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Multimodal Assessment of Sport-related Concussion

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Abstract

Objective: The purpose of this study was to determine which assessments best identify athletes with sport-related concussion (SRC) from healthy controls in the acute/early subacute (within 10 days of SRC) of injury.

Design: Prospective, cohort study.

Setting: Specialty concussion clinic.

Participants: Sixty-four athletes with SRC (52% male) and 59 matched (age, sex), healthy controls (56% male) aged 12 to 20 years old (M=15.07, SD=2.23).

Assessment: Participants completed symptom, cognitive, vestibular/oculomotor, near point of convergence, and balance assessments.

Main Outcome Measures: Univariate analyses were conducted to compare athletes with SRC to healthy controls across all assessments. Assessments that significantly differed between the SRC group and healthy controls were used as predictors in an enter method logistic regression (LR) model, and subsequent forward stepwise LR.

Results: Results of LR analyses indicated that symptom inventory and symptom provocation on vestibular/oculomotor assessments significantly predicted athletes with SRC versus controls. The forward stepwise LR accurately classified 84.6% of the overall sample (78.3% of athletes with SRC and 91.2% of controls were accurately predicted), and accounted for 60.5% of the variance in predicting athletes with SRC versus controls. Total symptom inventory score (p=.003) and vestibular/oculomotor symptom provocation (p<.01) were the most sensitive and specific measures in a comprehensive, multimodal assessment for distinguishing athletes with SRC from healthy controls within 10 days of injury.

Conclusion: Elements within a multimodal evaluation that are the most robust at discriminating athletes with SRC from healthy controls in the acute/early subacute phase of injury include symptom report and provocation of symptoms on vestibular/oculomotor assessment. These assessments should be considered in conjunction with other objective assessments (i.e., near point of convergence measurement, cognitive testing) as part of a comprehensive evaluation of SRC.

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Keywords

sport-related concussion; symptoms; vestibular; oculomotor; multimodal; mtbi

Introduction

International consensus statements[1–5] have advocated for the inclusion of a multimodal approach to managing SRC[1] due to the heterogeneous nature of the injury and to improve diagnostic yield. Based on recently defined criteria by the National Institute of Health (NIH)[6] the standard components of a comprehensive, multimodal approach to assessing SRC includes an assessment of symptoms[7–9], cognitive/mental status [10–15], vestibular/oculomotor function [16,17], near point of convergence [17–21], and balance [22–25]. Researchers have demonstrated the effectiveness of a multimodal approach for diagnosing mild traumatic brain injury (mTBI) in adult populations with non-sport injuries, and found that an integration of vestibular/oculomotor and cognitive assessments has good sensitivity and specificity for identifying individuals with mTBI from healthy controls[26,27]. However, the generalizability of these study findings to populations of adolescent/young adult athletes with uncomplicated, sport-related injuries is questionable given these studies did not exclude patients with complicated mTBI (e.g., intracranial bleed, skull fracture) or life-threatening traumatic injuries (e.g., bullet-related, blast exposure)[26,27], some patients were evaluated up to five years post-injury[26], and the studies were conducted among adults[26,27] who are known to demonstrate different recovery patterns from youth[28–30]. McDevitt et al.[31] evaluated the utility of a battery of vestibular/oculomotor assessments for differentiating athletes diagnosed with SRC within 4–90 days post-injury in a sample of collegiate athletes, and found good sensitivity (91.7%) and specificity (81.7%) for components of vestibular/oculomotor screening. However, other elements of a standard evaluation of SRC (i.e., cognitive testing, symptom inventories)[6] were not included as part of their analyses, thus limiting conclusions regarding the usefulness of vestibular/oculomotor screening within a multimodal model for evaluation of SRC. Although these studies provide preliminary support for the use of a multimodal assessment approach for diagnosing concussion, the results may not be generalizable to evaluating adolescent and young adults with recently sustained, uncomplicated sport-related concussions, who are otherwise healthy. Limited studies have investigated the sensitivity and specificity of a multimodal approach for diagnosing SRC, or the tools within a standard evaluation[6] that are most robust for detecting the injury among athletes. Understanding which tools within a multimodal evaluation are the most robust in discriminating athletes with SRC from healthy athletes is important for clinicians who rely on functional outcomes to make clinical judgments regarding diagnosis and return to play decisions after a suspected injury.

The objective of the current study was to determine which assessments from a comprehensive, multimodal approach- including symptom inventory, cognitive testing, vestibular/oculomotor screening, near point of convergence (NPC) measurement, and balance assessments- best identify adolescent and young adult athletes with SRC from healthy controls within 10 days of injury (i.e., acute/early subacute). We hypothesized that higher symptom severity scores on the symptom inventory; worse cognitive, balance, and vestibular/oculomotor impairment; and higher NPC distance would discriminate athletes with SRC from healthy controls

Methods

Participants

Participants in this study were prospectively recruited through an outpatient concussion clinic as part of a larger research initiative, and must have been diagnosed with an SRC by a licensed healthcare professional based on international criteria[1]. Specifically, diagnosis was made based upon the presence of 1) evidence of a forcible blow to the head, 2) acute onset of symptoms or markers of head injury (e.g., headache, loss of consciousness [LOC], 3) performance on SRC assessment tools (i.e., cognitive testing, vestibular/oculomotor screening), and 4) a pattern of symptoms characteristic of SRC over time that could not be accounted for by another medical condition (e.g., learning disorder, history of strabismus). Given that the diagnosis of SRC remains a clinical judgment, clinicians in this study rendered a diagnosis based upon a multitude of available evidence from a thorough clinical interview, review of records (e.g., performance on sideline assessments, emergency department visits, pediatrician examinations), SRC assessment tools (i.e., cognitive testing, symptom inventories, balance testing, vestibular/oculomotor screening), and consideration of past personal and family medical history. Although the assessments in the multimodal evaluation of interest in this study were considered by clinicians when determining diagnosis of SRC, the assessment tools are only a portion of the available evidence that clinicians considered when making a diagnosis. Inclusion criteria for participants with SRC included: a sport-related mechanism of injury, males and females aged 12 to 20 years old, and completion of their initial visit for evaluation of SRC within 10 days of injury. Athletes with SRC sustained their injury within 2 to 10 days (M=6.94, SD=2.30) of their initial clinic visit, and completed the multimodal assessment at this visit. Healthy controls (i.e., non-concussed individuals per self-report) were recruited from the local community (i.e., through a voluntary general research registry at the University of Pittsburgh, family/friends of SRC participants), and matched as closely as possible to concussed athletes on the basis of year of age and sex. Data was collected from October 2014 through June 2017. No incentives were provided for this study protocol and participation was voluntary. For healthy controls, inclusion criteria included: males or females aged 12 to 20 years old who were able to cooperate with consent procedures and complete all assessments. Information on the healthy controls' participation in sports or physical activity was not collected as part of this study. Participants in both groups were excluded from the study if they met one or more of the following criteria: musculoskeletal disorder, brain surgery, moderate/severe TBI, persistent symptoms from a prior concussion, substance abuse disorder, psychiatric disorder, pre-existing vestibular disorder, symptomatic orthopedic injury to lower body, or neurological disorder. Healthy controls were also excluded if they were currently experiencing symptoms or impairment from a prior concussion or had a history of two or more concussions.

Measures

Symptom Inventory.—Symptoms were evaluated using the Post-Concussion Symptom Scale (PCSS) [8,32] as part of a computerized test battery. The PCSS is a 22-item symptom inventory for SRC, which encompasses physical, cognitive, affective, and sleep-related symptoms of concussion.[32,33] Participants rated the presence and severity of symptoms on a Likert-type scale from 0 (not experiencing the symptom) to 6 (severe), for a total symptom severity score ranging from 0 to 132.

Cognitive.—The Immediate Post-concussion Assessment and Cognitive Testing (ImPACT)[8] was used to evaluate cognitive impairment. The ImPACT tests yields four composite scores including verbal and visual memory, visual motor speed, and reaction time. cognitive-memory (Verbal Memory composite and Visual Memory composite) and cognitive-processing speed components (Visual Motor Speed composite and Reaction Time composite) were calculated using averaged z-score conversions from normative data[34,35].

Vestibular and Oculomotor.—The Vestibular/Ocular Motor Screening (VOMS) tool is a brief clinical screening tool that assesses vestibular/oculomotor symptoms and impairment. The VOMS includes evaluations of the following head and eye movements: 1) smooth pursuits, 2) horizontal saccades, 3) vertical saccades, 4) horizontal vestibular ocular reflex (VOR), 5) vertical VOR, 6) visual motion sensitivity (VMS), and 7) near point of convergence (NPC). Patients rate on a Likert-type scale ranging from 0 (none) to 10 (severe) their experience of headache, dizziness, nausea and fogginess symptoms at baseline (i.e., prior to vestibular/oculomotor screening in static head and eye position) and following each VOMS component.[16,17] Symptoms reported across each vestibular/oculomotor task can be totaled to yield a total VOMS score; the use of a combined score across vestibular/oculomotor tasks has demonstrated utility in discriminating between subjects with mTBI and controls[17,26]. Clinicians diagnosing SRC utilized the established cutoff (i.e., a score ≥2 on any vestibular/oculomotor task of the VOMS) for clinical decision making. Provocation of reported symptoms on the VOMS was calculated by subtracting baseline symptoms from the total VOMS score (excluding symptom provocation during NPC measurement)[28] to yield *provocation* of symptoms during VOMS[17,36], to isolate whether vestibular/oculomotor provocation when engaged in dynamic head/eye movement provides unique value to the multimodal assessment relative to evaluating symptoms in a static position, such as when completing a traditional symptom inventory. In addition, the average of three measurements (in centimeters) of NPC distance were conducted to evaluate convergence.

Balance.—The Balance Error Scoring System (BESS)[37] was used to measure balance. The BESS is a clinical assessment of balance that examines the number of errors during the performance of static and dynamic postural stability. The BESS includes three stances- fee together, single leg, tandem leg- performed with eyes closed and hands placed on the iliac crests on a flat surface followed by a foam pad for a total of six trials[23,37]. A higher total BESS error score reflects more balance impairment.

Procedures

This University of Pittsburgh Institutional Review Board (IRB) approved the current study procedures. Participants and/or their parents completed informed written consent/assent prior to enrolling in the study, and after being informed of the study and its risks and benefits. All participants included in the study then completed the comprehensive assessments in the following order: PCSS, ImPACT, VOMS, and BESS. For participants diagnosed with SRC, assessments were completed as part of standard clinical care during their initial appointment in a concussion specialty clinic, with the exception of the BESS, which was conducted by research staff supervised by clinicians immediately preceding the clinic appointment. Healthy controls completed all assessments in a research laboratory by research staff trained in concussion assessment.

Data Analysis

Groups were compared using independent samples t-tests and chi-squared tests to evaluate differences on demographic variables. A series of univariate analyses of variance (ANOVAs) with Bonferroni correction for multiple comparisons ([α=.05/6] to control for multiple comparisons, $p < .008$) were conducted to compare the athletes with SRC and controls at their initial visit on total symptom inventory scores, cognitive-memory, cognitive-processing speed, VOMS, NPC measurement, and BESS. Assessments that significantly differed between the athletes with SRC and controls were then included in subsequent regression analyses. An initial enter method logistic regression (LR) was conducted to determine the ability of significant predictors from ANOVAs (symptom inventory score, cognitive-memory, vestibular/oculomotor screening, and NPC) to discriminate between athletes with SRC and controls. A follow-up forward stepwise LR was then performed that included only the significant predictors from the first model.

Results

A total of 64 athletes with SRC (52% male) and 59 controls (56% male) aged 12 to 20 years old (M=15.07, SD=2.23) were recruited as part of a larger study. There were no significant differences between the SRC and control groups on age, $t(121) = -0.14$, p=.89, sex, $\chi^2(1, N=123) = .001$, p=.97, history of greater than three concussions, $\chi^2(1, N=121) = 2.74$, p=.10, history of an attention disorder, $\chi^2(1, N=123) = 2.07$, p=.15, or a history of a learning disability, $\chi^2(1, N=123) = 1.09$, p=.30. A series of one-way ANOVAs revealed that athletes with SRC and controls significantly differed across symptom inventory score, cognitive-memory, vestibular/oculomotor screening, and NPC measurement. Results are presented in Table 1.

These assessments were therefore included in subsequent analyses. An enter method LR was performed with athletes with SRC versus controls as the dependent variable, and the following assessments as predictor variables: symptom inventory score, cognitive-memory, vestibular/oculomotor screening, and NPC. A total of 117 cases were analyzed and the full model significantly predicted group membership for athletes with SRC and controls (χ^2= 73.10, df = 4, p<.001). The model accounted for 62.0% of the variance in predicting athletes with SRC versus controls, with 83.8% of subjects correctly predicted (78.3% of athletes with SRC and 89.5% of controls were accurately predicted). Significant predictors in the model included the symptom inventory and vestibular/oculomotor screening, while all other predictors were non-significant (see Table 2).

A follow-up forward stepwise LR was performed with athletes with SRC versus controls as the dependent variable, and the symptom inventory and vestibular/oculomotor screening as predictors. A total of 117 cases were analyzed and the full model significantly predicted athletes with SRC from controls (Step 1: $\chi^2 = 62.94$, df = 1, $p < .001$; Step 2: $\chi^2 = 70.71$, df = 2, $p < .001$). The model accurately predicted 84.6% of the overall sample (78.3% of athletes with SRC and 91.2% of controls were accurately predicted), and accounted for 60.5% of the variance in predicting athletes with SRC versus controls. Both predictors were retained in the model indicating that vestibular/ocular motor screening contributed unique variance beyond a symptom inventory in classifying SRC versus controls (see Table 3). These results suggest that symptom inventory and vestibular/oculomotor assessments are the most robust tools for differentiating athletes with SRC from healthy controls.

Discussion

The purpose of this study was to determine which clinical tools utilized in a standard multimodal assessment best discriminated athletes with SRC from healthy controls. The assessment methods evaluated in this study included total symptom inventory score, cognitive testing of memory and processing speed, vestibular/oculomotor screening, NPC measurement, and balance assessment. Results of a stepwise logistic regression yielded a significant model with the symptom inventory and vestibular/oculomotor screening as the most robust methods for discriminating athletes with SRC from controls. Utilizing these two clinical tools correctly classified 85% of the overall sample, with 78.3% of athletes with SRC and 91.2% of controls accurately classified. Performance on tests of cognitive-memory and NPC measurement significantly differed ($p < .008$) between athletes with SRC and controls on univariate analyses, but these assessments did not remain significant predictors when entered into a logistic regression model.

Results of this study are consistent with prior research demonstrating that athletes with SRC endorse more concussion symptoms than controls on self-report post-concussion symptom inventories[38,39]. However, this study also demonstrates that there are unique sensory-motor indicators after SRC, such as those elicited during vestibular/oculomotor screening that are not fully captured using a symptom inventory. Although symptoms characteristic of vestibular dysfunction (e.g., dizziness, headache, nausea, fogginess) are often assessed on post-concussion symptom inventories[7–9], this study shows that evaluating the provocation of these symptoms during vestibular/oculomotor screening adds significant value to simply asking about these symptoms on an inventory. This is noteworthy given that central vestibular dysfunction is a common subtype of SRC that occurs in about 60% of injured athletes[17]. It is presumed that athletes may be unaware of vestibular symptoms until tasked with engaging in specific dynamic head and eye movements that elicit vestibular/oculomotor reflexes. This is consistent with prior research indicating that signs and symptoms reported during vestibular/oculomotor stimulation were a sensitive measure of SRC in a collegiate athlete population[31], and vestibular, balance and oculomotor assessment were sensitive predictors of mTBI in non-sports-related injuries, among adults, and in protracted cases of mTBI[26,27]. Other domains of assessment in this study, including memory and NPC measurement significantly differed between SRC and control groups, but the symptom inventory and vestibular/oculomotor screening were the most sensitive and specific measures for accurately classifying athletes.

Although symptoms reported on an inventory and provoked by vestibular/oculomotor screening appear to be robust in diagnosing SRC, there are limitations to relying on measures that only examine symptoms. The practice of relying solely on reported symptoms rather than including objective measures in the evaluation of SRC is contraindicated for several reasons.[40–43] First, athletes tend to underreport their symptoms in an effort to avoid missing playing time, and there can be other complicating psychosocial factors that may also influence symptom reporting (e.g., secondary gain, psychological diagnoses)[1,44–47]. Second, multimodal assessment is important for injury management beyond accurate diagnosis. Some studies have shown that symptoms resolve prior to cognitive or vestibular deficits[28,42,48] and symptoms may not be the best measure to distinguish athletes who continue to exhibit concussion sequelae from healthy controls in later phases of recovery. Similarly, a multimodal approach should include a combination of both subjective and objective measures to delineate a comprehensive clinical profile of sequelae from the injury[1–5] to assist with treatment recommendations.

Although this study provides information about the most useful methods for discriminating athletes with SRC from healthy controls, on an individual level there may be nuanced deficits after SRC across other clinical tools (e.g., balance assessment, cognitive testing), that were not fully captured in this study. For instance, athletes may have premorbid strengths and weaknesses in certain cognitive functions (e.g., above average reaction time), that after sustaining an SRC fell to the average range. This may be a significant decline for an individual athlete, but not fully captured when conducting research using a design evaluating between-group differences. In the future, it would be advantageous to collect larger samples with baseline (i.e., preinjury) data of athletes to explore within and between-group differences across subtests included in each of the assessment modalities investigated to further assist in clinical decision-making. There is research to indicate nuanced differences (i.e., premorbid cognitive strengths and weaknesses) in the performance of different athlete groups and non-athletes on traditional concussion assessment tools[49–51], which were not accounted for in this study as our control group consisted of individuals from the local community regardless of their participation in sport. In the future, it would be advantageous to use a multimodal assessment to compare athletes with a concussion to a control group of athletes with other types of injuries (e.g., orthopedic injuries). Lastly, although vestibular/oculomotor screening yields both subjective information (i.e., reported provocation of symptoms), as well as an objective, clinical examination of neuromotor function, this study only utilized athletes' report of provocation of symptoms as an outcome variable. Future studies should include coding of clinically observed impairment to determine whether this objective data adds additional utility to vestibular/oculomotor screening for SRC.

Overall, the current study demonstrates that symptom reporting on a post-concussion symptom inventory and symptom provocation on vestibular/oculomotor screening are the most sensitive and specific measures in a multimodal assessment for differentiating concussed athletes from controls within 10 days of injury. Utilizing a combination of these measures results in the correct classification of 85.0% of athletes. The findings from this study have several clinical implications. First, results of this study warrant the use of both symptom report inventories and vestibular/oculomotor screening in a multimodal assessment when determining diagnosis of concussion within 10 days of a potential injury. It also provides empirical evidence to assist clinicians' judgment of which measures in a multimodal assessment offer the greatest utility in diagnosing SRC. This is important as the diagnosis of SRC largely remains a functional assessment guided by clinical judgment. The assessment model utilized in the current study indicated an acceptable diagnostic yield for SRC, but there remains a subset of individuals who were incorrectly classified (15%). This is particularly concerning in the case of false negatives (i.e., a concussed athlete who is misdiagnosed as healthy) in which an athlete may be at risk for being prematurely returned to play. This study supports the need for clinicians to understand the sensitivity and specificity of the clinical tools utilized when evaluating SRC and utilize multiple sources of information when available (e.g., clinical interview, sideline data) to supplement a multimodal assessment. Despite our findings that symptom reporting on an inventory and vestibular/oculomotor screening were the most useful measures for diagnosis in a multimodal assessment, we continue to advocate for a comprehensive, multimodal evaluation when assessing and managing the individual athlete with SRC. Future research should focus on the advancement of concussion assessment tools to improve clinical diagnosis and management of SRC.

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Clinical Relevance:

Clinicians should include both symptoms and vestibular/oculomotor outcomes as part of a multimodal assessment to inform more accurate diagnosis of SRC in the acute and early sub-acute phases of injury.

Table 1.

Results of ANOVAs with Bonferroni Correction for Multimodal Assessments

	Concussed		**Controls**			
	M	***SD***	***M***	***SD***	***F***	***p***
Balance	12.60	4.54	10.59	4.77	5.69	.019
Cognitive Memory	90.02	20.14	102.16	13.77	14.91	<.001 *
Cognitive Processing Speed	89.03	24.67	98.64	15.09	6.63	.011
Near Point of Convergence	5.06	8.23	1.16	2.20	12.40	.001 *
Symptom Inventory	27.81	19.56	4.95	9.79	65.27	<.001 *
Vestibular/Oculomotor Screening	38.23	31.86	4.14	11.73	57.89	<.001 *

*P < .008

Table 2.

Results of Enter Method Logistic Regression for Predicting Athletes with SRC from Controls

	β	SE	Wald test	p-value	OR (95% CI)
Symptom Inventory	−0.09	.03	6.93	.008 *	0.92 (0.86 – 0.98)
Vestibular/Oculomotor Screening	−0.05	.02	4.82	.03 *	0.95 (0.91 – 0.99)
Cognitive Memory	.002	.02	0.02	.90	1.00 (0.97 – 1.04)
Near Point of Convergence	−0.17	.12	2.13	.15	0.84 (0.67 – 1.06)

* $p < .05$

Table 3.

Results of Forward Stepwise Logistic Regression for Predicting Athletes with SRC from Controls

	β	**SE**	**Wald test**	**p-value**	**OR (95% CI)**
Step 1					
Constant	1.68	.35	22.52	<.001 [*]	5.34
Symptom Inventory	−0.14	.03	26.82	<.001 [*]	0.87 (0.82 – 0.92)
Step 2					
Constant	1.84	.37	24.11	<.001 [*]	6.27
Symptom Inventory	−0.09	.03	9.07	.003 [*]	0.91 (0.86 – 0.97)
Vestibular/Oculomotor Screening	−0.06	.02	6.09	.01 [*]	0.95 (0.90 – 0.99)

[*] $p < .05$