



Natalie Fish Bailey, DPT
Department of Physical Therapy,
University of Florida, Gainesville,
Florida, 32610

Correspondence:
NatalieFishBailey@gmail.com

Unique physical therapy management of a young adult with post-concussion symptoms: a case report.

Purpose: Current research is controversial on initiation of exercise in individuals experiencing post-concussion symptoms at rest. There is also minimal evidence associated with exertion protocols and vision therapy in this population. The purpose of this report is 1) to evaluate the Buffalo Concussion Treadmill Test (BCTT) on an individual with post-concussion symptoms at rest and its implications for clinical decision making with treatment progression, and 2) to describe unique physical therapy management of post-concussion impairments in vision and activity tolerance. **Measures and Interventions:** 20-year-old male with persistent post-concussion symptoms presented with deficits in activity tolerance, gaze stability and oculomotor performance. He was seen once per week for 3 weeks; symptoms were documented at rest and during visual performance and exertion tests. BCTT was used to diagnose concussion symptoms and establish a safe exertion program. Treatment consisted of graded exercise and vision therapy focused on vergence and saccadic exercises. **Outcomes:** At discharge, the patient reported zero symptoms via the Post-Concussion Scale, indicating clinically significant improvement in post-concussion symptoms. He performed all provocative visual performance and exertion tests without symptoms. **Conclusions:** Customized vision therapy with a home exercise program may be beneficial in treating visual and vestibulo-ocular deficits after concussion. The BCTT with advanced exertion testing, appears to be effective in determining safe return to sport when managing individuals with physiologic dysfunction after concussion. Further research is needed to develop standardized exertion tests in addition to its safety and effects on individuals who present symptomatically at rest. **Clinical Relevance:** When to begin exercise with individuals suffering from concussion remains controversial, and one purpose of this report was to help fill this gap. This paper describes the effects of initiating exercise in an individual symptomatic at rest. No adverse effects were reported throughout treatment.

Key Words: *post-concussion symptoms, exertion testing, vision therapy*

INTRODUCTION

A concussion is a subclass of mild traumatic brain injury (mTBI) often caused by a direct blow to or a traumatic acceleration of the head. Up to 3.8 million sports-related concussions occur annually, and over the past decade, emergency department visits for TBI-related incidences have increased by 70%.^{1,2} Following concussion, the injured brain undergoes a "neurometabolic cascade", resulting in disrupted ion channels and membrane potentials requiring significant demand of glucose in a limited supply environment and decreased cerebral blood flow.^{3,4,5} This energy crisis can last for hours to days.

During the neurometabolic cascade, the brain is in a vulnerable state and cannot keep up with energy demands required by physiologic (e.g. exercise) and cognitive (e.g. reading) stresses. While post concussive individuals are in this state, some theories suggest they are susceptible to exercise and cognitive-induced exacerbation of symptoms.

Post-Concussion Symptoms

Depending on the severity and location of the head injury, multiple signs and symptoms may emerge after concussion (Table 1). Symptoms may be delayed and can develop over hours or days and remain for

weeks to months. In rare cases, they can persist for years. Most frequently, symptoms resolve within 7-10 days, however 20% of individuals report persistent symptoms beyond this time frame.^{6,7} Headache and dizziness are the most commonly reported initial symptoms,^{4,8} and vision problems are reported in up to 60% of individuals.⁹

Several prospective cohort studies have identified post-concussion predictors that help distinguish individuals who are at risk for prolonged symptoms. These include higher levels of initial symptom reporting,^{9,10} post-traumatic migraines and immediate dizziness after concussion.¹¹

Table 1. Common Signs and Symptoms Post-Concussion

Signs	Symptoms
Loss of consciousness (present or absent)	Headache*
Dazed or stunned	Difficulty concentrating*
Coordination problems	Fatigue*
Retrograde amnesia	Drowsiness*
Post-traumatic amnesia	Dizziness*
Confusion	Mental "fogginess"*
Memory disturbance	Light and/or audio sensitivity*
Behavior or personality change	Balance problems*
Delayed response rate	Memory disturbance*
	Blurred or double vision
	Nausea
	Difficulty sleeping or change in sleep pattern
	Depression

Notes: (*) most commonly reported symptoms in athletes at 1-7 days post-concussion, derived from Kontos and colleagues.¹³

Concussion Management

The Zurich International Consensus Statement on Sport Concussions recommends a graded return to play protocol for athletes suffering from concussive symptoms (Table 2).⁷ The first step for acute concussion treatment is a cognitive and physical rest period, prescribed by the physician, to allow the brain to heal, minimize energy demands and normalize function.^{3,5,12} During the rest phase, it is recommended the individual avoid all forms of exercise, phone and computer use, video games, television, reading, academics, chores, driving, social environments and any other activity that may cause physical or cognitive stress.

Effectiveness of rest period duration is poorly established, typically lasting between a day and a few weeks, or until the individual is asymptomatic at rest.^{7,13} New research studies continue to search for the most effective length and stringency parameters for the rest phase in this population. In a randomized control trial (RCT), Thomas et al. determined that a 5-day strict rest after concussion did not have advantages over a 1-2-day rest period. However, the strict rest group demonstrated slower recovery of symptoms.¹⁴

Typically, if an individual continues to experience symptoms following the rest period, the physician may then refer to physical therapy (PT) for evaluation and treatment of symptoms. Therapy may include vestibular, exertional, oculomotor and cervical rehabilitation exclusively or in combination, and is customized to the individual's impairments.

Over the past decade, clinical research regarding concussion management has focused on the young, athletic population and return to play protocols. Evidence associated with management standards, advanced exertion tests and visual training techniques for concussion recovery is inadequate and primarily relies on expert opinion and widely accepted recommendations. No gold standard interventions have been established and minimal scientific data exists to support reliability and validity of visual training in this population. The purpose of this report is 1) to evaluate the use of the Buffalo Concussion Treadmill Test (BCTT) on an individual with post-concussion symptoms at rest and its implications for clinical decision making with treatment progression, and 2) to describe unique physical therapy management of post-concussion impairments in vision and activity tolerance.

Table 2: Graded Return to Play Protocol adapted from McCrory et al. Zurich Guidelines Consensus

Rehabilitation Stage	Functional exercise at each stage of rehabilitation	Objective of each stage
1. No activity	Symptom limited physical and cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming or stationary cycling keeping intensity <70% maximum permitted heart rate	Increase HR
3. Sport-specific exercise	No resistance training Skating drills in ice hockey, running drills in soccer. No head impact activities	Add movement
4. Non-contact training drills	Progression to more complex training drills, eg, passing drills in football and ice hockey May start progressive resistance training	Exercise, coordination and cognitive load
5. Full-contact practice	Following medical clearance participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6. Return to play	Normal game play	

CASE DESCRIPTION

Patient Description

A 20-year old male was referred to PT in Gainesville, Florida with a physician diagnosis of concussion, secondary to a motor vehicle accident (MVA). The patient denied any direct blow to the head or loss of consciousness, yet noted difficulty remembering events up to 20 minutes after the accident (referred to as anterograde amnesia). The following day, the patient reported to a physician, experienced in concussion management, with complaints of headache, dizziness, fogginess, imbalance, fatigue and soreness in neck, hip and lower back. After evaluation, the physician recommended a 2-week rest period, unless symptoms subsided earlier, and gave the patient a class excusal. He advised the patient to seek PT management if symptoms persisted past two weeks. The physician insisted the patient not participate in any contact activities until further notice. Per recommendations, the patient discontinued classes and recreational activities.

The patient was a full-time college student and participated in weight lifting, running and recreational sports that included monthly skiing trips out of state. He underwent a Chiari malformation surgery four years prior, and had not experienced issues since the surgery. This was the patient's first known concussion. Prior to the MVA, vision impairments, headaches and

concentration problems were nonexistent, and he did not require glasses for vision correction.

Seventeen days after the MVA, the patient sought PT with complaints of headaches, blurred vision and difficulty concentrating. At initial evaluation, he reported headache onset began 30-40 minutes into class and lasted for 40 minutes afterwards. He noticed blurred vision when glancing at or reading far distances, such as looking at the lecture board from his seat. His goals for therapy were to be able to perform school work without headaches and go on his next skiing trip in four weeks.

Examination

The Post-Concussion Scale (PCS) is a questionnaire compiled of 22 most commonly reported post-concussion symptoms. The individual rates the severity of each symptom between 0 (absent) to 6 (severe) for a maximum score of 132. Higher scores correlate to higher severity of symptoms. In clinical settings, the number of symptoms and level of severity are often reported separately. The PCS is reliable (internal consistency of reliability = 93)¹⁵ and valid¹⁶ in concussion populations. On initial examination, the patient completed a PCS indicating 8 symptoms. The highest level of severity he assigned was 3/6, allocated

to “difficulty concentrating” and “visual problems” symptoms.

No functional impairments in gait, strength, balance or cervical spine were identified through screenings. Based on self-reported symptoms and patient goals, the initial examination focused on Vestibulo-Ocular Motor Screening (VOMS) and activity tolerance assessment. The VOMS is a set of provocative tests used to identify impairments post mTBI. It has demonstrated high internal consistency and positive correlation with the PCS.¹⁷

The VOMS provocative tests selected for this patient were also components of reading (Appendix 1). Reading is a complex task requiring normal function of saccades (eye movement coordination), convergence (eye muscle coordination and fixation), accommodation (oculomotor control) and vestibulo-ocular reflex (VOR) (gaze stabilization). After each provocative test, the patient rated severity of symptoms on a 0 (absent) to 10 (severe) point scale. For this case report, the VOMS was used to diagnose impairments to guide treatment, and to monitor their clinical progression and symptom recovery.

Evidence supports the use of controlled, graded exercise in post-concussive individuals.¹⁸ Based on its standardization for this population, the BCTT is the most widely used activity tolerance test. It has demonstrated good reliability¹⁹ and is used to diagnose post-concussion physiologic dysfunction. In addition to its diagnostic use, the BCTT was mainly used in this study as a decision-making tool for physical exertion progression. During the test, the patient wore a heart rate (HR) monitor and ambulated on a treadmill at 3.3 miles per hour (mph) for 15 minutes. Every minute, the incline grade percentage was increased, and HR and change in symptoms was documented.

Evaluation-Diagnosis

The BCTT, VOR, saccades and convergence screenings provoked symptoms in this patient (Table 3). Based on these findings and subjective symptom report, the patient’s primary deficits included activity intolerance, gaze instability and impaired oculomotor performance required for reading, academics and recreational activity participation. Using Ellis and colleagues’ evidence-based classification system, these impairments place the patient in diagnostic categories:

vestibulo-ocular and physiologic post-concussion disorders.²⁰

Evaluation-Prognosis

The majority of post-concussion symptoms resolve within the first 10 days. Persistent symptoms require careful diagnosis and customized management to promote recovery without worsening symptoms. The patient exhibited adherence with the physician’s 2-week rest period and stated his motivation to accomplish therapy goals and daily compliance with the Home Exercise Program (HEP). Based on the patient’s internal factors, examination findings, and several years of clinical experience in concussion management, the clinician anticipated symptom recovery within 3-4 weeks contingent on patient adherence to activity modifications and HEP.

INTERVENTION

The patient participated in one PT session per week for three weeks; each session lasted 60 to 75 minutes. Interventions included vestibulo-ocular motor exercises, physical exertion and a daily HEP. The patient was to advised to stop any home exercise if any symptom increased to, or above, 5/10 severity. After a 24-hour rest period, he was allowed to resume a less intense activity at the previous asymptomatic level.

Vestibulo-Ocular Motor

At the first visit, the patient was given a HEP to address vision problems and reading difficulty with classroom participation (Table 3). The HEP included pencil pushups (PP) for vergence insufficiencies along with VOR exercises. PP’s addressing convergence were performed with the patient holding a pencil vertically at arm’s length. With eyes fixed on the pencil, the patient slowly brought it towards the nose until double vision occurred. While maintaining visual focus, he then “pushed” the pencil one inch closer to the nose before slowly returning to start position. For accommodation, the patient used one hand to hold the pencil and the opposite hand to cover the ipsilateral eye. He used the same technique as convergence, one eye at a time. Although scientific evidence is limited, vergence therapy has been supported by several studies and eye care practitioners use PP interventions frequently for convergence insufficiency.²¹⁻²³

Table 3: Outcome Measures and Associated Symptoms

	Visit 1	Visit 2	Visit 3
Number of Total Tests with Provoked Symptoms	3/4	0/4	0/4
Convergence²³ (cm)	3.5* (3/10 dizziness; inc. frontal head pressure)	4	4
Accommodation (cm)	R: 12 L: 15.5	R: 5 L: 7	R: 5 L: 6
Horizontal Saccades²³ (reps/sec)	78/30* (6/10 dizziness)	98/30	96/30
Horizontal VOR²³ (head turns/sec)	70/60* (5/10 dizziness; 4/10 headache)	112/60	120/60

Notes: *cm*, centimeters; *sec*, seconds; *VOR*, vestibulo-ocular reflex; *reps*, repetitions; *inc*, increase. (*) symptom provocation.

The patient performed horizontal VOR using the same technique as in the VOMS assessment (Appendix 1). Recent evidence supports vestibular rehabilitation in combination with traditional physical therapy to treat persistent dizziness in post-concussions and may decrease the amount for medical clearance to return to sport.²⁴

At the second visit, the patient identified 3 symptoms via the PCS, indicating 1/6 severity with “difficulty concentrating”, “visual problems” and “difficulty remembering.” He reported daily HEP completion and was able to participate in school for longer periods of time before the onset of headache. He still experienced blurred vision when reading the lecture board from his seat. Following the subjective report, objective measures were performed without provocation of symptoms (Table 3). To address the persistent reading impairment, the clinician administered advanced saccades (column jumps using Hart Charts) and added the exercise to the HEP. Although column jumps have not been specifically validated through clinical research, oculomotor rehabilitation (to include saccadic eye training) in brain

Physical Exertion

On the day of initial evaluation, the patient began the BCTT with a post-concussion symptom (headache, 3/10 severity). McCrory and colleagues return to play

injury populations have demonstrated improvements in subjective reading ability.^{25,26}

Column jumps involve eye coordination from left to right and near to far, mimicking the action of looking back and forth from a desk to board in the classroom environment. The two charts were different sizes containing identical 10-line grids of 100 letter and number combinations. The larger version was placed 12 feet away and the smaller version in the patient’s hand, held six inches away. One column jump repetition equated to the patient reading the first and tenth columns from the near chart as quickly and accurately as possible, followed by the corresponding columns from the far chart. This process continued sequentially until columns five and six were completed. Repetitions then reverted to columns four and seven and continued until the starting columns were reached. One set equaled ten repetitions.

At the third visit, the patient reported HEP adherence and zero symptoms via the PCS. He was symptom-free with all reading activities and academic work. Objective measures were performed a final time and without provocation of symptoms (Table 3).

protocol recommends light aerobic exercise after the individual is asymptomatic at rest and suggests intensity remain under 70% of maximum heart rate (MHR) (Table 2).⁷ Despite the presence of headache, the BCTT was administered with patient consent. This decision was

based on patient history and prior level of function, normal musculoskeletal and balance screenings, low severity of symptoms, and number of days since concussive episode. Using clinical judgement the therapist established a cutoff score of 4/10 symptom severity as identification of symptom exacerbation and indication to terminate the test. During the 15-minute BCTT, the patient's headache diminished to 0/10 three minutes into the test (at 57% of age adjusted MHR) and gradually escalated back up to 3/10 at 14 minutes (at 78% of MHR). At test end, he reached 86% of MHR. The clinician allowed the patient to perform aerobic activity at an intensity above 70% of MHR since he did not reach the 4/10 symptom severity cut-off score.

Although the patient's headache severity fluctuated during the BCTT, which indicated possible exertion sensitivity, it ultimately remained unchanged by the test's end. This outcome, in addition to his ability to walk to class without symptom exacerbation, resulted in the clinician initiating a light jogging HEP. He was educated on post-concussion symptoms and symptoms requiring immediate medical attention, such as the onset of slurred speech, weakness/ numbness/ tingling in limbs, repeated nausea and vomiting and/or increased confusion.

Five days later, the patient reported accomplishment of one jogging session via treadmill between 6.0-7.0 mph for 15 minutes. He stated headache symptoms began 10 minutes into the exercise and increased to 3/10 severity. During the treatment session, the BCTT was re-administered in a quiet treatment room. The patient reached 80% of MHR without exacerbation of symptoms, revealing normal results and physiologic function to exercise. It also indicated further exertion testing was necessary to identify his current level of dysfunction.

The patient progressed with a series of physical exercises of increased intensity and complexity. A dynamic circuit adopted from the UPMC EXertion Test (EXiT) for Concussion Clearance was first utilized.²⁷ The EXiT was established from clinical practice-based evidence and has yet to be supported by research-based evidence. It has been administered to incorporate athletic coordination and speed while

maintaining HR. The absence of symptoms during and after the EXiT results in normal findings, while symptom reporting is considered abnormal and requires a regimented exertion program.

This circuit purposely took place in the main treatment room with 25 additional rehabilitation staff and patients. Busy environments (similar to classrooms) create distractions cognitively, visually and auditorily which can draw out, or magnify, symptoms in post-concussive individuals. The patient performed two circuits of squats, alternating lunges and medicine ball rotations with minimal rest (Table 4). He reached 68% of MHR and without symptom provocation, indicating normal test results.

The next exertion tests included hand-eye coordination requiring functional gaze stability, oculomotor control and fine motor skills. During single leg stance and lateral plyometric jumps, the patient caught and threw tennis balls (Table 4). Based on the patient's absence of symptoms, reaction time, coordination and normal physiological response to exercise, he was instructed to progress intensity and duration of the jogging HEP while maintaining the symptom exacerbation precautions. He was also advised to return to weight lifting activities three times per week using light weight and high repetitions.

Nine days later at the third and last visit, the patient reported HEP completion and was symptom-free with all aerobic and weight lifting exercises. Since the patient was asymptomatic during the previous BCTT, the clinician advanced the physical exertion exercises (Table 4). The patient proceeded with treadmill jogging, plyometrics, speed sets and agility drills. Eighty-five percent MHR was reached without symptom provocation.

At 31 days after initial concussion, the patient presented with an absence of symptoms during all cognitive and physical activities. After findings and recommendations were reported to the treating physician, he concluded the patient was safe to return to all recreation activities. The patient met his personal goals for physical therapy and was able to participate in his upcoming skiing trip.

Table 4: Interventions and HEP

Visit 1	HEP 1	Visit 2	HEP 2	Visit 3
<ul style="list-style-type: none"> • PP's, x 5 each • Horizontal VOR, 60 sec Aerobic Exercise: BCTT (MHR: 171 bpm)	<ul style="list-style-type: none"> • PP's, 10 reps, 3x/day • Horizontal VOR, 2 x 60 sec, 3x/day Light jogging	<ul style="list-style-type: none"> • Advanced Saccades: Column Jumps, 4 reps • Aerobic Exercise: BCTT (MHR: 159 bpm) • Exertion Test: 15 squats, lunges, medicine ball rotations, x 2 (MHR: 135 bpm) • SLS, ball toss, 60 sec Lateral plyos, ball toss, 30 sec	<ul style="list-style-type: none"> • PP's, 10 reps, 3x/day • Column jumps, 1 set, 3x/day Jogging; increase frequency & intensity	<ul style="list-style-type: none"> • Treadmill Jogging; 5 mph, 8 min (MHR: 164 bpm) • Box Jumps, 12 in step, x 20 • Jump, ball toss, rotation, 30 sec • Pushup, jump, ball toss, x 10 • Speed steps, 60 sec Lateral plyos, 8 in step, cone taps, 30 sec (MHR: 170 bpm)

OUTCOMES

Seventeen days after concussion, the patient began PT with primary functional impairments in vision and activity tolerance. Subjective symptoms and severity were recorded per visit before treatment (via the PCS) and during the VOMS (Table 3). The BCTT and exertion exercises were utilized diagnostically and for decision making on exertion progression versus tools for outcome measures.

PCS

At initial evaluation, the patient presented with 8 symptoms via the PCS, indicating 15/48 severity. At the second visit, the PCS totaled 3 symptoms with 3/9 totaled severity. By the last visit, the patient reported zero symptoms. Between the first and third visit, there was a 15-point difference, indicating a meaningful change in symptom reporting (PCS meaningful change score = 14.8-point change).²⁸

Visual Performance

Convergence, accommodation, saccades and VOR were screened quantitatively and qualitatively each visit (Table 3). Normal ranges exist for convergence and accommodation, but there is a lack of scientific evidence to support normal ranges for saccadic eye movements and VOR screenings without use of external equipment (Appendix 1). On the first visit, the patient reported symptom provocation with >2/10 severity following three out of four VOMS tests (saccades, convergence and VOR), indicating abnormal

responses. Although measured convergence was within normal limits, the associated symptom provocation indicated an abnormal test result.^{17,29} Accommodation screenings did not provoke symptoms, however the patient's left eye measured at 15.5 cm when the normal cut-off score is <15 cm.

By the last visit, the patient reported zero symptoms with all four VOMS tests. Bilateral accommodation measured in normal ranges. He was able to read near and far distances for all classroom work asymptotically. Since initial visit, quantitative scores increased in saccades and VOR measurements signifying change, however no MCID has been established for these visual screenings. Also, baseline measurements pre-concussion did not exist, which would have assisted in the identification of concussion recovery and clinically significant change. The patient did not report any adverse effects throughout the course of treatment.

DISCUSSION

The purpose of this study was to describe PT management of an individual with persistent post-concussion symptoms and to evaluate the effects of introducing aerobic exercise while symptomatic at rest. Treatment was tailored to the patient's distance reading and activity intolerance impairments. At discharge, the patient reported asymptomatic status with all cognitive and physical activities, subjectively indicating concussion recovery.

A limitation to this study is the patient may not represent a wider population tested. He repeatedly

demonstrated keen body awareness, internal motivation and adherence to HEP and activity modifications, which may be an elevated expectation when considering the average young adult experiencing persistent post-concussion symptoms. It was a result of these internal factors that the HEP was successfully utilized as a large portion of PT management in this case.

Another limitation was the lack of baseline measurements pre-concussion which could have assisted in identification of symptom recovery. Although the BCTT and VOMS helped diagnose post-concussion deficits, they did not accurately recognize the recovery from concussion. At the second visit, the patient “passed” the BCTT with zero symptoms and normal HR response to exercise, and “passed” the VOMS with zero symptoms and observed change in objective measurements since last assessment. However, he still experienced symptoms with jogging and distance reading activities, which indicated he had not fully recovered from his concussion. This is why the clinician utilized a busy environment with background distractions to further challenge exertional abilities to diagnose concussion symptom thresholds.

When to begin exercise with individuals suffering from concussion remains controversial in current literature, and one purpose of this report was to help fill this gap. In management of this patient, aerobic exercise was initiated earlier than recommended by McCrory’s et al. return to play protocol.⁷ Based on patient internal factors, outcomes and zero adverse effects throughout this study, I believe this was the best choice to safely and efficiently rehabilitate this individual. The patient’s subjective and physiologic responses to the BCTT were used to customize advanced exertion tests. Results helped facilitate

decision making to safely progress exercises and identify the need for further testing.

Currently, the return-to-play protocol for this patient population are vague guidelines and not supported by scientific research. In this study, exertion tests were also utilized as interventions. Standardized exertion tests and interventions are not established for this population, however these programs, along with the UPMC EXIT, are widely accepted in the post-concussion management community. Further research is required to fill this knowledge gap and should include a RCT investigating the treatment effects of an experiment group (standardized aerobic and physical exertion testing) compared to a control group (stretching program and low-level exercise <60% MHR). Change from baseline would be reassessed at 3, 8 and 52 weeks post initial evaluation. Blinding could be applied to the outcome assessor and the clients (regarding which group they fall under). Outcome measures will include symptoms at rest via the PCS, and reported symptoms throughout treatment sessions. Vital signs and rate of perceived exertion should be taken before, during and after exercise and correlated to symptoms.

Post-concussion individuals with persistent symptoms require careful diagnosis of deficits to guide treatment which should incorporate musculoskeletal, cervical, balance, vestibular and oculomotor screenings. In this case, the therapist implemented a customized vision and physical exertion program for a young adult with persistent post-concussion symptoms. At the time of discharge, the patient reported an absence of all initially reported symptoms, was within normal ranges of all visual performance measures and asymptomatic with heavy physical exertion activities.

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Appendix 1: Vestibular and Oculomotor Screenings Selected for Patient with Associated Values

Horizontal Saccades	
Test Description	Patient's arms held out in front of patient with index fingers as targets (~3 ft. apart). Patient scans eyes back and forth from each target without moving head. Tested in sitting position.
Concussed Values²³	2.5-4.8 out of 10 symptom provocation severity
Normal Values²³	0-2 out of 10 symptom provocation severity

Convergence	
Test Description	Patient holds target at arm's length. Patient is instructed to fixate both eyes onto target and slowly bring it towards the nose until target doubles. NPC is the distance between the nose and target, measured in cm. Tested in sitting position.
Concussed Values²³	NPC: 5.9-7.7 cm 2.2-4.0 out of 10 symptom provocation severity
Normal Values²³	NPC: 1.9-3.2 cm 0-2 out of 10 symptom provocation severity

Accommodation	
Test Description	Patient holds target at arm's length while using other hand to cover ipsilateral eye. Patient is instructed to focus one eye onto target and slowly bring it towards the nose, until target doubles. Distance between the nose and target is measured in cm. Repeat with other eye. Tested in sitting position.
Concussed Values	Not determined.
Normal Values	Normal Value: <15 cm

Horizontal (VOR)	
Test Description	Patient holds a business card at arm's length and visually focuses on one word. Patient is instructed to rotate head from side to side (head rotates ~30 deg left and right at 2 Hz) while maintaining fixed eye position. Number of full head turns are counted in 60 sec. Tested in standing position.
Concussed Values²³	3.7-5.1 out of 10 symptom provocation severity; 61% concussed patients
Normal Values²³	0-2 out of 10 symptom provocation severity

Notes: *ft*, feet; *cm*, centimeter; *NPC*, near point convergence; *VOR*, vestibulo-ocular; *deg*, degrees; *Hz*, hertz; *sec*, seconds.