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Combined Use of Vestibular and Aerobic Exercise to Treat a Patient with Post-Concussion Syndrome Following a Mild Traumatic Brain injury: A Case Report

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Abstract

Background: Prolonged Concussive symptoms following an acute injury, known as Post-Concussion Syndrome (PCS) are beginning to be discussed in literature. There has been recent evidence produced on the benefits of aerobic exercise and vestibular rehabilitation to assess and manage this unique patient population. **Purpose:** The purpose of this case study is to describe a protracted recovery of a patient experiencing PCS and provide specific assessment tools as well as interventions to help guide rehabilitation strategies following a concussion. **Case Description:** A 33-year-old female arrived at physical therapy 3-weeks after experiencing a mild traumatic brain injury (mTBI), following a motor vehicle accident (MVA). She was experiencing constant headaches, dizziness, nausea, right-sided neck pain, difficulty sleeping, decreased concentration, fatigue, increased irritability and frustration, and decreased function in daily responsibilities. **Interventions:** The patient received 22 sessions of physical therapy over a 12-week period, while also receiving psychological services. The interventions included functional strengthening, manual therapy, sub-symptom aerobic exercise, vestibular and oculomotor training, balance interventions, and work simulated tasks. **Outcomes:** The patient was evaluated using the Vestibular/ Ocular Motor Screening (VOMS) assessment tool. The patient improved from symptomatic with all items of the VOMS to mild headache symptoms with 3 items of the assessment. In addition, on initial evaluation the patient reported 7 on a 0-10 cm on a visual analog scale (VAS) for neck pain, which was reduced to 0/10. The patient returned to previous level of employment following physical therapy rehabilitation demonstrating improvement in overall function. **Discussion:** Through the physical therapy plan of care the patient demonstrated improvements with reduced frequency and severity of headaches with accompanying dizziness, increased tolerance to activity, and decreased neck pain, and improved concentration. This case study provides an example of a positive outcome following outpatient physical therapy for a patient with prolonged PCS, with full return to work and pre-injury activity.

Keywords: Post-concussion syndrome; traumatic brain injury; physical therapy; rehabilitation; vestibular rehabilitation; aerobic exercise

Background:

Concussions have been recognized through medical practice as a clinical entity for hundreds of years to date. But recently there has been growing healthcare, government, and media attention to concussions as a public health issue to all ages. Concussion is often used interchangeably with the term mild traumatic brain injury (mTBI), and is defined in the American Academy of Neurology as, "Trauma induced alteration in mental status that may or may not result in loss of consciousness."

Currently in the United States healthcare providers are becoming more educated and experienced the detection and the management of concussion. In 2017, the Center for disease and Control reported 1.7 million United States citizens presented to a hospital emergency room with reports of a traumatic brain injury (TBI). While most publicity highlights sports related concussions, the leading cause of head injury in adults is experienced from falls and motor vehicle accidents (MVA).[1] Data collected from Seiger et al, has shown preliminary evidence that the mechanism of injury of concussion may play a role in the duration of recovery. Patients who suffer a concussion from an MVA take longer on average to recover from their symptoms than those who suffer a concussion from a sport-related injury.[2]

The clear majority of individuals who sustain a concussion will reach a full recovery in a 1-2-weeks, however ~20% will present with persistent signs and symptoms greater than 3 weeks from the incident. Risk factors for a prolonged recovery include younger age, female gender, past medical history (PMH) of anxiety or depression, PMH of migraines, concurrent significant life stressors, and history of previous concussion.[3] Patients that are unable to return to pre-injury neurological level are then at a risk for increased risk for further co-morbidities such as aerobic deconditioning, anxiety, depression, fear avoidance, and poor academic or work performance.[4]

At 3-4 weeks with prolonged signs and symptoms following an acute concussion the diagnosis of Post-Concussion Syndrome (PCS) is given. The management of patients with sub-acute concussion and PCS remains controversial and poorly established. Past medical recommendations advised both mental and physical rest until symptoms subsided, but recent literature would suggest that patient specific symptoms must be monitored and progressed appropriately. The exact amount of cognitive and physical rest is not yet well defined, but it is recommended that after 24-48 hours of complete rest the patient can be supervised and gradually progressed in activity staying below cognitive and physical symptom exacerbation thresholds.[5]

Regarding exercise prescription for PCS, there has been emerging evidence in the benefit of aerobic exercise with favorable effects when prescribed with appropriate dosage. Leddy and Willer have developed strong research from the Buffalo Concussion Treadmill Test (BCTT), used to diagnose safely and reliably physiologic dysfunction in concussion, differentiate it from other conditions, and quantify the clinical severity and exercise tolerance of concussed patients following mTBI. The BCTT is based on the Balke cardiac treadmill test and utilizes a very gradual increase in workload that has been shown to be safe. The heart rate (HR) and blood pressure (BP) are then recorded at the threshold of symptom exacerbation. This allows the clinician to then prescribe an individualized home exercise plan at sub-threshold of symptom onset to increase aerobic conditioning and speed recovery and return to activity.[4]

The broadest and most sensitive PCS definition provided by the World Health Organization's International Classification of diseases includes 3 or more of the following: dizziness, headache, fatigue, irritability, insomnia, concentration difficulty, or memory difficulty. Furthermore, PCS is a broad diagnosis that encompass separate sub-categories based on specific signs and symptoms, however there is no gold standard diagnostic test for this. Three of the subtypes of Post-Concussion Disorders (PCD) have been delineated into physiologic PCD, vestibulo-ocular PCD, and cervicogenic PCD based on the clinical history and objective measurements.[3]

Literature of post-concussion syndrome describes the evaluation of vestibulo-ocular impairments in addition to balance a crucial component to assess function following injury. The Vestibular/Ocular Motor Screening (VOMS) assessment tool has been used to document improvements in multiple domains

within 7 days compared to baseline. Elbin et al, assessed scores from the VOMS with patients who recently suffered a concussion, and revealed impairments in all testing components in comparison to baseline within the 1-7-day post-injury period. However, this same study demonstrated impairments at 8-14 days are uncommon. Utilization of this data shows that following two weeks' post injury symptoms should be reduced independently. If symptoms are positive or higher within the VOMS, it is more indicative the patient is suffering from post-concussion syndrome in the 2-weeks post-injury period.[6,7]

Case Presentation

The patient was a 33-year-old ectomorph female teaching assistant who suffered a mTBI following a MVA where she was hit while on a motor cycle without wearing a helmet. The patient saw a Sports Medicine Physician who performed computed tomography (CT) to rule out fractures and assess the degree of head injury following the MVA. The physician diagnosed her with a mTBI, without loss of consciousness. The patient was then referred to physical therapy in which she began 3-weeks following initial injury. The patient prolonged physical therapy evaluation due to personal life conflicts at the time. The patient reported that since her injury she had been dealing with dizziness, neck pain, headaches, difficulty with concentration, and difficulty with vision. The patient stated that she has been unable to work and unable to perform child care duties without extreme challenges and fatigue. The patient had irritability to sensory information and could not be upright for longer than 30 minutes without symptoms. Bright lights and loud noises caused her to experience a headache with ensuing dizziness. The patient stated, "I have a room spinning sensation whenever I lie down in bed so I have not been able to sleep". The patient stated her right neck feels tight and painful to the touch. The patient responded that turning lights off and closing her eyes minimized her dizziness, but never eliminated it. The patient stated that she had experienced migraines in the past, but they felt completely different than this experience. The patient's past medical experience was unremarkable with no previous concussions or head injuries.

The patient reported that she lived at home with her 3 children and is currently going through a divorce. Prior to the injury she worked at Target as a cashier for the summer and as a Teaching Assistant for a high-school. This accident occurred during the summer, when she had no teaching responsibilities, however was working full time over 40 hours per week at Target. Since the injury the patient was unable to work without an increase in her symptoms. The patient stated her main goal was to reduce her neck pain, reduce her dizziness and headaches to the point that she could return to work an 8-hour shift, perform all her child care responsibilities, re-engage in previous exercise, and sleep throughout the night.

Examination and Evaluation

Visit 1

The patient completed a clinic specific intake questionnaire upon arrival called "Care Connections". Care Connections provides a functional index and is scored based on ability to complete daily tasks scaling symptom provocation within 10 different categories. The 10 different categories include; walking, work, personal care, sleeping, recreation sports, concentration, headaches, reading, driving, and reading. The scores for each category are added together in-order to determine an overall functional index of patient quality of life ranging from 0-100, with 100 being fully functional without limitations. The patient described had a care connections score of 30/100 at initial evaluation, which indicated notable functional limitations. In addition, the patient scored her pain index on a VAS scale from 0-10. The patient reported right sided neck pain on the VAS scale listed as 7/10 that was worst with any activity, physical or cognitive that required attention. The patients' signs and symptoms had not resolved 21-days post-injury prior to arrival to physical therapy, which is atypical of most diagnosed with a concussion.[6]

Following the subjective interview the cervical spine was screened for any instabilities or irregularities that may have been present following a high-velocity MVA. Objective measurements were recorded for active range of motion (AROM) of the cervical spine listed in Table 1, indicating that active

ROM of the cervical spine was painful and limited. Exaggerated thoracic kyphosis was observed in resting posture with bilateral scapular winging. The sharp purser test was performed to assess the transverse ligament integrity which was found to be negative indicating the ligamentous structure was in-tact. Next the alar ligament test was performed to assess integrity of the alar ligaments and thus upper cervical stability which also were found to be normal. Finally, a vertebral artery test was performed to ensure there was not vertebral artery insufficiency present following the mTBI. Results indicated there was no arterial compromise present bilaterally. Following this clearance of the cervical spine, the next stage of the assessment was set to identify the primary deficits the patient experienced to progress patient specific interventions.

Throughout the first two weeks of physical therapy evaluations were performed as the patient could tolerate more. During visit 1 the patient was highly irritable to loud noises and bright lights. Thus, visit 1 evaluation was performed in a dark isolated room. Items assessed during this visit are listed in Table 1.

Table 1: Objective evaluations from visit 1

Name of Objective Test	**Results/Score**	**Test Findings**
Cervical AROM in degrees (deg) via goniometry	Extension: 50 deg* Flexion: 35 deg* Rotation: (R) 60 deg* (L) 65 deg Lateral Flexion: (R) 20 deg* (L) 20 deg*	Pain reproduction with active motion of the cervical musculature
Dix-Hallpike Right and Left	Negative in both directions	Absence of BPPV following MVA
Gaze evoked nystagmus	Absent in both right and left	Nystagmus not present
Cervical Distraction Test	Increased cervicogenic pain to 8/10 on the Right side.	R cervical musculature hypertonic.
Tandem balance: firm surface	Eyes open: 30 seconds Eyes closed: 12 seconds	Impaired static balance
SL balance: firm surface, eyes open	Right leg: 14 seconds Left Leg: 10 seconds	Impaired static balance
Palpation	Hypertonic and palpation tenderness to the R upper trapezius, sternocleidomastoid, levator scapulae, sub-occipitals.	Increased pain with palpation and at rest

*denotes pain with concordance of testing, (R) = Right, (L) = Left

Visit 2

Initial examination continued in visits 1 and 2 due to the high irritability of the concussive symptoms. At this point the VOMS assessment tool was implemented to identify symptom provocation or vestibular dysfunction following a concussion. This once again was performed in a dark room due to high irritability to bright lights. The VOMS assessment resulted in an increase in symptoms from baseline as listed in Table 2. Each assessment component of the VOMS can help identify certain impairments. As in our patient's case, the increase in symptoms with the vestibular ocular reflex testing (VOR) indicates impairments in the ability to focus gaze with cervical motion. In addition, the inability to focus on an object beyond 12 cm in the near point of convergence test indicates impairments in the vestibule-ocular system, as normal testing should allow ability to track an object to a distance less than 6 cm from the subject's nose. Following assessment, the patient was not asked to participate in further evaluation.

Table 2: Initial VOMS Assessment

Vestibular/ocular Motor Test	**Headache 0-10**	**Dizziness 0-10**	**Nausea 0-10**	**Fogginess 0-10**	**Comments**
Baseline symptoms:	1	2	0	1	Test completed in isolated treatment room
Smooth Pursuits	2	2	0	3	
Saccades Horizontal	3	2	1	1	
Saccades Vertical	3	2	3	4	
Convergence (near point)	3	3	1	0	**(Near Point in cm)** **Measure 1:** 12 cm **Measure 2:** 11 cm **Measure 3:** 11 cm
VOR Horizontal	4	2	1	0	
VOR Vertical	4	2	1	2	
Visual Motion Sensitivity Test	4	2	1	3	

Table adapted from vestibular/ocular motor assessment screen from Mucha et al 2014.

Visits 3 & 4

During the subsequent visits following the implementation of the VOMS assessment home exercises were given to improve symptom provocation and irritability from vestibular exercises. These exercises are then described in the interventions section of the paper. To address strength impairments of the cervical deep neck flexors, a deep neck flexor endurance test in supine was implemented in visit 3. During this visit the patient demonstrated a time of 20 seconds prior to fatigue indicating decreased strength and endurance of the deep cervical neck flexors.

During visit 4 in the rehabilitation process, the patient had improved in tolerance to bright lighting and noise. To address aerobic exercise capacity and physiologic deconditioning the patient completed a modified aerobic exercise evaluation tool to quantify aerobic exercise capacity prior to symptom onset. Typically, the BCTT would be performed, however in this clinical setting the treadmill was positioned in an area non-conducive to our patient's specific symptoms and comfortability. For this reason, a modification to the BCTT was utilized with the subject performing the aerobic exercise test on a stationary bicycle rather than a treadmill. This was due to accessibility to a stationary bicycle at work and bright lighting and large glass windows positioned in front of the clinic specific treadmill. Results from the initial and subsequent modified aerobic exercise test are shown later in Table 3.

The initial and following evaluations describe a complex case of a patient experiencing PCS with prolonged dysfunction. She presented with bilateral vestibular dysfunction, aerobic deconditioning, and cervicogenic neck pain with reported muscular trigger point that would reproduce her symptoms when passively or actively moved.

Interventions

The patient was seen for 22 physical therapy sessions over the course of 12-weeks. Along with physical therapy interventions, the patient was also seeing a licensed mental health counselor to manage stress related to ongoing divorce and frustration following MVA. The interventions provided during physical therapy were broken into phases of rehabilitation; sub-acute static vestibular training,

dynamic vestibular training, sub-threshold aerobic training, and return to activity/work phase. During all therapy sessions symptoms were assessed on a 0-10 scale utilized for the VOMS assessment to gauge patient reported headaches, dizziness, nausea, fogginess, and cervicogenic neck pain and if at any point a category was increased to greater than 4/10 the vestibular or strengthening exercises were paused to allow symptoms to subside. During aerobic exercise prescription, the patient was educated exercise should be discontinued if there was any increase in symptoms. This was carried over in all phases of rehabilitation.

Phase I Static Gaze stabilization

During the initial phase of the rehabilitation process interventions were symptom limited. Patient education was a crucial component at this stage and throughout the plan of care. The patient was advised to avoid continued activities that provoke symptoms and to encourage improved sleep patterns. Vestibular exercises were performed in static positions on level surfaces. Therapeutic exercises were incorporated to engage and strengthen deep cervical neck flexors and scapular musculature. Manual therapy was implemented to address soft tissue restrictions and muscle imbalances following the traumatic injury. A final component of phase I addressed static balance exercises that were introduced in standing in the Romberg positions to challenge postural control.[8] Vestibular exercises included seated horizontal and vertical saccades, seated horizontal and vertical Vestibular Ocular Reflex (VOR1) exercises using a blank sheet with a circle drawn on. The patient began looking straight ahead with her gaze fixated on the circle, she then rotated her head side to side and up and down, while keeping her gazed fixated on the circle. At the initiation of therapy, the patient could only tolerate 30 second bouts of these exercises in sitting before symptom onset, but as she progressed could tolerate multiple sets of increased durations, with increased cadence. The patient was given supine chin tucks, and gross shoulder strengthening to address muscular weakness of the scapular stabilizers and deep neck flexors. Due to posture and prior habit the patient rarely utilized her deep neck flexors and presented with hypertonic sub-occipital musculature. The chin tuck was prescribed to strengthen the neglected deep cervical flexors and stretch the hypertonic sub-occipitals. At this point the patient was instructed on the importance of de-escalation techniques. The patient found that eye cupping and manual pressure to her right sub-occipital musculature relieved her symptoms. The patient was advised through this stage to utilize diaphragmatic breathing as a de-escalation technique, which proved effective to reduce symptoms. The patient utilized accessory respiratory muscles such as sternocleidomastoid and upper trapezius when breathing. Diaphragmatic breathing gave the patient the opportunity to relax these already hypertonic muscles and found reduction of her specific headache and neck pain symptoms with this technique. In phase I manual therapy was structured at addressing the hypertonic upper trapezius bilaterally and improve thoracic mobility. Once static vestibular exercises could be performed for 2 minute durations on 2 simultaneous days without increased symptoms greater than 4/10, the exercises could be progressed to more dynamic and challenging positions.

Phase II Dynamic Gaze Stabilization

Phase II of the rehabilitation process began 2 weeks into physical therapy and 5-weeks post-injury. The patient began to tolerate more activity without symptom onset. The patient had yet to return to work at Target as a cashier due to her headaches, nausea, and concentration difficulty. However, the patient tolerated all seated vestibular exercises without increased symptoms greater than 4/10 for multiple sessions. This warranted increased difficulty in vestibular exercises focusing on improving vestibular oculomotor deficits and balance and postural demands in more functional positions.[9]

During this phase of rehabilitation, the vestibular exercises consisted of standing horizontal and vertical saccades on firm and uneven surfaces. Standing and walking horizontal and vertical VOR exercises on more challenging surfaces. These standing and dynamic motions offered more challenge incorporating more proprioceptive input and mimicked more functional positions.

Manual therapy exercises included sub-occipital release to reduce patient reported neck pain on the right side. In addition, the patient received interventions to address soft tissue restrictions of the pectoralis major and minor muscles that were hypertonic and lead to exaggerated thoracic kyphosis in sitting positions. Finally, manual therapy in the form of joint mobilizations were introduced to the cervical and thoracic spine in the form of grade II-III to introduce more proprioceptive feedback and in an effort to reduce patient reported cervicogenic pain.[10]

Balance exercises began to introduce dual task training on firm surfaces and uneven surfaces. This included double leg and single leg standing on foam solving math equations with eyes open and closed. These exercises were aimed at improved postural control and strength with impairments in static balance on evaluation.

Finally, functional strengthening continued to incorporate strengthening of the deep neck flexors as well as the scapulothoracic muscles to have a more stable support of neck muscles with functional movements. This included theraband standing shoulder horizontal abduction, weighted shoulder press, modified push-ups, front and side planks, and prone scapulothoracic muscle strengthening performed on the swiss ball as shown in Figures 1-3.

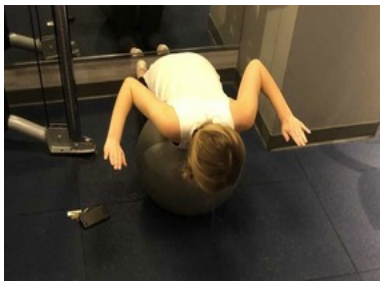

Figure 1. Prone W with chin tuck performed on swiss ball. Goal to improve rhomboid muscular strength and endurance

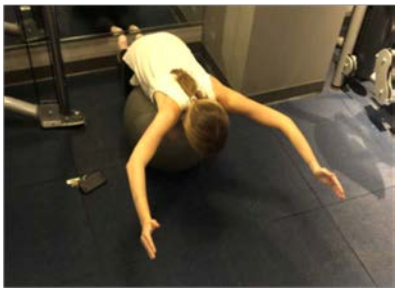

Figure 2. Prone Y with chin tuck performed on swiss ball. Goal to improve lower trapezius muscular strength and endurance

Figure 3. Prone T with chin tuck performed on swiss ball. Goal to improve middle trapezius muscular strength and endurance

Phase III Sub-Symptom Threshold Aerobic training

Beginning the same week as the patient progressed to dynamic gaze stabilization exercises which took place week 2 of physical therapy and week 5 post-injury, the patient was assessed for tolerance to aerobic exercise. Literature has shown utilization of the aerobic exercise to gauge sub-symptom thresholds for aerobic exercise tolerance via heart rate measurement in individuals suffering from post-concussion syndrome. As stated previously, literature has validated the BCTT in the assessment of tolerance to aerobic exercise in this patient population. However, due to extrinsic factors within the clinic making the treadmill not a suitable option, the physical therapist chose to have the patient utilize a stationary bicycle for the mode of aerobic exercise. Like the BCTT, each minute the grade of the bicycle was to be increased by 1 level, while the revolutions per minute (RPM) were to stay at the same rate of 50 rpm for a duration of 1 minute. The patient began each session at level 1 on the stationary bicycle and was not asked to increase intensity level beyond 15. In the event the patient achieved an intensity level of 15 on the stationary bicycle, she maintained this for the remainder of her session. Heart rate was assessed via pulse oximetry at each minute interval. The patient achieved a heart rate of 106 beats per minute (bpm), 61% of her age predicted heart rate max before symptom provocation at initial testing. She was unable to complete the entire test. In addition, the patient was asked her rating of

perceived exertion (RPE) on the Borg scale of 6-20, and she reported an 11 RPE. The patient was initially instructed to perform 20-30 minutes a day of light aerobic activity at a sub-symptom level at a 10 RPE or 100 bpm to prevent onset of symptoms and promote increased aerobic conditioning.

Following initial aerobic sub-symptom threshold testing, the patient performed aerobic exercise on the stationary bicycle at subsequent visits to progress her home exercise plan to combat physical deconditioning because of her post-concussion diagnosis which is shown in Table 3.[11,12]

Table 3: Aerobic sub-symptom threshold testing on stationary bicycle

Date since injury	Heart Rate at Symptom Onset or termination of test	RPE	Minutes Completed	Reason for termination of test
5-weeks post mTBI	106 bpm	11	5 minutes	Symptom onset headache and dizziness
7-weeks post mTBI	128 bpm	13	7 minutes	Symptom onset dizziness
8-weeks post mTBI	140 bpm	14	12 minutes	Symptom onset headache
9-weeks post mTBI	147 bpm	14	14 minutes	Symptom onset headache
11-weeks post mTBI	150 bpm	16	20 minutes	No symptoms with 20 minutes of continuous aerobic exercise

As the patient tolerated an increased heart rate with aerobic exercise, she was prescribed a higher intensity to supplement her home exercise routine. She was still advised to engage in aerobic exercise 20-30 minutes per day at a sub-symptom threshold. Based on the RPE at symptom onset, the exercise intensity was prescribed 1 level of RPE lower than that reported for symptom onset in her treatment session, as she did not have a way to measure her heart rate at home. This continued towards discharge as she exercised at 80% her heart rate max for over 20-minutes without increased symptoms. At this point the patient was cleared to utilize the stationary bicycle without restrictions on intensity as it no longer reproduced her symptoms.

Phase IV Return to Work/ Return to Activity

In the final weeks of this protracted recovery, therapy became more tailored to return to work and activity following her concussion. The patient returned to work as a teaching assistant with restrictions at week 7 of therapy, 11-weeks post-injury. At that point the patient tolerated half days with limitations on lifting. As a behavioral disorder special needs teaching assistant, her job requirements called for lifting upwards of 50 pounds.

At this phase, physical therapy interventions included cervical joint position sense retraining using a laser pointer mounted onto a headband light projected onto a wall. The patient practiced relocating the laser beam onto a target from various positions. This exercise was aimed at improving coordination of cervical motion activating large and small muscles with the optimal amount of activation of cervical musculature to improve proprioceptive input to the cervical muscles with cervical motion. The treating therapist continued gross functional strengthening in work specific tasks such as lifting 40 pounds from the floor, carrying 20 pounds in each arm, and cognitive dual task training while exercising at a moderate to vigorous exercise intensity. Manual therapy at this point was limited to thoracic mobilizations grade III-V. At this point the treatment sessions focused on activities that could be performed at home and in the clinic. All interventions at this phase were tailored to increase tolerance

to activity and cognitive challenges to increase tolerance to activity and work. The patient returned to full work without any lifting restrictions at 11 weeks of therapy 14-weeks post-injury.

Outcome Assessments

The outcome assessments utilized in this patient's treatment of care were the VOMS assessment tool, cervicogenic pain on a 0-10 VAS scale, the clinic specific Care Connections and the deep neck flexor endurance test. Following physical therapy treatment, the patient demonstrated improvements in cervicogenic pain at rest and with activity, reduced headaches and dizziness, improved tolerance to activity and exercise, improved static and dynamic balance, and improved strength. The patient's initial neck pain reported on VAS reduced from the initial 6.8/10 to 0/10 at the final visit with physical therapy. The patient returned to full time work as a teaching assistant without any limitations on the 11th week of physical therapy, however due to life stressors and previous exacerbations, the patient was seen for two more visits following return to work. The clinic specific care connections assessment of the cervical/thoracic region showed large improvements in function from the initial evaluation scoring a 30/100 to the final assessment 12 weeks later scoring an 86/100. Upon further assessment of strength of the deep neck flexors in supine, the patient completed 38 seconds without pain on the deep neck flexor endurance test on the final evaluation. The modified aerobic sub-symptom threshold test continued to illuminate dysfunction in the autonomic system throughout the plan of care. Upon final assessment 11-weeks post-injury, the patient was able to complete the exercise protocol for the 20-minute duration without the onset of symptoms. Demonstrating improvement in aerobic conditioning and regulation of the autonomic system following the mTBI. Finally, the VOMS was assessed three times throughout the plan of care with the initial assessment captured in Table 2, and the final assessment shown in Table 4. The final VOMS assessment demonstrated reductions in symptoms above 2 with any of the vestibular ocular motor tests. All the outcome assessments, reductions in pain, and patient return to work without limitations demonstrate the improvements made in physical therapy toward patient specific goals.

Table 4. Final VOMS assessment

Vestibular/ocular Motor Test	**Headache 0-10**	**Dizziness 0-10**	**Nausea 0-10**	**Fogginess 0-10**	**Comments**
Baseline symptoms:	0	0	0	0	Test completed following full day of work
Smooth Pursuits	0	0	0	0	
Saccades Horizontal	0	0	0	0	
Saccades Vertical	0	0	0	0	
Convergence (near point)	0	0	0	0	**(Near Point in cm)** **Measure 1:** 4 cm **Measure 2:** 4 cm **Measure 3:** 4 cm
VOR Horizontal	1	0	0	0	Turning head to the right increased symptoms.
VOR Vertical	1	0	0	0	Symptoms unchanged from previous test.
Visual Motion Sensitivity Test	1	0	0	0	Symptoms unchanged from previous test.

Table adapted from vestibular/ocular motor assessment screen from Mucha et al 2014.

Discussion:

The purpose of this case study was to highlight the use of specific evaluation assessment tools to aid in specific treatment and interventions used for an adult patient with a protracted recovery from PCS following a mTBI. This patient had multiple life stressors that affected the patients' quality of sleep and compliance to the home exercise routine. In addition, the patient did not attend physical therapy until 3 weeks after initial MVA, which literature has shown prolonging physical therapy can result in prolonged symptoms following a concussion.[2]

The physical therapy treatment focused on the patient specific impairments of vestibular-ocular deficits, impaired balance, poor posture, increased cervical stiffness and hypertonicity of the cervical musculature, and decreased activity tolerance resulting in the inability to work or perform activities of daily living such as caring for her 3 children. The physical therapy demonstrated progressions of vestibular-ocular exercises, balance and postural training, functional upper and lower body strengthening, sub-symptom aerobic exercise, and work specific tasks.

Previous literature has shown that increased aerobic exercise and vestibular/balance activities initiated 1 month following a concussion are significantly correlated with lower cognitive and vestibular symptoms at 3 months' post-injury.[13] Physical therapy treatment of this patient had a similar effect with integration of aerobic exercise at a sub-symptom threshold. The patient reported improved mood with reductions in headache and dizziness symptoms with ensuing visits. In addition, previous literature looked at specific heart rate thresholds experienced on aerobic exercise testing to predict delayed recovery following a concussion.[14] The patient experienced symptoms and had to terminate exercise at initial assessment due to symptom onset at a heart rate of 106 bpm with only a change in heart rate of 30 bpm from the resting heart rate of 76 bpm. Which supports the prediction of previous literature that symptom onset at a change in heart rate less than or equal to 50 bpm on the BCTT increases the likelihood the patient would experience a delayed recovery following concussion.[14] While the patient in this case study did not perform the specific BCTT, the protocol was similar in terms of assessment.

In patients who have suffered a concussion, literature has shown there to be a sensory organization impairment that vestibular rehabilitation is designed to address. For that reason, through graded exercise training the ability to effectively alternate between utilization of the proprioceptive, visual, and somatosensory systems for balance and postural control is crucial to recovery.[15]

While the results of this specific patient example demonstrated a positive result in regards to reduction in symptoms, increased activity tolerance, and return to work, future research should continue to be done to examine the success of different intervention programs over a larger scale of patients. In addition, majority of the literature addressing concussion management and PCS have been addressed at adolescents or sports related concussions. This makes it difficult when using protocols or setting expectations for the adult patient population wishing to return to work or recreational exercise. Finally, additional research should be done to facilitate increased progression guidelines for the vestibular exercises, as majority is utilized now based off clinical experience.

This case provides the reader a theoretical model of how to evaluate and treat post-concussion syndrome with specific examples of interventions and progressions to treat a patient experiencing PCS following a concussion sustained from a MVA. This was met by providing specific exercise lists with accompanying progressions used to treat and resolve patient specific symptoms following a concussion. As well specific assessment tools, such as the VOMS and the sub-symptom aerobic threshold test, that aided in the measurement of symptoms between sessions to track patient specific progress. Overall, this case study provides one specific example of the treatment and assessment tools utilizing in the management of a patient suffering from PCS.

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