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Concussion Recovery Phase Affects Vestibular and Oculomotor Symptom Provocation

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Key words
near point convergence, optokinetic stimulation, concussion, vestibular, balance

accepted after revision 02.08.2017

Bibliography
DOI https://doi.org/10.1055/s-0043-118339
Published online: 30.11.2017
Int J Sports Med 2018; 39: 141–147

ISSN 0172-4622

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ABSTRACT

Vestibular and oculomotor testing is emerging as a valuable assessment in sport-related concussion (SRC). However, their usefulness for tracking recovery and guiding return-to-play decisions remains unclear. Therefore the purpose of this study was to evaluate their clinical usefulness for tracking SRC recovery. Vestibular and oculomotor assessments were used to measure symptom provocation in an acute group (n = 21) concussed ≤ 10 days, prolonged symptoms group (n = 10) concussed ≥ 16 days (median = 84 days), healthy group (n = 58) no concussions in > 6 months. Known-groups approach was used with three groups at three time points (initial, 2-week and 6-week follow-up). Provoked symptoms for Gaze-Stabilization (GST), Rapid Eye Horizontal (REH), Optokinetic Stimulation (OKS), Smooth-Pursuit Slow (SPS) and Fast (SPF) tests, total combined symptoms scores and near point convergence (NPC) distance were significantly greater at initial assessment in both injury groups compared to controls. Injury groups improved on the King-Devick test and combined symptom provocation scores across time. The acute group improved over time on REH and SPF tests, while the prolonged symptoms group improved on OKS. A regression model (REH, OKS, GST) was 90 % accurate discriminating concussed from healthy. Vestibular and ocular motor tests give valuable insight during recovery. They can prove beneficial in concussion evaluation given the modest equipment, training and time requirements. The current study demonstrates that when combined, vestibular and oculomotor clinical tests aid in the detection of deficits following a SRC. Additionally, tests such as NPC, GST, REH, SPS, SPF OKS and KD provide valuable information to clinicians throughout the recovery process and may aid in return to play decisions.

Introduction

Despite a recent increase in awareness about potential cumulative effects of repeated head impacts, an estimated one third of all concussions remain undiagnosed [27]. Moreover, a study of 730 NCAA Division I football athletes found that during a football player's career, they experience nearly three undiagnosed concussions and twelve hits which result in one or more symptoms [5]. The subjectivity and variance of symptoms and lack of objective diagnostic criteria complicate efforts to accurately identify a concussion [12, 19, 21]. A multifaceted approach including not only signs and symptoms (S/S) but the inclusion of ocular-motor, cervical, and vestibular screenings has been suggested to overcome this obstacle [7, 23, 24, 27, 35, 38]. Clinical evaluations incorporating advanced posture control analysis and oculomotor assessment have been shown to identify concussed athletes with 98.6 % accuracy [25]. Supporting reports show that incorporating a brief vestibular/ocular motor screening increases the probability of detecting a concussion by 50 % [27]. However, the extent to which these tests detect individuals suffering from prolonged recovery, and aid in return to play decisions is unknown.

Many diagnostic tests have been shown to reliably detect deficits in postural control in a concussed population [14, 25, 29]. Common tests include the Balance Error Scoring System (BESS) and the

Sensory Organization Test (SOT) [6], while others include advanced technology such as the use of virtual reality [32, 33, 35, 36]. Objective outcome measures with high sensitivity and specificity often require costly instruments such as high-resolution cameras and force plates that are not readily available on the sideline. Furthermore, instrumented balance exams such as the SOT, which examines the integration of vestibular, visual, and somatosensory inputs cannot be performed on a sideline. This lack of accessibility has led researchers to look at the potential sensitivity of additional expedient and accessible tests that target alterations in cognition [3, 26], oculomotor function [2, 17], and/or vestibular function [25, 28, 38].

Feasibility, accessibility and validity are the primary concerns when considering the recommendation of an assessment tool [12]. Self-reported symptoms are generally the first indication of a concussion, therefore the purpose of this study was to evaluate the usefulness of several oculomotor and vestibular tests for assessing S/S of concussion and tracking recovery. Because tracking the timeline of recovery is essential for clinical management, each test was performed at 2 weeks and 6 weeks post initial evaluation. The proposed multifaceted approach will allow clinicians to detect deficits in vestibular and/or oculomotor structures allowing for targeted diagnosis and treatment.

Methods

Study design

A prospective repeated measures design with a known-groups approach (i. e. healthy vs. concussion vs. prolonged recovery) was implemented. Group 1 consisted of healthy participants without head, vestibular, ocular and/or lower extremity injury diagnosis in the previous 6 months. Group 2 (acute) included participants who had recently (≤ 10 days) suffered a diagnosed concussion. Group 3 prolonged recovery consisted of participants who had self-reported suffering a concussion in the previous 6 months and continued to suffer from one or more symptoms. All evaluations for injured athletes occurred following an initial injury and therefore no baseline data is available. Follow-up assessments for all 3 groups were completed at 2 weeks and 6 weeks following the initial evaluation.

Subjects

A total of 89 students participating in either Division I NCAA sport or club sport volunteered to participate in this study (48 males; 41 females). There were 58 healthy control participants (21.7 ± 3.5 years; 173.2 ± 9.4 cm; 71.4 ± 12.2 kg), 21 concussed (20.5 ± 2.3 years; 174.4 ± 10.7 cm; 72.8 ± 8.4 kg) and 10 prolonged recovery (20.5 ± 2.7 years; 178.3 ± 9.9 cm; 75.1 ± 8 kg). The acute group had experienced symptoms for 3–12 days, while the prolonged recovery group had experienced symptoms for 16–120 days post injury. The study was approved by the Temple University IRB and all subjects signed a consent form prior to data collection [16].

Instrumentation

The dependent variable for each of the four symptom-oriented clinical tests was a validated 7-point verbal rating scale used to report dizziness, headache, and nausea ("No symptoms" = 0, the highest level of symptoms = 6) [25, 28]. Each participant was asked to rate his or her level of dizziness, headache, and nausea from 0–6 prior to clinical testing to establish a baseline symptom severity score. They were asked to rate the same symptoms immediately following each test. The within-subject change from initial level was used as the outcome measure in the statistical analysis. Following each test, scores were summed across each of the three symptoms (maximum score 18) as the number of symptoms provoked for that specific test.

Symptom-oriented clinical testing

The following clinical tests were performed following established methodology. The rapid horizontal eye saccades (REH), slow and fast smooth pursuit (SPS, SPF), optokinetic stimulation (OKS) and horizontal gaze stabilization test (GST) [25, 28]. During all tests the examiner watched the participant's eyes for overshoot or disconjugate eye movement as well as the participant's ability to fixate on the appropriate target. SPS, SPF, and REH were used to test the participant's ability to follow a slow- or fast-moving target. OKS was evaluated by having the participant view a moving striped visual stimulus on an iPad in the visual field in order to expose participants to a fast moving optic flow field to elicit nystagmus and potentially induce S/S. Lastly, the GST tested the ability to stabilize vision while the participant fixated on a single point while rapidly rotating the head back and forth (as if indicating "no").

Signs of oculomotor dysfunction

Near point of convergence (NPC) and King-Devick (KD) tests were also performed in order to assess each participant's oculomotor function [17, 25]. A convergence insufficiency is the inability to maintain binocular focus causing diplopia resulting in blurriness. Accommodation difficulties which result in an inability to maintain focus at a close distance may also be detected using these test. Poor performance on the KD test may be a sign of diminished saccadic movement speed and/or cognitive and language processing.

Statistical analysis

Group differences in demographics at initial assessment were analyzed using a one-way ANOVA. Group differences in KD, NPC, and symptom provocation following each clinical test at the three time points (initial assessment, 2 weeks and 6 weeks) were analyzed using a mixed-model repeated measures ANOVA. Due to large differences in group samples, violations of sphericity were checked by Mauchly's test, and in cases where a large violation of sphericity occurred a MANOVA was used [11]. Data normality was examined by looking at the skewness and kurtosis followed by viewing scatter and box and whisker plots. In cases where the data were not found to be normally distributed non-parametric analysis using Kruskal-Wallis and Mann-Whitney tests for between-group comparisons were performed. Additionally Friedman's test and Wilcoxon's signed ranks test for repeated measures analysis were used, which are appropriate for ordinal scale measures. A logistic regression for binary outcomes ("Enter Method" and "Forward Conditional") was performed to examine the known-groups validity of symptom provocation during vestibular and oculomotor assessments when combined with NPC and KD. Accuracy was calculated as the sum of

the true positives and true negatives divided by the total sample size. All statistical analyses were conducted using SPSS software (version 22.0; IBM Corporation, Armonk, NY) and significance was set at alpha less than or equal to 0.05. Bonferroni correction was used to adjust p-values for multiple comparisons.

Results

Demographic Data

Means and standard deviations between groups are reported in ▶ **Table 1**. There were no differences in sex, height, weight, or age. The healthy group was different from the acute concussion and prolonged recovery group in both years' experience in primary sport ($p = 0.006$) and number of previous self-reported concussions ($p < 0.001$).

Change in outcome measures over time

The mixed-model repeated measures ANOVA revealed significant within-group differences across time in KD total time ($F4,144 = 3.71$, $p = 0.007$). KD total time improved across time relative to the initial assessment at both 2 weeks ($p = 0.04$) and 6 weeks ($p = 0.002$) for the prolonged recovery group; however, the acute group did not significantly improve until the 6 week time point ($p = 0.001$). Although NPC demonstrated between group differences ($F2,70 = 8.53$, $p < 0.001$) there was not a significant change across time ($F4,140 = 1.05$, $p = 0.38$). The combined symptom provocation scores showed a significant decrease over time relative to baseline ($F4,150 = 7.47$, $p = 0.007$) for the acute group at both 2 weeks ($p = 0.005$) and 6 weeks ($p = 0.005$) and for the prolonged recovery groups at the 6 week time point ($p = 0.037$). The changes across time for each individual outcome measure are displayed in ▶ **Fig. 1**.

Between-group difference in concussion outcome

In addition to the initial mixed models repeated measures ANOVA, non-parametric Mann-Whitney tests were performed to further explore group differences for each of the clinical tests (see ▶ **Table 2).** Statistically significant differences in provoked symptoms between acutely concussed group and healthy participants at initial evaluation were observed for the GST ($p = < 0.001$), REH ($p = < 0.001$), SPS ($p = 0.004$), SPF ($p = < 0.001$) and OKS ($p = < 0.001$) as well as the total combined symptoms provocation score ($p = < 0.001$). Additionally, mean NPC was higher in the acutely concussed group (5.4 ± 2.8 cm) compared to the healthy control group (3.4 ± 1.9 cm). A significant difference between the healthy participants and prolonged recovery participants was also observed at baseline for NPC ($p = 0.004$) as well as symptoms provoked following the GST ($p = 0.001$), REH ($p = < 0.001$), SPS ($p = 0.001$), SPF ($p = < 0.001$), OKS ($p = < 0.001$) tests. At the 2-week time point the only significant difference between the healthy and acute concussion group was for symptoms following the OKS test ($p = < 0.001$), while significant differences between the healthy and prolonged recovery group were only found in symptoms following SPS ($p = < 0.001$) and SPF ($p = 0.001$) tests.

Discriminating healthy from concussed participants

Mann-Whitney test revealed no significant difference between the acute concussion and the prolonged recovery groups. Therefore, these groups were combined and a logistic regression model for binary outcomes (healthy vs. concussed) was performed by testing the assessments that were found to differ between initial evaluation group statuses (▶ **Table 2**).

A multivariate logistic regression for binary outcomes using the "Enter" method was performed first (▶ **Table 3**). This analysis identified the best subset of independent predictors of concussion as NPC, and number of symptoms following the REH, OKS and GST tests (accuracy = 89.7 %, $p = 0.001$). A second assessment using the "Forward conditional" method was performed in order to evaluate the effectiveness of summing symptom provocation scores across all clinical tests and produced a second model with this combined symptoms metric and NPC. This model could identify group status with 90 % accuracy ($p = < 0.001$).

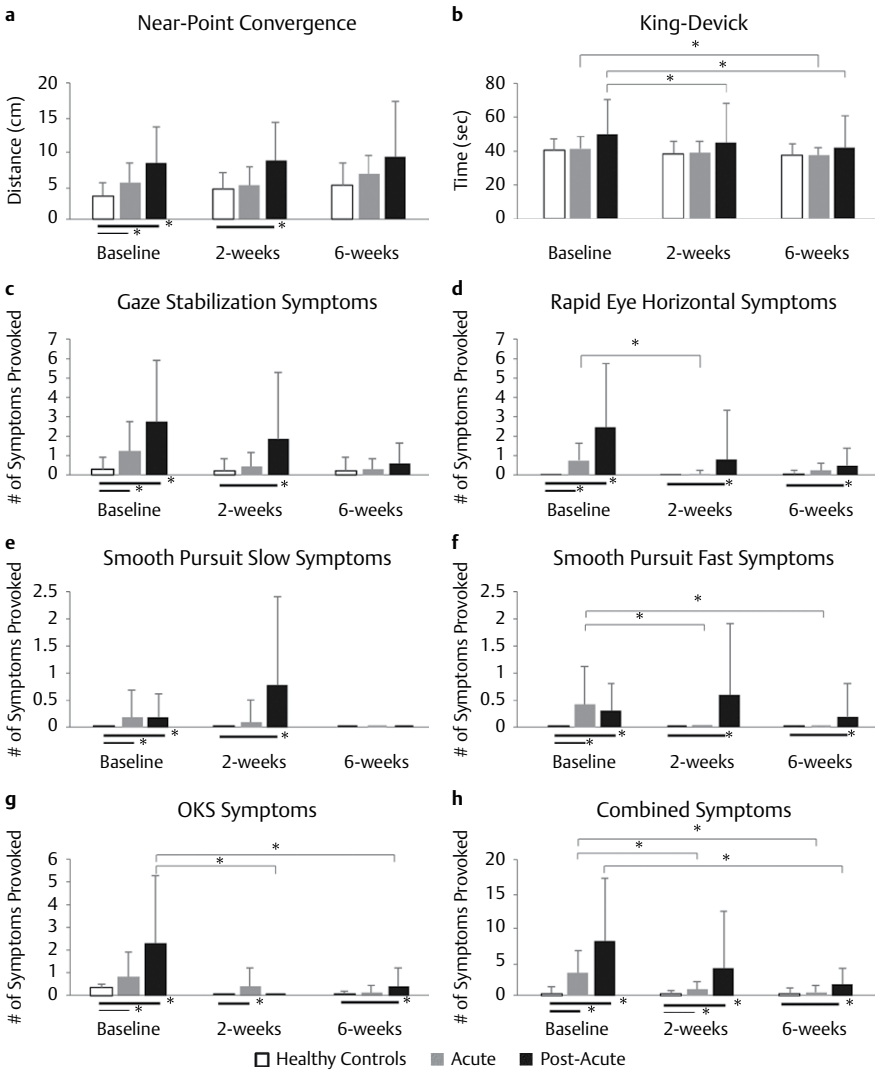
Discussion

The results of the present study show a brief test battery that requires no specialized equipment or extensive training and can accurately (90 %) differentiate between healthy and concussed athletes. Moreover, when performed at intervals following the initial evaluation, progress can be tracked and help in a return-to-play decision. Timely evaluations that are both sensitive and specific are crucial to making appropriate decisions whether to remove or re-

▶ **Table 1** Descriptive characteristics of participants enrolled in study.

Variables	Healthy	Acute Concussion	Prolonged Recovery	P
	N = 58	N = 21	N = 10	
	M ± SD	M ± SD	M ± SD	
Age (yrs)	21.68 ± 3.7	20.57 ± 2.37	20.5 ± 2.7	0.289
Height (cm)	173.30 ± 9.4	174.37 ± 10.6	178.56 ± 9.9	0.336
Weight (kg)	71.17 ± 12.2	75.68 ± 15.85	75.06 ± 8.1	0.332
Years experience	10.55 ± 5.4	6.11 ± 6.2	6.88 ± 3.1	0.006 *
Previous concussions	0.34 ± 0.8	0.95 ± 1.1	4 ± 3.3	0.000 *
Sex (%)				0.436
Male	35 (60 %)	15 (71.4 %)	7 (70 %)	
Female	23 (40 %)	6 (28.6 %)	3 (30 %)	

M (Mean), SD (standard deviation), n (number). * significance at $p < 0.05$



▶ **Fig. 1** Vestibular and oculomotor tests provoke symptoms in acute and post-acute mTBI. Comparisons across time (baseline, 2-weeks, 6-weeks) for each group: healthy (white bars), acutely concussed (grey bars), prolonged recovery (black bars). The healthy group showed no changes across time in any assessment. Near point of convergence (NPC), Gaze stabilization test (GST) and SPS (slow smooth pursuit) showed no change across time. KD (King-Devick Test, total time), REH (rapid eye horizontal), SPF (fast smooth pursuit), OKS (optokinetic stimulation), and combined S/S all showed changes across time and between groups. KD showed no between group differences. * Significant differences within-groups across time (bracket above bars) or between-groups (line below bars), $p < 0.05$.

turn an athlete to the competition. Many considerations such as the risk of potential further damage [13, 22], legal implications [18], expectations of peers [20], and the player's willingness to accurately report must be weighed with the potential negative effects of withholding an athlete that could have otherwise competed [20].

Symptoms: what are they and what do they mean

Current concussion position statements define a concussion as a pathomechanical event that elicits one or more symptoms [15, 24], and much is known about concussion symptoms such as headache, dizziness, nausea and fatigue [21, 31]. However, these symptoms are not unique to concussion; comorbid pathologies such as whiplash [22], exertional heat illness [1, 4], exertional sickling [8], dehydration [9], sleep deprivation or hunger [10] can induce similar symptoms and signs. These overlapping pathologies and S/S necessitate a greater ability to identify specific damaged structures and processing pathways associated with each symptom [7, 27, 37]. Clinical tests such as NPC, KD, GST, SPS, SPF, and OKS have been well-suited to test the volitional and reflexive vestibular and oculomotor function [17, 34]. Recent investigations of clinical testing following concussion have reported that perhaps as important as the presence and number of symptoms following a suspected concussion is whether or not these symptoms intensify during clinical testing or exercise [2, 12, 21, 24, 30]. The results from the present study demonstrated significant between-group differences in NPC and in symptoms provoked during the GST (<0.001), REH (<0.001), SPS (.004), SPF (<0.001) and OKS (<0.001) between healthy controls and concussed patients independent of number of baseline

▶ **Table 2** Means and standard deviations of concussion assessment scores across recovery time.

	Group			P-Value		
	Healthy M ± SD	Acute M ± SD	Prolonged Recovery M ± SD	Healthy vs. Acute	Healthy vs. Prolonged Recovery	Acute vs. Prolonged Recovery
Initial Visit						
	N = 58	**N = 21**	**N = 10**			
NPC (cm)	3.41 ± 1.9	5.37 ± 2.8	8.19 ± 5.3	0.020 *	0.004 *	0.114
KD (sec)	40.1 ± 6.6	41.1 ± 7.3	49.6 ± 20.4	0.641	0.096	0.214
GST S/S Score	0.25 ± 0.71	1.23 ± 1.5	2.75 ± 3.17	< 0.001 *	< 0.001 *	0.201
REH S/S Score	0.0 ± 0.0	0.76 ± 0.83	2.45 ± 3.3	< 0.001 *	< 0.001 *	0.268
SPS S/S Score	0.0 ± 0.0	0.19 ± 0.51	0.2 ± 0.42	0.004 *	0.001 *	0.852
SPF S/S Score	0.0 ± 0.0	0.42 ± 0.7	0.3 ± 0.5	< 0.001 *	< 0.001 *	0.917
OKS S/S Score	0.34 ± 0.18	0.84 ± 1.1	2.3 ± 1.3	< 0.001 *	< 0.001 *	0.164
Combined S/S	0.36 ± 0.99	3.38 ± 3.3	8.1 ± 9.16	< 0.001 *	< 0.001 *	0.173
2 WEEK						
	N = 52	**N = 20**	**N = 10**			
NPC (cm)	4.46 ± 2.0	4.9 ± 2.85	8.51 ± 5.6	0.756	0.010 *	0.046
KD (sec)	38.2 ± 4.7	38.6 ± 6.7	44.3 ± 23.6	0.950	0.954	0.779
GST S/S Score	0.21 ± 0.6	0.45 ± 0.7	1.9 ± 3.4	0.050	0.004 *	0.194
REH S/S Score	0.0 ± 0.0	0.05 ± 0.2	0.8 ± 2.5	0.107	0.023 *	0.576
SPS S/S Score	0.0 ± 0.0	0.10 ± 0.4	0.78 ± 1.6	0.107	< 0.001 *	0.141
SPF S/S Score	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 1.3	1.00	< 0.001 *	0.042
OKS S/S Score	0.0 ± 0.0	0.41 ± 0.8	0.0 ± 0.0	< 0.001 *	1.00	0.122
Combined S/S	0.21 ± 0.6	0.95 ± 1.1	4.0 ± 8.3	< 0.001 *	0.004 *	0.650
6 Weeks						
	N = 51	**N = 15**	**N = 7**			
NPC (cm)	4.93 ± 3.3	6.64 ± 2.6	9.17 ± 8.08	0.059	0.043	0.739
KD (sec)	37.0 ± 6.4	37.3 ± 4.5	41.8 ± 18.3	0.773	0.937	0.698
GST S/S Score	0.22 ± 0.7	0.27 ± 0.6	0.6 ± 1.1	0.457	0.133	0.481
REH S/S Score	0.04 ± 0.2	0.2 ± 0.4	0.5 ± 0.8	0.040	0.005 *	0.435
SPS S/S Score	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.00	1.00	1.00
SPF S/S Score	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.6	1.00	0.024 *	0.237
OKS S/S Score	0.02 ± 0.1	0.13 ± 0.4	0.4 ± 0.8	0.065	0.015 *	0.543
Combined S/S	0.27 ± 0.9	0.53 ± 1.1	1.7 ± 2.4	0.294	0.004 *	0.243

NPC (Near Point of convergence). KD (King-Devick Test, total time), GST (Gaze stabilization test), REH (rapid eye horizontal), SPS (slow smooth pursuit), SPF (fast smooth pursuit), OKS (optokinetic stimulation), Combined S/S (sum of symptoms provoked during each of the 5 clinical tests), S/S Score (difference between baseline symptoms severity score and symptom severity score following clinical test) * Significant between group difference at Bonferroni corrected p = 0.025

symptoms. Moreover, these differences were also observed when comparing healthy participants and those suffering from persistent symptoms (▶ **Table 2**). Symptom provocation during selected clinical tests that assess the vestibular and/or oculomotor pathway can potentially provide vital information about the location and severity of the potential injury.

Differentiating the concussed from the healthy

The results of the current study suggest that a short 5–10 min screening, which requires minimal equipment, can differentiate between healthy and concussed individuals with up to 91 % accuracy. Previous studies have indicated that using a small battery of tests which includes symptom provocation using OKS test, NPC, and a SOT could differentiate concussed individuals from healthy controls with 98 % accuracy [25]. The present study suggests that even without the SOT, which requires advanced postural analysis equipment, concussions can be detected with a high degree of sensitivity. Other recent studies also report that including a brief vestibular/oculomotor exam increases the likelihood of diagnosing a concussion by 50 % [28]. Increased accuracy allows those athletes who have suffered a concussion to receive the care they need and minimizes the risk of a false positive concussion diagnosis allowing healthy individuals to return to play.

A second primary goal of the present study was to track symptoms in both the acute and prolonged recovery groups relative to a healthy control group. It is notable that by the 2-week time point no significant differences remained between the acute group and healthy controls for any of the outcome measures. However, when comparing the prolonged recovery group to the healthy controls, significant differences in NPC and symptom provocation following

▶ **Table 3** Concussion assessment model-binary logistic regression.

Variables	β	SE	Wald X^2	p
Oculomotor score model (89.7 %)				
NPC	0.643	0.192	11.22	0.001 *
REH S/S	2.36	1.18	3.96	0.047 *
OKS S/S	2.91	1.00	8.42	0.004 *
GST S/S	−0.553	0.639	0.749	0.387
Constant	−4.83	1.11	18.9	<0.001 *
Convergence + Combined (90 %)				
NPC	0.622	0.195	10.218	0.001 *
Combined S/S	1.134	0.284	15.957	<0.001 *
Constant	−4.912	1.147	18.332	<0.001 *

SE (standard error), NPC (Near Point of convergence). GST (Gaze stabilization test), REH (rapid eye horizontal), OKS (optokinetic stimulation), S/S (difference between baseline symptoms severity score and symptom severity score following clinical test); * Significance at $p < 0.05$.

SPS and SPF and total symptom provocation score were evident at the 2-week and 6-week time points.

Some limitations should be noted. First, no baseline data were gathered for the two injury groups, therefore all post-injury evaluations had to be compared to healthy controls as opposed to their own baseline. Additionally, while we were able to collect data at all three time points for 51 of our healthy controls, only a total of 15 participants from the acute concussion group and seven from the prolonged recovery group completed all three time points. This attrition over the course of the three time points weakens our ability to generalize our results. An additional point regarding the longitudinal nature of our study is that three members in the acute group still reported one or more symptoms at the 2-week assessment. While we did not reassign them to the prolonged recovery group at that point for subsequent analyses because this would introduce internal validity threats to our repeated measures experimental design, it is noteworthy that typically less than 20 % report symptoms 2 weeks after a concussion. This led to our next limitation, which is there was significant variability in both number of symptoms and duration of symptoms in our prolonged recovery group. They had a median time since injury of 84 days, ranging from 16–120 days, which may have led to larger variances in outcome measure response. Future research on the progression of S/S at concurrent time points following an initial diagnosis is warranted. Another limitation was the use of subjective symptom reports in the current study. This may inherently affect reliability due to subjectivity, fidelity and motivation. This limits any attempt to precisely categorize the various stages of concussion recovery. Throughout the concussion literature, differing definitions of acute, subacute, and post-concussion syndrome are used, which is in part due to the fact that diagnosis of concussion is based on symptomatology. It is commonly accepted that symptoms following concussion resolve within 2 weeks [24], however, identification of S/S is largely dependent on the sensitivity of the outcome measure. Although our classification of prolonged recovery in this study was based on the currently accepted timeline of recovery, depending on what biomarkers for concussion may be identified in the future, classification categories of concussion may change and therefore must be viewed with caution. Despite these limitations, significant results and excellent accuracy were found using the current battery of tests.

Conclusions

These findings suggest that a brief ocular-motor screen including NPC, KD, GST, SPF, SPS and OKS can aid in the diagnostic process when evaluating for a suspected concussion. Moreover, repeating the same screening at regular intervals following an initial diagnosis of a concussion may aid in return to play protocol and track the healing process. The findings also reiterate the importance of symptom provocation following clinical testing, suggesting that perhaps more important than baseline symptoms is change in symptom score following testing.

What is known about the study

Recent research has demonstrated that the addition of oculomotor testing such as the King-Devick test and near point of convergence may increase the likelihood of detecting a concussion following a SRC. However, the extent to which these tests aid in tracking the natural progression of symptoms following recovery from SRC is less clear.

What this study adds to existing knowledge

Our results add to the emerging literature concerning the importance of including oculomotor and vestibular testing in the diagnosis of sports-related concussion. The value of including oculomotor and vestibular testing to track injury recovery following a SRC is demonstrated since evidence suggests that not all signs and/or symptoms may recover within 2 weeks.

Conflict of Interest

The authors have no conflict of interest to declare.

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