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A Preliminary Formula to Predict Timing of Symptom Resolution for Collegiate Athletes Diagnosed With Sport Concussion

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Context: Symptom presentation and recovery after sport concussion (SC) are variable. Empirically based models documenting typical symptom duration would assist health care providers in managing return to play after SC.

Objective: To develop a prediction model for SC symptom duration.

Design: Cross-sectional study.

Setting: Two National Collegiate Athletic Association Division I university laboratories.

Patients or Other Participants: Seventy-six (51 male and 25 female) concussed athletes with an average age of 19.5 ± 1.65 years who were evaluated within 24 hours of diagnosis.

Intervention(s): Participants completed the Revised Head Injury Scale (HIS-r), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), and Sensory Organization Test within 24 hours of SC diagnosis.

Main Outcome Measure(s): A stepwise multivariate regression incorporating ImPACT and Sensory Organization Test composites and HIS-r symptom severity-duration was used to predict the number of days athletes reported symptoms after SC. The resulting regression formula was cross-validated using the Stine cross-validation coefficient.

Results: The final formula consisted of the HIS-r's self-reported neck pain, drowsiness, tingling, and nervousness duration and ImPACT total symptom severity ($R = 0.62$, $R^2 = 39\%$, $R^2_{adj} = 34.2\%$, $P < .001$). Approximately 29% ($R^2_{cv} = 29\%$) of the variance associated with total days symptomatic after SC was explained by our preliminary formula when cross-validated. The current formula correctly identified 76% of participants who recovered within 10 days of injury.

Conclusions: Our results suggest that self-reported duration of 4 symptoms during the initial 24 hours after injury along with total symptom severity as measured by ImPACT accounted for a considerable amount of variance associated with days symptomatic after SC in collegiate athletes. Until the formula is cross-validated in a college-aged sample, caution is warranted in using it clinically.

Key Words: traumatic brain injuries, prediction, prolonged recovery, symptom severity, symptom duration

Key Points

- A formula to predict symptom resolution after sport concussion primarily consisting of initial symptom duration and severity correctly identified 76% of National Collegiate Athletic Association Division I collegiate athletes who recovered within 10 days.
- Before it can be used clinically, the formula must be cross-validated on larger samples.

The clinical presentation of and recovery from sport concussion (SC) are variable among athletes. Recovery curves based on animal models suggest the metabolic vulnerability associated with concussion resolves within approximately 7 to 10 days.[1,2] During this period of metabolic dysfunction, athletes experience neurocognitive and motor deficits as well as a constellation of symptoms.[3–5] These sequelae serve as markers that clinicians can measure to track recovery and make informed return-to-play and return-to-learn decisions.[6]

The resolution of motor (eg, postural stability) and neurocognitive (eg, memory, reaction time, information-processing speed) deficits, along with self-reported symptoms (eg, headache, nausea, dizziness), varies based on a number of factors. These factors include age, sex, background history, comorbid conditions, and signs and symptoms reported or observed at the time of injury.[7–12] For example, in terms of age, only 50% of high school athletes (14–18 years of age) were reported to recover from SC in approximately 7 days, whereas 90% of adult athletes ≥18 years of age recovered in 7 days.[8,13–15] Regarding sex differences, Covassin et al[16] observed that female high school athletes may take up to 14 days to recover in terms of memory and processing speed after concussion. In a separate study, Covassin et al[12] noted that concussed high school- and college-aged females consistently demonstrated higher symptom levels than male participants up to 14 days after concussion.

Though the majority of concussion symptoms in older athletes resolve in ≤7 days of injury, approximately 10% of concussed athletes experience persistent symptoms up to 3 months after their diagnosis.[17] Additionally, a subset of patients may experience 3 or more postconcussion symptoms for 3 months or longer, which is classified as *postconcussion syndrome* (PCS). Babcock et al[18] found that 29% of pediatric concussion patients diagnosed in the emergency department for whom sport was the primary mechanism of injury (35%) were later diagnosed with PCS, which equates to 105 000 cases of pediatric PCS annually in the United States. The authors suggested that being able to prospectively identify candidates at risk for PCS would assist clinicians in discharge planning (eg, education, medications, and ongoing follow-up), ultimately resulting in improved patient outcomes.

Studies examining predictors of SC recovery have usually addressed the dichotomy of typical recovery (7–13 days) versus protracted recovery.[3,12] *Protracted recovery* has been defined as resolution of SC lasting longer than 14,[10] 21,[11] 45, or 90 days.[17,19] Several predictors, including loss of consciousness (LOC), posttraumatic amnesia (PTA), retrograde amnesia, total symptom severity, dizziness severity, and headache severity, have been associated with a 1.8- to 6-fold increase in risk for protracted recovery.[11,17,18] Of these predictors, LOC and amnesia are points of debate because of their infrequent occurrence and questionable relationship with injury severity and recovery.[8,11,20]

The objective of our study was to determine if the number of days an athlete reported concussion-related symptoms could be predicted from dependent variables derived from clinical measures commonly used to manage this injury. The ability to determine how many days an athlete will report SC-related symptoms may assist clinicians by allowing identification of athletes at risk for prolonged recoveries and institution of the appropriate medical and psychosocial infrastructure to assist in a full recovery.

METHODS

Participants

Participants consisted of National Collegiate Athletic Association (NCAA) Division 1 collegiate athletes considered to be at high risk for concussion as defined by the NCAA.[21] Data were collected from 2 large metropolitan universities between the 2004 and 2013 sport seasons. Participants were assessed as part of an ongoing study addressing SC. Participants were excluded if English was not their primary language; they had been diagnosed with attention-deficit disorder, attention-deficit/hyperactivity disorder, or learning disability; they had incomplete data for any measure 24 hours after their injury or upon reporting they were asymptomatic; the injury was non-sport related (eg, motor vehicle accident, assault); or they had been previously diagnosed with a psychiatric condition. Consistent with the clinical care procedures related to SC at each institution throughout the data-collection period, *concussion* was defined as "a trauma-induced alteration in mental status that may or may not involve loss of consciousness."[22] Although this definition first appeared in 1997, it is still considered an acceptable and appropriate description for SC and was used consistently throughout the data-collection period.[22,23]

Measures

Immediate Post-Concussion Assessment and Cognitive Testing. Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; versions 2.3.813 to 6.7.723; ImPACT Applications, Inc, Pittsburgh, PA) is a common neurocognitive screening test that measures attention, memory, reaction time, and information-processing speed. The ImPACT consists of 8 tests: immediate and delayed word recall, immediate and delayed design recognition, a symbol-matching test, 3-letter recall, X's and O's test of attention, and a choice reaction-time color-match test. The ImPACT also uses invalidity criteria that assess gross evidence of poor effort during testing, which have been described elsewhere.[24]

Revised Head Injury Scale. The original Revised Head Injury Scale (HIS-r) consisted of 22 symptoms related to concussion,[4] which were later reduced to the 16- and then 9-item inventories described by Piland et al.[4,5] Participants are asked to circle *yes* or *no* if they were or were not, respectively, experiencing the listed symptom during the past 24 hours. If a participant responded *yes* to any symptom, then he or she rated the symptom for duration (1–6) and severity (0–6) using a Likert scale. Specifically, duration ranged from *brief* (eg, ≤15 minutes) to *consistent* (eg, constant during the 24-hour period) and severity ranged from *mild* to *severe*. The duration and severity for each of the HIS-r's 22 items were then summed, for a potential maximum total of 132 for each column. The severity and duration of each symptom as well as the summed total for duration and severity were included in our analyses.

Sensory Organization Test. The NeuroCom Smart Balance Master Sensory Organization Test (SOT; NeuroCom, Clackamas, OR) is a computerized assessment of postural stability. Participants completed 3 trials of 6 conditions (18 total trials) in randomized order to determine a composite balance/equilibrium score. The 6 conditions consisted of having a participant's eyes open or closed while referencing a fixed or sway support surface. Visual, vestibular, somatosensory, and visual conflict ratios were then calculated. These ratios provide information to assist clinicians in interpreting which sensory inputs are used to maintain balance and determining potential sensory conflicts that may exist as a result of SC.[25] A more detailed description of the SOT can be found elsewhere.[25]

Testing Protocol. The current study was approved by both participating universities' institutional review boards. The testing protocol consisted of assessments performed at the preinjury baseline, postinjury, and asymptomatic time points. Baseline testing occurred 2 to 6 weeks before the start of each athlete's sport season. A diagram of the protocol design is shown in the Figure.

Baseline Assessment. Upon providing written consent, participants completed the HIS-r and a health history questionnaire. Next, they completed ImPACT followed by the SOT. The ImPACT was administered to 1 participant at a time on a desktop computer. Each athlete was monitored by a trained examiner to verify that he or she understood the test instructions and to encourage good effort

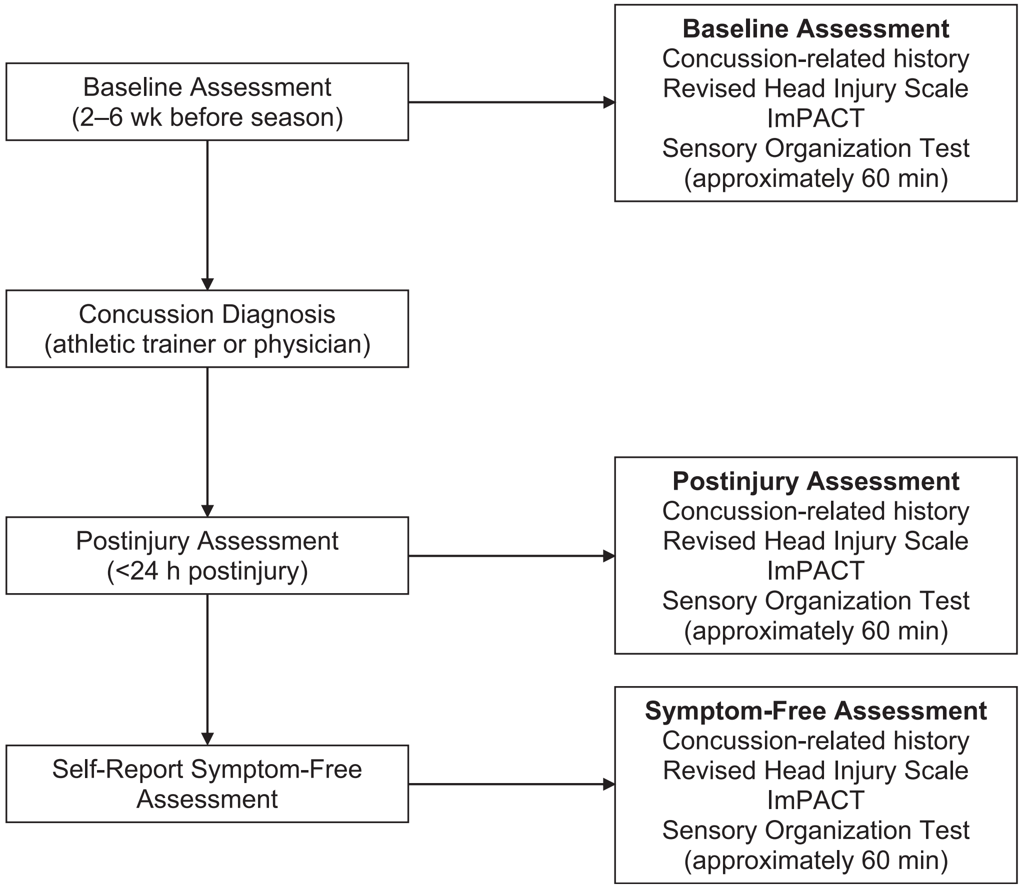

Figure. Protocol design. Abbreviation: ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.

throughout the test. Completion of ImPACT took approximately 25 minutes. The baseline ImPACT assessment was reviewed for validity. Before completing the SOT, each participant was provided instructions to familiarize him or her with the test. Completion of the SOT's 18 trials took approximately 15 minutes. The entire baseline test session took approximately 60 minutes.

Postinjury Assessment. In the event of an SC as diagnosed by either a certified athletic trainer or physician (or both), the participant returned to the sports medicine laboratory within 24 hours of diagnosis. At that time, he or she completed a detailed health history that addressed the injury along with the HIS-r, SOT, and ImPACT.

Asymptomatic Assessment. After the initial postinjury assessment, each participant was administered the HIS-r daily at the same time by his or her certified athletic trainer. Once an athlete indicated that he or she was not experiencing any symptoms listed on the HIS-r, the athlete returned to his or her sports medicine laboratory to complete the assessment battery at the asymptomatic time point.

Statistical Procedures. We used multivariate regression to predict the number of days (dependent variable) an athlete would be symptomatic before symptoms resolved and he or she returned to play. The number of days actually lost was measured from the time of the postinjury assessment to the asymptomatic assessment. The stepwise selection method with entry set at .05 was used to determine which independent variables contributed significantly to the final prediction model. A total of 58 independent variables were assessed as potential predictors of the number of days an athlete would report concussion-related symptoms. The independent variables may be found in Table 1. We did not include LOC and PTA as independent variables based on their low incidence in SC and the related literature, which suggests their limited predictive value.[8,20,26]

Sample size was determined based on the following formula:

$$N = \frac{L}{f^2} + k + 1 \qquad (1)$$

where N equals total sample size and f^2 is effect size; L is the significance criterion based on k predictors and the desired power and is calculated using the formula[27]

$$L = f^2(N - k - 1) \qquad (2)$$

For this study, we calculated sample size based on a large effect size, power equal to 0.80, and 58 predictors. The dependent variable was the number of days an athlete self-reported concussion-related symptoms. A total of 152 participants would be needed to meet these criteria. Our current sample ($N = 76$) accounted for only 50% of what was needed to achieve the desired power and effect size using all 58 independent variables. The final formula consisted of 5 independent variables ($k = 5$) instead of 58, which equated to a power between 0.95 and 0.99.

Table 1. Independent Variables Used in Initial Analysis to Predict the Number of Days an Athlete Reported Concussion-Related Symptoms

Demographics	Revised Head Injury Scale (Severity and Duration 24-h Recall)	ImPACT	Sensory Organization Test
Age	Headache	Verbal memory	Composite score
Sex	Nausea	Visual memory	Somatosensory ratio
No. of prior concussions	Difficulty balancing	Visual motor speed	Visual sensory ratio
	Fatigue		Vestibular sensory ratio
	Drowsiness	Reaction time	Visual conflict sensory ratio
	Sleep disturbance	Total symptom score	
	Difficulty concentrating		
	Feeling as "in a fog"		
	Feeling "slowed down"		
	Sensitivity to light		
	Sadness		
	Vomiting		
	Sensitivity to noise		
	Nervousness		
	Difficulty remembering		
	Numbness		
	Dizziness		
	Tingling		
	Neck pain		
	Irritability		
	Feelings of depression		
	Blurred vision		

Abbreviation: ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.

Cross-validation of the prediction formula was conducted using the squared cross-validity coefficient (R^2_{cv}).[28] We used the Stine procedure to perform cross-validation instead of a separate concussed sample because of the relatively low incidence of concussion.[29] The equation is defined as

$$R^2_{cv} = 1 - \left(\frac{N-1}{N}\right)\left(\frac{N+k+1}{N-k-1}\right)(1-R^2) \qquad (3)$$

where R^2 is the estimated squared cross-validity coefficient, N is sample size, and k is the number of predictors.[28] Additionally, an analysis of variance was performed to determine if sex differences existed for any of the 58 independent variables along with actual and predicted time loss. All analyses were conducted with $\alpha = .05$ using SPSS statistical software (version 19.0; IBM Corporation, Armonk, NY).

RESULTS

Participants

A total of 76 (51 male and 25 female) concussed athletes with an average age of 19.5 ± 1.65 years were included in our analyses. Participants' sports consisted of football (n = 44), men's (n = 7) and women's (n = 6) basketball, cheerleading (n = 6), equestrian (n = 3), volleyball (n = 2), soccer (n = 2), softball (n = 2), baseball (n = 1), track and field (n = 1), gymnastics (n = 1), and tennis (n = 1). Participants reported 0.66 ± 0.92 prior concussions (range, 0–5) and were symptom free in 9.0 ± 5.85 days (range, 2–31 days). Approximately 67% (51 participants) stated they were symptom free in ≤10 days. Descriptive statistics for each clinical measure are found in Table 2. In terms of sex, only the SOT composite score was different ($F_{1,75} = 5.29$, $P = .02$), with males scoring higher (81.3 ± 7.57) than females (76.0 ± 12.6). We used the stepwise approach to conduct our regression analysis. Of the 58 predictors, only 5 were significantly related to the amount of time an athlete self-reported symptoms ($F_{5,75} = 8.80$, $P < .001$): ImPACT total symptom score, duration of neck pain, duration of drowsiness, duration of nervousness, and duration of tingling. The multiple correlation coefficient (R) for the

Table 2. Descriptive Statistics (Mean ± SD) for the Revised Head Injury Scale, ImPACT, and Sensory Organization Test at the Initial Postinjury Time Point (≤24 h) = $P \leq .05$

Measure	Men (n = 51)	Women (n = 25)	Total (n = 76)
Revised Head Injury Scale			
Total symptom duration	25.1 ± 17.0	27.6 ± 17.4	25.9 ± 17.08
Total symptom severity	25.3 ± 17.1	26.4 ± 17.4	25.7 ± 17.10
ImPACT			
Verbal memory	86.3 ± 11.8	86.1 ± 15.3	86.3 ± 12.94
Visual memory	71.8 ± 13.5	67.2 ± 13.0	70.3 ± 13.42
Reaction time	0.59 ± 0.10	0.63 ± 0.15	0.61 ± 0.12
Visual motor speed	37.8 ± 6.26	37.2 ± 10.1	37.6 ± 7.65
Impulse control	7.3 ± 7.1	6.68 ± 6.15	7.1 ± 6.75
Total symptom score	15.0 ± 15.56	17.2 ± 14.26	15.7 ± 15.09
Sensory Organization Test			
Composite score	81.3 ± 7.57	76.0 ± 12.6	79.6 ± 9.77
Somatosensory ratio	95.9 ± 4.58	93.6 ± 5.03	95.1 ± 4.82
Visual ratio	93.2 ± 8.01	88.8 ± 12.0	91.7 ± 9.64
Vestibular ratio	79.0 ± 9.84	73.6 ± 13.48	77.2 ± 11.4
Visual conflict	101.0 ± 6.95	101.6 ± 7.62	101.2 ± 7.13

Abbreviation: ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.

formula was 0.62, which explained 39% of the variance associated with the athlete's reporting concussion-related symptoms with an adjusted R^2 value of 34.2%. A second analysis was completed with the 5 variables to verify that the equation resulted in the same R and R^2 values and to account for our moderate sample size. The following regression formula was determined:

$$\text{Days} = 5.883 + \text{NPD}(1.193) + \text{TSS}(0.233) + \text{DD}(-0.773) + \text{ND}(-3.861) + \text{TD}(-1.231) \quad (4)$$

where Days is number of days symptomatic, NPD is duration of neck pain, TSS is ImPACT total symptom score, DD is duration of drowsiness, ND is duration of nervousness, and TD is duration of tingling. The final regression formula had an R^2_{cv} value of 29%. A significant correlation ($r = 0.62$, $P < .001$) was observed between the actual and predicted number of days athletes reported concussion-related symptoms. An independent t test revealed no difference between the actual (9.0 ± 5.85) and predicted (9.3 ± 3.74) number of days until concussed athletes reported being asymptomatic ($P > .05$). The formula correctly identified 59% and 76% of athletes who reported symptoms for 7 and 10 days, respectively. If the predicted number was >10 days, 64% of the sample was correctly identified. This suggests that the accuracy of the prediction formula decreased as symptoms persisted beyond 10 days. This preliminary formula based on self-report of symptoms 24 hours after injury was most accurate in identifying those who recovered within 10 days of their concussion diagnosis. Therefore, the proposed formula identified the majority of athletes who recovered within 10 days and those who experienced a prolonged recovery (>10 days) based on concussion-related symptoms.

DISCUSSION

The purpose of our study was to determine if variables derived from commonly used clinical measures of SC could predict the number of days until a collegiate athlete would report being asymptomatic after injury. Our analysis identified 5 variables—ImPACT total symptom score and duration of neck pain, drowsiness, nervousness, and tingling on the HIS-r within 24 hours of injury—at the time of postinjury assessment as predictors of the number of days an athlete would report ongoing concussion-related symptoms. Combined, these variables accounted for 39% of the total variance associated with the total number of days that participants reported concussion-related symptoms. When we cross-validated our formula, 29% of the variance was accounted for. Additionally, the formula correctly identified 76% of participants who reported concussion-related symptoms for ≤10 days. Though our findings are preliminary, the variables identified by the proposed formula suggest that symptom duration and severity may be important to consider when assessing concussed athletes within 24 hours of diagnosis.

As previously mentioned, this formula is to be considered preliminary given the relatively small sample size. Although this formula needs to be cross-validated with a larger independent sample of concussed collegiate athletes, it may be used with caution to preemptively identify those student-athletes who are at risk for a prolonged recovery. Collegiate athletes who are predicted to have a prolonged recovery may benefit from additional clinician-guided patient education and appropriate academic and psychosocial interventions. These interventions include but are not limited to graded cognitive rest or classroom strategies such as providing breaks in quiet places, acquiring preprinted class notes, allowing additional time for work, and postponing tests.[30] Theoretically, these return-to-learn strategies are sound, but limited evidence exists to support them after SC.[30,31]

An additional consideration is the implementation of subsymptom threshold exercise for candidates who seem to be at risk for prolonged recoveries. Leddy et al[32] investigated a submaximal exercise protocol in patients with PCS (athletes and nonathletes) who had reported concussion-related symptoms for a minimum of 6 weeks. Using a submaximal exercise protocol, the authors demonstrated that participants experienced an increased capacity for exercise as measured by heart rate and blood pressure without exacerbation of concussion-related symptoms. The authors concluded that athletes with protracted recoveries may benefit from submaximal exercise that does not exacerbate concussion-related symptoms. Although research continues, exercise may be a viable intervention for those with prolonged recoveries. Last, referral of at-risk students to appropriate counseling resources may be in order, particularly because additional background risk factors such as comorbid psychiatric symptoms (eg, depression) may be present among a subset of individuals.[33]

Several groups[6,9–11,17,34] have addressed the ability to predict protracted recoveries based on the signs and symptoms of SC. Despite the finding that LOC and PTA increase the risk of a prolonged recovery by 1.8 to 4.2 times,[17] a majority of the remaining literature addresses prolonged recovery based on the presence of specific symptoms and their severity or neurocognitive deficits (or both).[6,9–11] To support this body of literature our study design included variables derived from the HIS-r, ImPACT, and SOT in addition to age, sex, and the number of prior concussions. Despite this multimodal approach to SC assessment, the final prediction formula consisted solely of self-reported symptoms.

One dependent variable identified as contributing to the total number of days symptomatic after SC was ImPACT total symptom score. This finding is consistent with that of McCrea et al,[17] who reported that a 20-point increase in symptom severity when compared with preinjury levels was associated with a 2.6 times increased risk of prolonged recovery in concussed high school and collegiate athletes. Similarly, Meehan et al[34] observed that the total Post-Concussion Symptom Severity score was related to patients' reporting of concussion-related symptoms beyond 28 days.

Symptom clusters or constructs have been proposed to describe postconcussion symptoms.[4] Proposed somatic/migraine (eg, headache, nausea, and balance disturbances), neuropsychological/cognitive (eg, memory, concentration, and judgment problems), sensory (eg, visual disturbances and sensitivity to noise), and affective/neurobehavioral (eg, anxiety and irritability) clusters have been associated with prolonged recovery.[4,5,35] Symptom clusters may be derived from several available self-report symptom checklists and scales.[36] Applying symptom clusters to our results, our final prediction formula consisted of ImPACT total symptom score plus neck pain and tingling (somatic cluster) and drowsiness and nervousness (neuropsychological/cognitive cluster) duration within a 24-hour period to predict total days symptomatic.[4,5,9]

The individual variables of neck pain, tingling, drowsiness, and nervousness were included based on self-reported duration. The ImPACT total symptom score is a composite of symptom severity. Varying forms of total symptom severity have been addressed in the literature as a predictor of prolonged recovery.[9,34] Of these symptoms, self-rated severity of drowsiness has been reported as a common symptom of concussion,[9,37] unlike neck pain, tingling, and nervousness. Specifically, neck pain was removed from a recently published empirically derived symptom scale as it was considered to be associated more with a cervical strain than SC.[38] Given this rationale, neck pain and frequently associated tingling may indicate healing of a soft tissue injury in addition to the diagnosed SC, which may explain their association in the proposed formula. In terms of duration of nervousness, it can be argued that nervousness and anxiety, in the current context, are synonyms and have been defined as such elsewhere.[39] A systematic review of prognostic models after mild traumatic brain injury concluded that severity of postinjury anxiety was a predictor of outcome.[40] Additionally, van der Horn et al[41] reported postinjury anxiety and depression as predictors of delayed return to work in a cross-sectional sample of participants who ranged from 15 to 78 years of age. That said, with the exception of drowsiness, though the remaining variables are less likely to be associated with SC, they can theoretically be associated with the length of postconcussion symptoms.

Unique to this study is the finding of symptom duration in addition to severity as a predictor of the number of days an athlete is symptomatic. The self-reported symptoms of neck pain, tingling, drowsiness, and nervousness are potentially modifiable in duration throughout the initial 24 hours after an SC.[42] Mittenberg et al[43] reported that early structured education of concussed patients by a therapist, which consisted of techniques for stress reduction and gradual resumption of premorbid activities along with providing a 10-page educational manual, significantly reduced recovery time compared with those who received routine hospital treatment and discharge. The theoretical rationale for this finding is based on the cognitive-behavioral model. This model suggests that a self-reinforcing cycle may develop, with attentional bias, anxiety, and depression resulting in persistence of symptoms.[43] Based on our results, the appropriate home care and management may be prescribed to an injured athlete to lessen neck pain and tingling duration through the initial period of the injury. In terms of neuropsychological/cognitive symptoms, again, the appropriate education regarding sleep hygiene and concussion recovery to reduce nervousness may be supplied to assist in a favorable outcome. To address drowsiness, a checklist may be given to help educate and remind athletes about proper sleep hygiene.[42] Information about limiting barriers to sleep may reduce drowsiness duration within the initial 24 hours by facilitating sleep the night of the injury.

Although the results of this study are unique, they are not without their limitations. As mentioned previously, in order to account for the number of independent variables used to generate the prediction equation, a larger sample would be needed. Given the period of time needed to recruit the current sample size from 2 NCAA Division I universities and our stringent methods, we believe that reporting these findings as preliminary is appropriate and encouraging, despite the need to further validate and refine the prediction formula. For example, including additional background variables such as family and psychiatric history or genetic information (eg, apolipoprotein E status) might further enhance prediction models. Last, 67% of our sample was male, so results may be biased toward similar populations. Prior researchers have addressed sex differences associated with SC specific to length of recovery and self-reported symptoms after injury, suggesting that sex-related factors may be important in the recovery process and merit further exploration.[12,26,44–46]

CONCLUSIONS

The purpose of our study was to determine if the amount of time an athlete reported concussion-related symptoms after the diagnosis of SC could be predicted using variables from a multidimensional assessment. Our analysis resulted in a formula based primarily on symptom duration from the HIS-r and ImPACT total symptom score. Given this preliminary analysis, we recommend caution when considering the use of this formula in determining the length of recovery of concussed athletes. That said, we hope the results of this study support the use of education about managing expected signs and symptoms during the initial hours after injury to mitigate the time until an athlete reports being symptom free. This promising formula may help to identify those concussed collegiate athletes who need accommodations to facilitate recovery and lead to improved patient outcomes. However, further investigation is needed to validate this prediction formula before it is relied on for clinical use.

REFERENCES

1. Barkhoudarian G, Hovda DA, Giza CC. The molecular pathophysiology of concussive brain injury. *Clin Sports Med*. 2011;30(1):33–48.
2. Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology*. 2013;80(24):2250–2257.
3. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75(suppl 4):S24–S33.
4. Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the factorial and construct validity of a self-report concussion symptoms scale. *J Athl Train*. 2003;38(2):104–112.
5. Piland SG, Motl RW, Guskiewicz KM, McCrea M, Ferrara MS. Structural validity of a self-report concussion-related symptom scale. *Med Sci Sports Exerc*. 2006;38(1):27–32.
6. Babcock L, Byczkowski T, Wade SL, Ho M, Mookerjee S, Bazarian JJ. Predicting postconcussion syndrome after mild traumatic brain injury in children and adolescents who present to the emergency department. *JAMA Pediatr*. 2013;167(2):156–161.
7. Guskiewicz KM, Valovich McLeod TC. Pediatric sports-related concussion. *PM R*. 2011;3(4):353–364.
8. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med*. 2000;28(5):643–650.
9. Lau B, Lovell MR, Collins MW, Pardini J. Neurocognitive and symptom predictors of recovery in high school athletes. *Clin J Sport Med*. 2009;19(3):216–221.

10. 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;39(6):1209–1216.
11. Lau BC, Kontos AP, Collins MW, Mucha A, Lovell MR. Which on-field signs/symptoms predict protracted recovery from sport-related concussion among high school football players? *Am J Sports Med*. 2011;39(11):2311–2318.
12. Covassin T, Elbin RJ, Harris W, Parker T, Kontos A. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med*. 2012;40(6): 1303–1312.
13. Collins M, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. *Neurosurgery*. 2006;58(2):275–286.
14. McCrea M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. *J Int Neuropsychol Soc*. 2005;11(1):58–69.
15. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *JAMA*. 2003;290(19):2556–2563.
16. Covassin T, Elbin RJ, Nakayama Y. Tracking neurocognitive performance following concussion in high school athletes. *Physician Sportsmed*. 2010;38(4):87–93.
17. McCrea M, Guskiewicz K, Randolph C, et al. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. *J Int Neuropsychol Soc*. 2013;19(1):22–33.
18. Babcock L, Byczkowski T, Wade SL, Ho M, Mookerjee S, Bazarian JJ. Predicting postconcussion syndrome after mild traumatic brain injury in children and adolescents who present to the emergency department. *JAMA Pediatr*. 2013;167(2):156–161.
19. Cantu RC, Guskiewicz K, Register-Mihalik JK. A retrospective clinical analysis of moderate to severe athletic concussions. *PM R*. 2010;2(12):1088–1093.
20. Cantu RC. Posttraumatic retrograde and anterograde amnesia: pathophysiology and implications in grading and safe return to play. *J Athl Train*. 2001;36(3):244–248.
21. Klossner D, ed. *The 2013–14 NCAA Sports Medicine Handbook*. Indianapolis, IN: The National Collegiate Athletic Association; 2013.
22. Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. *Neurology*. 1997;48(3):581–585.
23. Broglio SP, Cantu RC, Gioia GA, et al. National Athletic Trainers' Association position statement: management of sport concussion. *J Athl Train*. 2014;49(2):245–265.
24. Resch J, Driscoll A, McCaffrey N, et al. ImPACT test-retest reliability: reliably unreliable? *J Athl Train*. 2013;48(4):506–511.
25. Resch JE, May B, Tomporowski PD, Ferrara MS. Balance performance with a cognitive task: a continuation of the dual-task testing paradigm. *J Athl Train*. 2011;46(2):170–175.
26. Kontos AP, Dolese A, Elbin RJ, Covassin T, Warren BL. Relationship of soccer heading to computerized neurocognitive performance and symptoms among female and male youth soccer players. *Brain Inj*. 2011;25(12):1234–1241.
27. Cohen J, Cohen P, West SG, Aiken LS. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. 3rd ed. Mahweh, NJ: Lawrence Erlbaum Associates; 2003.
28. Pedhazur EJ. *Multiple Regression in Behavioral Research: Explanation and Prediction*. 3rd ed. Independence, KY: Wadsworth; 1997.
29. Huberty CJ, Olejnik S. *Applied MANOVA and Discriminant Analysis*. 2nd ed. Hoboken, NJ: Wiley-Interscience; 2006.
30. Master CL, Gioia GA, Leddy JJ, Grady MF. Importance of "return-to-learn" in pediatric and adolescent concussion. *Pediatr Ann*. 2012; 41(9):1–6.
31. Moser RS, Glatts C, Schatz P. Efficacy of immediate and delayed cognitive and physical rest for treatment of sports-related concussion. *J Pediatr*. 2012;161(5):922–926.
32. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med*. 2010;20(1):21–27.
33. Covassin T, Elbin RJ, Larson E, Kontos AP. Sex and age differences in depression and baseline sport-related concussion neurocognitive performance and symptoms. *Clin J Sport Med*. 2012;22(2):98–104.
34. Meehan WP, Mannix RC, Stracciolini A, Elbin RJ, Collins MW. Symptom severity predicts prolonged recovery after sport-related concussion, but age and amnesia do not. *J Pediatr*. 2013;163(3):721–725.
35. Ettenhofer ML, Barry DM. A comparison of long-term postconcussive symptoms between university students with and without a history of mild traumatic brain injury or orthopedic injury. *J Int Neuropsychol Soc*. 2012;18(3):451–460.
36. McLeod TC, Leach C. Psychometric properties of self-report concussion scales and checklists. *J Athl Train*. 2012;47(2):221–223.
37. Kontos AP, Elbin RJ, Schatz P, et al. A revised factor structure for the post-concussion symptom scale: baseline and postconcussion factors. *Am J Sports Med*. 2012;40(10):2375–2384.
38. Randolph C, Millis S, Barr WB, et al. Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. *Arch Clin Neuropsychol*. 2009;24(3):219–229.
39. Venes D, Taber CW, eds. *Taber's Cyclopedic Medical Dictionary*. 20th ed. Philadelphia, PA: FA Davis; 2005.
40. Silverberg N, Gardner AJ, Brubacher JR, Panenka WJ, Li JJ, Iverson GL. Systematic review of multivariable prognostic models for mild traumatic brain injury. *J Neurotrauma*. 2015;32(8):517–526.
41. van der Horn HJ, Spikman JM, Jacobs B, van der Naalt J. Postconcussive complaints, anxiety, and depression related to vocational outcome in minor to severe traumatic brain injury. *Arch Phys Med Rehabil*. 2013;94(5):867–874.
42. De La Rue-Evans L, Nesbitt K, Oka RK. Sleep hygiene program implementation in patients with traumatic brain injury. *Rehabil Nurs*. 2013;38(1):2–10.
43. Mittenberg W, Tremont G, Zielinski RE, Fichera S, Rayls KR. Cognitive-behavioral prevention of postconcussion syndrome. *Arch Clin Neuropsychol*. 1996;11(2):139–145.
44. Dick RW. Is there a gender difference in concussion incidence and outcomes? *Br J Sports Med*. 2009;43(suppl 1):I46–I50.
45. Covassin T, Elbin RJ. The female athlete: the role of gender in the assessment and management of sport-related concussion. *Clin Sports Med*. 2011;30(1):125–131.
46. Kontos AP, Covassin T, Elbin RJ, Parker T. Depression and neurocognitive performance after concussion among male and female high school and collegiate athletes. *Arch Phys Med Rehabil*. 2012;93(10):1751–1756.

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