverson GL. Predicting slow recovery from sport-related concussion: the new simple-complex distinction. *Clin J Sport Med*. 2007;17:31-37.
16. Iverson GL, Brooks BL, Collins MW, Lovell MR. Tracking neuropsychological recovery following concussion in sport. *Brain Inj*. 2006;20(3):245-252.
17. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol*. 2003;17:460-467.
18. Iverson GL, Lovell MR, Collins MW. Validity of ImPACT for measuring processing speed following sports-related concussion. *J Clin Exp Neuropsychol*. 2005;27(6):683-689.
19. Jacobson GP, Newman CW. The development of the dizziness handicap inventory. *Arch Otolaryngol Head Neck Surg*. 1990;116(4):424-427.
20. Kammerlind AS, Larsson PB, Ledin T, Skargren E. Reliability of clinical balance tests and subjective ratings in dizziness and disequilibrium. *Adv Phyiother*. 2005;7:96-107.
21. Lanska DJ, Goetz CG. Romberg's sign: development, adoption and adaptation into the 19th century. *Neurology*. 2000;55:1201-1206.
22. Lau BC, Collins MW, Lovell MR. Sensitivity and specificity of subacute computerized neurocognitive testing and symptom evaluation in predicting outcomes after sports-related concussion. *Am J Sports Med*. 2011 Feb 7 [Epub ahead of print].
23. Lau B, Lovell MR, Collins MW, Pardini J. Neurocognitive and symptom predictors in recovery in high school athletes. *Clin J Sports Med*. 2009;19(3):216-221.
24. Leininger BE, Gramling SE, Farrell AD, Kreutzer JS, Peck EA 3rd. Neuropsychological deficits in symptomatic minor head injury patients after concussion and mild concussion. *J Neurol Neurosurg Psychiatry*. 1990;53:293-296.
25. Lovell MR, Collins MW, Fu F, Burke C, Podell K. Neuropsychological testing in sports: past, present, and future. *Br J Sports Med*. 2001;35:367-372.
26. Lovell MR, Iverson GL, Collins MW, McKeag D, Maroon JC. Does loss of consciousness predict neuropsychological decrements after concussion? *Clin J Sports Med*. 1999;9:193-198.
27. Lovell MR, Iverson GL, Collins MW, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Appl Neuropsychol*. 2006;13(3):166-174.

28. Makdissi M, Darby D, Maruff P, Ugoni A, Brukner P, McCrory PR. Natural history of concussion in sport: markers of severity and implications for management. *Am J Sports Med*. 2010;38(3):464-471.
29. Maskell F, Chiarelli P, Isles R. Dizziness after traumatic brain injury: overview and measurement in the clinical setting. *Brain Inj*. 2006;20:293-305.
30. McCrory P, Johnston K, Meeuwise W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Clin J Sport Med*. 2005;15(2):48-55.
31. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the Third International Conference on Concussion in Sport held in Zurich, November 2008. *Phys Sportsmed*. 2009;37(2):141-159.
32. Meehan WP 3rd, d'Hemecourt P, Comstock RD. High school concussion in the 2008-2009 academic year: mechanism, symptoms, and management. *Am J Sports Med*. 2010;38(12):2405-2409.
33. Pellman EJ, Lovell MR, Viano DC, Casson IR. Concussion in professional football: recovery of NFL and high school athletes assessed by computerized neuropsychological testing, part 12. *Neurosurgery*. 2006;58:263-274.
34. 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*. 2003;13:230-237.
35. Randolph C, McCrea M, Barr WB. Is neuropsychological testing useful in management of sport-related concussion? *J Athl Train*. 2005;30:139-152.
36. Riemann BL, Guskiewicz KM. Effects of mild head injury on postural stability as measured through clinical balance testing. *J Athl Train*. 2000;35:19-25.
37. Schatz P, Pardini J, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT test battery for concussion in athletes. *Arch Clin Neuropsychol*. 2006;21(1):91-99.
38. Slobounov S, Slobounov E, Sebastianelli W, Cao C, Newell K. Differential rate of recovery in athletes after first and second concussion episodes. *Neurosurgery*. 2007;61(2):338-344.
39. Van der Naalt J. Prediction of outcome in mild to moderate head injury: a review. *J Clin Exp Neuropsychol*. 2001;23:837-851.
40. Van der Naalt J, Van Zomeren AH, Sluiter WJ, Minderhoud JM. One year outcome in mild to moderate head injury: the predictive value of acute injury characteristics related to complaints and return to work. *J Neurol Neurosurg Psychiatry*. 1999;66:207-213.
41. Van Kampen DA, Lovell MR, Pardini JE, Collins MW, Fu FH. The ''value-added'' of neurocognitive testing after sports-related concussion. *Am J Sports Med*. 2006;34(10):1630-1635.
42. Yang CC, Tu YK, Hua MS, Huang SJ. The association between post-concussion symptoms and clinical outcomes for patients with mild traumatic brain injury. *J Trauma*. 2007;62(3):657-663.
43. Yardley L. Contribution of symptoms and beliefs to handicap in people with vertigo: a longitudinal study. *Br J Clin Psychol*. 1994;33:101-113.
44. Yardley L, Beech S, Weinman J. Influence of beliefs about the consequences of dizziness on handicap in people with dizziness, and the effect of therapy on beliefs. *J Psychosom Res*. 2001;50:1-6.