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Derivation of a Focused, Brief Concussion Physical Examination for Adolescents with Sport-Related Concussion

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Abstract

Objective: To describe the derivation of a brief but pertinent physical examination (PE) for adolescents who have sustained sport-related concussion (SRC).

Design: Prospective cohort.

Setting: University concussion management clinic.

Participants: Acutely concussed (AC, n=52, 15.5±1.4 years, 4.4±2 days since injury, 26.2±38 days to recovery, 71% male) and healthy control adolescents (HC, n=30, 15.8±1.4 years, 73% male).

Intervention: AC had a PE on Visit 1 and were retested at Visit 2 (13.6±1 days after Visit 1). AC was further characterized as Normal Recovery (NR, n=41, 15.5±1.5 years, recovery time 13.0±7 days) and Delayed Recovery (DR, n=11, 15.5±1.2 years, recovery time 75.4±63 days).

Main Outcome Measure: PE findings, including cervical, vestibular, and oculomotor systems.

Results: Visit 1 abnormal PE signs were significantly greater in AC versus HC (2.79±2.13 vs 0.07±0.37, p<0.0001) but not in NR versus DR (2.61±2.2 vs 3.45±1.8, p=0.246). Visit 2 abnormal PE signs differentiated NR versus DR (0.17±0.7 vs 2.45±2.1, p<0.0001).

Conclusion: A brief focused PE can help to diagnose SRC, establish recovery, and may have prognostic value.

Keywords

Sport-related concussion; Buffalo; physical examination; vestibular; oculomotor, cervical.

Conflicts of Interest

The authors report no conflicts of interest.

INTRODUCTION

Sport-related concussion (SRC) is a common problem in clinics¹ and emergency departments (ED).² Adolescents are theoretically the group most at risk for potential long term consequences from repetitive SRC and data suggest that they take longer to recover than children, who in turn take longer than adults.³ Consensus does not exist for physicians how best to diagnose and establish recovery from SRC, including what constitutes pertinent physical examination (PE) findings in these patients. Physicians in the ED are concerned about ruling out serious injuries and may try to diagnose concussion based upon symptom reports alone,⁴ while others may not follow any guidelines.⁵ In a prospective study, emergency physicians relied predominantly upon historical data and symptom reports rather than PE signs when assessing head injured patients.² Recent consensus group publications describe the relative strengths and weaknesses of a variety of concussion evaluation instruments⁶⁻⁸ but do not specifically describe office PE tests that practitioners can practically employ in the busy clinical setting, something that would be very useful for assessment of a common medical problem like concussion.

There is an emerging literature describing PE findings in adolescents with SRC, especially with respect to oculomotor and vestibular system abnormalities. The vestibulo-ocular motor screening (VOMS) examination, for example, has been shown to be sensitive for diagnosing concussion.⁹ In a retrospective study, Corwin et al.¹⁰ reported that persistent post-concussive symptoms (PPCS, symptoms for > 4 weeks) and the need for school academic accommodations were associated with initial visit findings of abnormal near-point of convergence (NPC) or symptom provocation following oculomotor examination (i.e., during smooth pursuits, repetitive saccades or gaze stability testing). In another retrospective study,¹¹ the same group found that vestibular deficits on initial PE (either abnormal gaze stability or abnormal tandem gait) were associated with extended recovery from concussion. Heitger et al.¹² prospectively followed 37 patients with mild traumatic brain injury and reported that eye movement function at 1-week post injury was the most effective in distinguishing between PCS and non-PCS patients.

The clinical evaluation of concussed patients is challenging. There is no concussion definition applied uniformly in all clinical settings,¹³ lack of consensus on how to diagnose concussion and to establish recovery,¹⁴ and not all post-head injury symptoms emanate from the brain.¹⁵ The differential diagnosis includes injury to the vestibulo-ocular (vision) and the vestibulo-spinal (balance) sub-systems¹⁶ as well as to the cervical spine since symptoms from a cervical injury mimic those of concussion.¹⁷ Identifying easy-to-implement PE elements with diagnostic utility is crucial for diagnostic purposes, for guiding treatment decisions in those with persistent signs, and for preventing some from suffering the consequences of returning to sport before there is evidence of physiological recovery.¹⁸ The purpose of this study was to derive a brief, focused PE that contained no more elements than necessary for diagnosis, i.e., an examination for the busy clinician. We used the brief PE, consisting of specific cervical, oculomotor, and vestibular clinical tests, in a sample of adolescents with and without SRC to assess its utility for diagnosing concussion and for determining recovery. We hypothesized that acutely concussed adolescents would have more

abnormal PE findings than healthy controls and that recovered patients would have fewer signs than non-recovered patients two weeks after the initial PE.

METHODS

Study design

This study was part of a randomized control trial ([clinicaltrials.gov: 030-387696](https://clinicaltrials.gov/030-387696)) of provocative exercise testing (the Buffalo Concussion Treadmill Test, BCTT) on the day of clinic presentation (Visit 1) in adolescents who sustained SRC within 1–10 days of injury, conducted between March of 2013 and February of 2015.¹⁹ The BCTT is a graded exercise test that has been validated to diagnose exercise intolerance, which is a physiological biomarker for concussion.^{20,21} Concussed participants were assessed by a blinded physician at Visit 1 and at Visit 2 (13.6 ± 1 days after Visit 1). A control group of non-injured adolescent athletes were recruited from the same schools as many of the concussed participants and were tested once (Visit 1). The study was approved by the University at Buffalo Institutional Review Board.

Participants

Acutely concussed participants (AC) included male and female adolescent athletes (aged 13–19 years) who sustained SRC within 1–10 days of initial visit at the University Concussion Management Clinic and were evaluated by a study physician who diagnosed the concussion according to the 4th International Conference on Concussion in Sport.⁸ Exclusion criteria included (1) evidence of focal neurological deficit; (2) inability to exercise on the treadmill due to other injury; (3) known heart disease or increased cardiac risk; (4) current diagnosis of ADHD, learning disorder, depression, or anxiety; (5) history of moderate or severe TBI; (6) use of medications that affect cardiac output (e.g., beta blockers); or (7) greater than 3 prior concussions (because this is associated with delayed recovery).²² Healthy controls (HC) included male and female adolescent athletes recruited from local high schools who did not have a concussion within the past year. Exclusion criteria were identical to those for the concussed participants.

Physical Examination

Concussed participants had a PE that included cervical, oculomotor, and vestibular systems on Visit 1 and Visit 2. A Practical Management paper describes the complete brief PE and instructions on how to perform each test. (*submitted together*) A sample Buffalo Concussion Physical Exam assessment form is provided as a supplementary file. We assessed the clinical utility of 3 of the most pertinent tests in each system (total 9 tests, Table 1). PE tests were scored as positive (defined as symptom-eliciting and/or observed abnormality) or negative (no symptom exacerbation and no observed abnormality). Control participants completed the same PE on their first and only visit.

Diagnosis and Recovery Criteria

Participants were diagnosed with a concussion based on an independent, blinded physician's assessment that included a comprehensive history, the Post-Concussion Symptom Scale (PCSS),²³ and questions about cognitive function. The BCTT was performed if needed to

confirm the diagnosis (i.e., early exercise intolerance due to symptom exacerbation).²⁴ Participants were considered recovered when total symptom severity score was back to baseline plus normal exercise tolerance on the BCTT and recovery confirmed by the treating physician. Normal recovery (NR) was defined as recovered by Visit 2 (i.e., 21 days post-injury) and delayed recovery (DR) as persistent problems at Visit 2 (i.e., > 21 days post-injury).

Statistical Analysis

ANOVA was used to assess differences in age, days to initial visit, days to recovery, and symptom scores between groups. Chi-square was used to assess differences in gender and prior concussions between groups. PE findings were scored as either positive or negative and were compared between the groups using a Fisher's Exact Test. At Visit 1, AC was compared with HC. NR was compared with DR at Visit 1 and Visit 2 and both were compared with HC. Within each PE finding comparison, the family-wise error rate was controlled at 0.05 via a Bonferroni correction with 9 tests applied to the usual two-sided Fisher's exact test p-value so a p-value of 0.0056 was considered significant for individual PE findings. Tests with a zero cell count had 0.5 added to each cell in order to compute odds ratios and confidence intervals. Regression analysis was subsequently performed to see if there were any significant differences in PE findings between NR and DR on Visit 1 that might predict prolonged recovery. All data analyses were performed using the R programming language.²⁵

RESULTS

A total of 93 subjects participated in the study. Eleven AC subjects were excluded from the study: 10 did not follow-up with the physician and 1 refused to have the exercise test at the second visit. Subjects who did not complete the study (n=11: 6 males and 5 females) did not significantly differ on any characteristics or study variables from those who remained in the study. There were no exclusions in HC. The final study population included 82 adolescents: AC, n = 52, 15.5±1.4 years, 4.4±2 days since injury, 26.2±38 days to recovery, 71% male; and HC, n = 30, 15.8±1.4 years, 73% male. Table 2 presents participants' demographic information. Age (p=0.248), gender (p=0.835), and prior concussions (p=0.953) were not significantly different between AC and HC.

At Visit 1, elements of the PE were successful in distinguishing AC from HC after Bonferroni correction: cervical tenderness (p=0.0055) and abnormal smooth pursuits (p<0.0001), near point of convergence (NPC, p=0.0002), horizontal saccades (p<0.0001), vestibular ocular reflex (VOR, p=0.0002), and tandem gait (p=0.0009). Details of the individual tests are presented in Table 3 and Figure 1. On Visit 1, 42 out of 52 AC had 1 or more findings on the PE while 5 out of 30 HC had 1 or more findings on the PE.

At Visit 2, 41/52 AC had a normal recovery (NR) according to blinded physician assessment whereas 11/52 AC had delayed recovery (DR). Table 2 presents the demographic data of NR and DR. After Bonferroni correction, abnormal PE findings at Visit 2 for DR when compared with NR included abnormal smooth pursuits (p=0.0001), NPC (p=0.0002), and tandem gait (p=0.0002). Details of the individual tests on Visit 2 are presented in Table 4

and Figure 2. Of the 41 participants who were diagnosed as recovered, 37 (90%) had no PE signs of concussion. The four participants who still had a physical sign included 2 participants with abnormal NPC (> 10 cm), one with oculomotor dysfunction (causing reading problems, referred to a specialist), and one with neck muscle tenderness (referred to physical therapy). Of the 11 DR, 9 had positive PE results. The 2 participants with negative PE findings, however, were not considered recovered by the physician based on persistently abnormal symptoms and demonstrated early exercise intolerance, which was defined as symptom-exacerbation stopping exercise at less than 70% of age-appropriate estimated maximum heart rate on the BCTT.²⁶ Interestingly, there were six instances of a normal PE sign at Visit 1 that were recorded as abnormal at Visit 2. One participant from group DR had no neck tenderness on Visit 1 but had neck tenderness on Visit 2. Two participants initially did not have abnormal NPC but exhibited it at Visit 2 (one from DR and NR each). Three participants, all in group DR, exhibited an abnormal tandem gait test that was not initially present.

When comparing the Visit 1 PE findings of NR with DR, DR exhibited slightly abnormal cervical ROM ($p=0.0415$) and NPC ($p=0.019$), however, there were no statistically significant PE findings after a Bonferroni correction. Details of the individual tests on Visit 1 are presented in Table 5 and Figure 3.

DISCUSSION

This preliminary derivation study confirmed our hypothesis that elements of a brief but pertinent PE distinguished adolescents with SRC from healthy controls in the first week after injury and that PE findings usually returned to normal upon recovery from SRC. PE elements on the first clinic visit that clearly identified those who sustained a concussion included: cervical tenderness and abnormalities on testing ocular smooth pursuits, NPC, horizontal saccades, VOR, and tandem gait. Although the initial visit PE was clearly useful in helping to identify concussed from healthy participants it did not predict which participants recovered within a typical time frame (i.e., 3 weeks from injury). This study was conducted before the 5th CISG so we used the definition “symptoms persisting for more than 3 weeks from injury” for PPCS; the newer guidelines define PPCS as symptoms more than 30 days from injury.^{27,28}

The follow up PE, performed approximately two weeks after the first visit, was very useful for determining recovery from SRC, which we defined as a normal level of symptoms and normal exercise tolerance on the BCTT.^{24,28} Of the four cases that had PE signs at the second visit but who had recovered to normal exercise tolerance, two had secondary injuries (one to the neck and one to the oculomotor system) and two had abnormal NPC (without reported vision problems), which our data show can occasionally be seen in uninjured controls. The PE abnormalities most associated with delayed recovery included symptomatic ocular smooth pursuits, abnormal NPC, and unsteadiness on tandem gait/stance. Thus, persistent PE findings in the oculomotor and vestibular sub-systems appear to be associated with delayed recovery. This is important for clinicians because relying exclusively on symptom reports is not recommended because they are subjective, non-specific to concussion,¹⁷ and do not always coincide with recovery of physiological measures such as

exercise tolerance,²⁸ cerebral blood flow,^{29–31} brain metabolism,³² and white matter changes on diffusion tensor imaging.^{33,34} Another interesting observation was that some PE elements (e.g., tandem gait) recorded as negative on the first visit became positive on the second visit in those with delayed recovery. The reason is not clear. This may represent variation in the PE test application/ interpretation or that some injuries, for example to the vestibulo-spinal sub-system, may evolve over several days. Other forms of vestibular dysfunction have been shown to have evolution of physical signs over time.³⁵

The oculomotor and vestibular PE is being recognized as an important part of the neurological assessment of concussion.¹¹ The visual system is vulnerable to injury³⁶ and many concussed patients report blurred vision, difficulty focusing, and reduced peripheral vision that can affect concentration, reading ability, and balance.³⁷ Anzalone et al.³⁸ recently published that abnormal horizontal and vertical saccades were associated with delayed recovery from concussion in adolescents. Vestibulo-ocular sub-system dysfunction (dizziness, vertigo) and vestibulo-spinal sub-system dysfunction (altered balance) are common after concussion and have been associated with PPCS and greater disability.^{39,40} While in most SRC patients the vestibular dysfunction is central and generally resolves within a week of injury,⁴¹ it is important to identify persisting vestibular dysfunction because it can be treated with vestibular rehabilitation.^{42–44} Finally, the cervical spine PE is an important part of the assessment of head-injured patients⁴⁵ because head and neck injuries often occur simultaneously⁴⁶ and cervical symptoms mimic those of head injury,^{17,47} including headaches, dizziness, visual disturbances, and poor postural control. Even cognitive symptoms traditionally attributed to brain injury such as mental foggy, reduced concentration and short-term memory impairment are reported after whiplash injuries,^{17,48,49} and cervical injuries that cause persistent dizziness and headaches increase the risk of PPCS.²² Thus, a careful PE of the cervical spine is essential for managing concussed adolescents since cervical physical therapy can return athletes with PPCS and cervical injuries to sport more rapidly.⁵⁰

We have published a comprehensive “toolbox” of PE elements that clinicians may consider in the evaluation of concussion.³⁷ Physicians, however, do not always perform a PE when evaluating concussed patients. Boutis et al² showed that, relying on demographic, injury-related, and symptom variables, ED physicians diagnosed concussion less often relative to international consensus-based guidelines. Thus, ED physicians may be missing cases of concussion when using a predominantly symptom-based assessment. The advantage of seeing patients in the outpatient setting, where recent data suggest the majority of concussed youth are first evaluated,⁵¹ is that serial evaluations have more prognostic power. The results of the present study suggest that the diagnostic capability of a clinical assessment of recently concussed youth is improved by the serial application of a brief but pertinent PE. The PE used in this study can be performed in approximately 5 minutes with a little practice, which is well within the capacity of busy primary care providers to perform.

Concussion is a medical problem with a differential diagnosis because the symptoms after head injury are non-specific and can originate from several different neurological sub-systems or from structures other than the brain.^{16,17,52} Instruments like the VOMS are useful for the detection of symptom exacerbation during maneuvers that challenge the vestibulo-

ocular neural circuits and can identify concussed patients⁹ but the instrument does not include a cervical spine examination or a dynamic examination of the vestibulo-spinal system (gait), both of which often accompany the injury that produced the concussion. These systems are examined in the SCAT5 but it does not contain a systematic evaluation of oculomotor dysfunction. Instruments that don't evaluate these sub-systems may miss important objective information that have been associated with prolonged recovery in concussed patients.⁵³ Symptom reports and PE findings alone, however, may not establish etiology without further testing. It may be valuable for physicians to establish return of normal exercise tolerance for student athletes after SRC because it appears to be a reliable and valid indicator of cardiovascular and cerebrovascular physiological recovery from concussion.⁵⁴ The data from the present study indicate that it is valuable for physicians to do a pertinent PE since it is able to identify isolated neurological sub-system and cervical dysfunction early, which may allow the physician to direct specific therapy to those with persistent symptoms and perhaps prevent the development of PPCS.¹⁶

The strengths of this study are that it included a homogeneous sample with age- and sex-matched controls and, unlike most concussion studies, used an a-priori physiological measure of concussion recovery beyond symptom resolution (return of normal exercise tolerance).²⁸ Unlike other concussion evaluation tests (computerized neurocognitive tests, the BESS test), there does not appear to be a substantial learning/practice effect with each of these PE components, which is a strength within the multifaceted evaluation of concussion. Limitations of the study include that only 11 of the 52 subjects experienced delayed recovery. While the absolute number was small, it is nevertheless consistent with the incidence of delayed recovery in the literature.^{8,27} The control group consisted of healthy individuals and it would be advantageous to evaluate subjects with neck injuries without concussion to see if the PE battery distinguished SRC from cervical orthopedic injuries. It would be useful for clinicians' prognosis if the PE distinguished normal from delayed recovery after SRC at the initial examination. While significant and novel, the findings in this small derivation study warrant confirmation in larger trials to establish sensitivity, specificity and the predictive value of the PE. This study focused on adolescents injured in sport. Further research is necessary to see if these PE elements are appropriate for children, adults and in those with injuries from causes such as auto crashes and falls.

Conclusion

Our data show that a brief but pertinent PE distinguished patients with acute SRC from healthy controls and patients who have recovered from those who have not. Abnormal vestibular and oculomotor PE tests were the most useful for identifying concussion at the initial visit, which could help physicians more efficiently and objectively diagnose concussion. Another benefit of the PE is that normalization of the initial findings appears to be one objective indicator for clinical recovery. Persistent vestibular and/or oculomotor abnormalities 2–3 weeks after injury may be objective signs of delayed recovery from SRC, which could help physicians decide to institute specific therapies earlier on (e.g., vestibular/vision rehabilitation and/or sub-threshold exercise) to actively treat these patients and perhaps speed recovery or prevent evolution to PPCS. Finally, the PE should not be used as a standalone tool for concussion diagnosis and management; it should always be used in

combination with an assessment of symptoms, cognition, and physiological tests such as systematic exertion testing.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Initial Examination (Visit 1): Acute Concussion (AC) vs. Healthy Control (HC)
* indicates p-value < 0.05 but not significant
** indicates significance after Bonferroni correction, p-value < 0.0056

Figure 2.

Second Examination (Visit 2): Delayed Recovery vs. Normal Recovery

* indicates p-value < 0.05 but not significant

** indicates significance after Bonferroni correction, p-value < 0.0056

Figure 3.
Initial Examination (Visit 1): Delayed Recovery vs. Normal Recovery
* indicates p-value < 0.05 but not significant
** indicates significance after Bonferroni correction, p-value < 0.0056

Table 1.**Brief Buffalo Concussion Physical Examination Elements**

Oculomotor	Cervical Spine and Occipital Nerve	Vestibular
Near Point Convergence *	Range of motion	Vestibulo-ocular Reflex
Smooth Pursuits	Occipital and Cervical muscles tenderness	Romberg
Horizontal Saccades	Muscle spasm	Tandem Gait with Tandem Stance **

* Near Point Convergence considered abnormal if >10cm from glabella^{54,55}

** Tandem stance performed with eyes closed for 20 seconds

Table 2.

Characteristics of Acutely Concussed and Healthy Controls

	Healthy Control (n=30)	Acutely Concussed (n=52)	P-value	Normal Recovery (n=41)	Delayed Recovery (n=11)	P-value
Age (SD)	15.83 (1.37)	15.46 (1.41)	0.248	15.46 (1.47)	15.45 (1.21)	0.985
Sex	22 (73%) male	37 (71%) male	0.835	31 (75.6%) male	6 (54.5%) male	0.178
Prior Concussions	9 (30%)	14 (31%)	0.953	12 (29%)	2 (18%)	0.393
Days Since Injury to Visit 1 (SD)	NA	4.37 (2.03)	-	4.56 (2.10)	3.64 (1.63)	0.182
Days to Recovery (SD)	NA	26.19 (38.27)	-	13.00 (6.82)	75.36 (62.55)	<0.0001
Mean Symptom Score Visit 1 *	0.67 (1.27)	31.25 (22.89)	<0.0001	25.22 (19.16)	53.73 (22.32)	<0.0001
Total PE signs Visit 1 (SD)	0.07 (0.37)	2.79 (2.13)	<0.0001	2.61 (2.19)	3.45 (1.81)	0.246
Mean Symptom Score Visit 2 * (SD)	0.60 (1.13)	8.31 (15.06)	0.007	2.54 (5.93)	29.82 (19.26)	<0.0001
Total PE signs Visit 2 (SD)	NA	0.65 (1.14)	-	0.17 (0.67)	2.45 (2.11)	<0.0001

* On Post-Concussion Symptom Scale (PCSS), max = 13

Table 3.

Initial Examination (Visit 1): Fisher's Exact Test and Odds Ratio (OR) for Participants with Concussion (AC) vs. Healthy Controls (HC)

Test	OR	Lower	Upper	P-value
Cervical				
Spasm	4.3131	0.2153	86.4060	0.2954
Tenderness	16.9036	0.9586	298.0709	0.0058
ROM [*]	3.0198	0.1403	65.0201	0.5303
Oculomotor				
Smooth pursuits	38.0255	5.4632	1652.5872	<0.0001
Convergence	19.1184	2.7235	836.3153	0.0002
Saccades	22.3357	3.1974	974.5391	<0.0001
Vestibular				
VOR ^{**}	30.0704	1.7350	521.1642	0.0002
Tandem Gait	14.9831	2.1098	659.1322	0.0009
Romberg	7.0632	0.3769	132.3575	0.1527

* Range of motion

** Vestibulo-Ocular Reflex

Table 4.

Second Examination (Visit 2): Fisher's Exact Test and Odds Ratio (OR) for Delayed Recovery (DR) vs. Normal Recovery (NR) Groups

Test	OR	Lower	Upper	P-value
Cervical				
Spasm	21.8421	0.9672	493.2498	0.0415
Tenderness	13.8796	0.9788	801.5232	0.0262
ROM	11.8571	0.45	312.4451	0.2115
Oculomotor				
Smooth pursuits	41.8147	4.0001	2221.5053	0.0001
Convergence	19.9356	3.1593	173.7532	0.0002
Saccades	3.6087	0.0678	191.9797	1
Vestibular				
VOR	3.8612	0.0464	320.695	0.3816
Tandem gait	70.2308	3.4588	1426.0205	0.0002
Romberg	21.8421	0.9672	493.2498	0.0415

Table 5.

Initial Examination (Visit 1): Fisher's Exact Test and Odds Ratio (OR) for Delayed Recovery (DR) vs. Normal Recovery (NR) Groups

Test	OR	Lower	Upper	P-value
Cervical				
Spasm	8.3745	0.3967	534.8118	0.1095
Tenderness	1.533	0.2141	8.5491	0.6810
ROM	21.8421	0.9672	493.2498	0.0415
Oculomotor				
Smooth pursuits	2.2679	0.4582	15.1664	0.3186
Convergence	5.5352	1.1022	37.7497	0.0190
Saccades	0.4006	0.0599	1.9797	0.3081
Vestibular				
VOR	1.2257	0.2225	5.9123	1
Tandem gait	1.1	0.2007	5.2601	1
Romberg	6.9229	0.6806	95.7537	0.0574