Postural Orthostatic Tachycardia Syndrome (POTS) and its relevance, and importance, in the management of persistent post-concussive symptoms: a case series.

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ABSTRACT

***Objective**:* The purpose of this case series is to present the clinical assessment and diagnosis of postural orthostatic tachycardia syndrome (POTS) in three elite, professional athletes with persistent post-concussive symptoms (PPCS), and to describe and discuss the outcomes of an individualised and targeted, multi-system management approach provided by a chiropractor. *Clinical Features:* Three male elite, professional athletes, aged from 26 to 29 years old (mean age, 27.7 years), presented with PPCS which remained refractory to typical interventions. A clinical diagnosis of POTS, exertional intolerance, vestibulo-oculomotor dysfunction, motor coordination impairments, as well as cervical spine musculoskeletal impairments was made through synthesis of the patient history and detailed multi-system clinical assessment. *Intervention and Outcome:* Treatment addressed the specific dysfunctions and impairments identified on assessment in a hierarchical manner. The multi-system treatment and management approach for each patient was individualised, and first targeted and addressed the POTS and autonomic nervous system (ANS) dysfunction identified on clinical assessment. All three patients demonstrated significant decreases in PPCS symptoms and changes in mental health, as measured by the Post-Concussion Symptom Scale (PCSS), Rivermead Post-concussion Symptoms Questionnaire (RPQ) and 9-Item Patient Health Questionnaire (PHQ-9). All three patients had improvements in orthostatic vital signs, Infrared Video Goggle assessment, vestibulo-oculomotor assessment (including quantitative eye tracking technology), and motor coordination assessments (including balance via quantitative force plate technology). *Conclusion:* Three elite, professional athletes with PPCS which remained refractory to typical treatment, had quantitative subjective and objective improvements in symptoms and function following individualised, multi-system management that first targeted and addressed the POTS and ANS dysfunction identified on clinical assessment. Further research involving larger randomized controlled and clinical trials with long-term follow up are both required and warranted to clarify the effectiveness of a POTS and ANS hierarchically targeted, multi-system treatment approach in the management of PPCS.

Keywords: (MESH): Brain Concussion; Post-Concussion Syndrome; Postural Orthostatic Tachycardia Syndrome; Rehabilitation; Exercise Therapy

INTRODUCTION

Sport related concussion (SRC) is defined as a traumatic brain injury induced by biomechanical forces.[1] The pathophysiological process has been described by Harmon et al[2] as "force delivered to the brain causing disruptive stretching of neuronal cell membranes and axons resulting in a complex cascade of ionic, metabolic and pathophysiological events." Recent evidence suggests that concussion affects the autonomic nervous system (ANS), because of diffuse axonal injury including brainstem structures and pathways involved in normal regulation of the ANS, and that dysfunction of the ANS may be a factor that can contribute to persistent post-concussion symptoms.[3-6] Persistent symptoms following SRC are defined as concussion symptoms that persist beyond expected clinical recovery time frames (>10-14 days in adults and >4weeks in children).[1]

An individualised symptom-limited, submaximal aerobic exercise program has been shown to improve recovery of persistent post-concussive symptoms.[1,2] The Buffalo Concussion Treadmill Test (BCTT) is a graded exertion test that methodically establishes the heart rate at which exercise-induced symptom exacerbation occurs in concussion patients.[3,4] Individuals unable to exercise at maximal exertion following SRC have been categorized as having 'physiological' persistent post-concussion symptoms, likely related to autonomic dysfunction.[1] The data collected during the BCTT is then used to prescribe an individualised, progressive symptom-limited aerobic exercise program.[4] However, there has been recognition of ongoing exercise intolerance in some concussion patients, despite the use of an individualised, progressive symptom-limited aerobic exercise program.[7] Autonomic nervous system dysfunction could account for the inability to successfully complete aerobic exercise training, in some cases, due to orthostatic intolerance.[7] A retrospective study of concussion patients who had dizziness symptoms, described as light-headedness, during exercise and quiet standing, demonstrated significant tachycardia on tilt-table testing, providing evidence linking dizziness and ANS dysfunction.[8] It has been suggested that light-headedness in upright postures may be an indicator of dysautonomia in comparison to other descriptors of dizziness, such as vertigo, that are more likely indicative of peripheral or central vestibular dysfunction.[7]

In some cases of PPCS, the presence of a type of dysautonomia known as postural orthostatic tachycardia syndrome (POTS) may need to be identified and managed before commencing a concussion aerobic exercise program.[7] While there are many potential triggers of POTS, there is a growing body of evidence that head trauma and rapid deceleration injuries can be a trigger for ANS dysfunction.[7] The purpose of this case series is to: (1) present the clinical assessment and diagnosis of three elite, professional athletes with PPCS, which remained refractory to typical treatment interventions; and (2) to describe and discuss the outcomes of an individualised and targeted, multi-system treatment approach that first targeted and addressed the POTS and ANS dysfunction identified on clinical assessment, to allow practitioners to adopt a similar process in the assessment and management of PPCS.

CASE REPORTS

Background

Three male elite, professional athletes, aged from 26 to 29 years old (mean age, 27.7 years), were referred to the author from other health care professionals for further assessment and management of their PPCS, which remained refractory to typical interventions. Previous management strategies included vestibulo-oculomotor rehabilitation; aerobic exercise and graduated return-to-sport strategies; psychotherapy, meditation, and mindfulness; cervical spine musculoskeletal interventions; acupuncture; and naturopathy.

Case 1

A 26-year-old male, elite, professional Australian rules football (AFL) player presented with PPCS of 7-weeks duration. The concussive injury occurred in the last 5-mins of an AFL game, where he hit the right side of his head and face, with the left side of an opponent's face, as they were both running towards each other in a contest to gain possession of the ball. He continued to play the remaining 5-mins and reported having blurred vision and a headache immediately following the game. He stated his symptoms had worsened and he is "getting really frustrated". He described his headaches as a "pressure in the front" (of his head). He indicated that he has had some anxiety, and "feels panicky". He said that he "can't concentrate for more than 10-to-15-minutes, so have delayed university studies". Upon further questioning, he detailed that when he stands from a seated position, he gets some light-headedness, his "vision goes a bit blurry, and has to grab onto something". He also reported some issues with speaking ("feels like the words are in my head and I can't get them out"), as well as some short-term memory issues ("forgetting where I put my keys"). He had been treated with vestibulo-oculomotor rehabilitation, which had "been really aggravating the headaches". Additionally, he described trying to build up his heart rate (HR) during aerobic exercise on a stationary bicycle, as part of a graduated return-to-sport strategy, and that his headaches "seemed to kick in once his HR spiked to 135 beats per minute (bpm)". He had previously sustained "eight-to-nine concussions" in his professional career, four of those concussions involved loss of consciousness, and he had missed four games in total from the previous concussions.

On physical examination, orthostatic vital sign (OVS) assessment was indicative of POTS (Table 1). The Buffalo Concussion Treadmill Test (BCTT) was stopped at 14-mins due to a >3/10 increase in the patient's headache, with a 120 bpm HR recorded at the time of test termination. Infrared Video Goggle (VOG) assessment revealed horizontal saccadic intrusions and a slight rightward drift of the eyes with vision occluded. Quantitative eye tracking (RightEye, LLC, MD, USA) analysis, using the Dynamic Vision assessment battery, demonstrated decreased performance in saccades and fixation.[9] Double vision was perceived, with the left eye diverging, at 7.5 cm during near point convergence (NPC) testing. Anti-saccade bedside testing demonstrated more prosaccadic errors to the right, with a slower latency to inhibit the right stimulus. Reduced gain of the slow phase during optokinetic nystagmus (OKN) testing was detected in both horizontal and vertical directions, with the patient's body

observed to sway in the direction of the OKN stimulus. Quantitative balance assessment (Balance Tracking System (BTrackS) force plate) using the modified Clinical Test of Sensory Integration in Balance (mCTSIB) and Cervical Challenge assessment battery revealed decreased postural control in Standard (19th percentile), Proprioception (9th percentile), Vision (9th percentile) and Vestibular (14th percentile) BTrackS mCTSIB conditions, and decreased postural control in the Cervical Flexion, Cervical Extension and Right Cervical Rotation head positional testing.[10,19] Dysdiadochokinesia (DDK) was observed on the left (and slightly on the right) during pronation/supination testing of the upper extremity, and the three-step Luria test was abnormal on the right. Cervical spine musculoskeletal assessment identified decreased performance on the deep neck flexor endurance test (18-secs) and cranio-cervical flexion test (22 mmHg). Other physical examination and testing procedures including cranial nerve examination, sensory examination, muscle stretch reflexes, muscle tone and strength, Vestibulo-Ocular Reflex (VOR) Test, Head Impulse Test (HIT), heel-to-toe tandem gait, dual-task tandem gait, and cervical spine orthopaedic and sensorimotor examinations were unremarkable.

Case 2

A 29-year-old male, elite, professional surfer presented with PPCS of 8-months duration. The concussive injury occurred as he took off on a wave, dropped down to the right-side of the wave and then fell off his board in a forward-right direction. The individual then impacted the water with the right-side of his head where he reported briefly losing consciousness. Initial symptoms of motion sickness, sensitivity to sound and light, brain fog, fatigue, and sleep disturbances were recalled. He now describes his current symptoms as “mainly being bad brain fog”, sleep disturbances and “jolts in my sleep”, fatigue, neck and lower back spinal spasms, frontal headaches, and sometimes “full emotional breakdowns”. Upon further questioning, he indicated his brain fog “feels like I am here, but I am not there”, and that being in a noisy environment or post a surfing competition would aggravate this feeling. The patients also reported that while surfing recently his brain fog and neck spasms would be exacerbated if he tried to perform a manoeuvre that involved spinning (left or right), or if he had a wipe-out, or had to duck-dive, “especially where it was dark underwater”.. He described that “too much sensory stimulus is one of the hardest things to deal with”. He had been treated with vestibulo-oculomotor rehabilitation, which aggravated the brain fog, headaches, as well as the neck and spinal spasms, “which wouldn’t go away, so stopped doing the exercises”. Psychotherapy, including working with fear strategies (e.g., falling backwards into a foam pit), would aggravate the neck spasms and bring on “bad brain fog”. And, meditation would cause a “full emotional breakdown”, where he “felt completely lost and destabilised”. He had previously sustained “numerous concussions” (he was unable to recall how many) in his professional career, the most recent occurring seven-months prior to this injury, reporting symptomatic recovery within one-week.

On physical examination, OVS assessment was indicative of POTS (Table 1). The BCTT was stopped at 12-mins 18-secs due to a >3/10 increase in the patient’s fogginess and a 4/10 onset of light-headedness, with a 115 bpm HR recorded at the time of test termination. Vision occluded VOG assessment revealed horizontal saccadic intrusions, while also aggravating the patient’s headache and fatigue. Eye

tracking analysis, using the RightEye Dynamic Vision assessment battery, demonstrated significant decreased performance in overall score, pursuits and saccades[9], with the vertical saccade testing causing fatigue and brain fog, where the patient needed to rest for approximately 10-mins before being able to perform the next test in the RightEye assessment battery. Bedside testing of gaze-holding (fixation) triggered the patient's headache during upward gaze assessment, with a resultant closure of his eyes. Fatigue and eye closure was observed on the third repetition of horizontal smooth pursuit testing, while upward smooth pursuits immediately triggered fatigue and eye closure. Testing of NPC measured 3 cm before double vision was perceived but triggered the patient's headache and a sensation of "feeling spacey". Anti-saccade testing was ended after four repetitions due to the patient closing his eyes and his head dropping forward. He maintained this position for approximately two-to-three mins after the test was terminated and then reported this response as bad brain fog ("feels like I am here, but I am not there"). There was a suppressed OKN reflex during rightward OKN testing (he also stated it made him feel "spaced out"), while upward and downward testing resulted in the same reactions as the anti-saccade test, but the effects lasted longer following the upward OKN test. Horizontal and vertical VOR testing was within normal limits (WNL) during the assessment, however, post-horizontal VOR test the patient's eyes were observed to roll up and right, and he reported that he "felt out of it". Rightward HIT testing also revealed the patient's eyes to roll up and right, a resultant closure of his eyes, and he again reported that he "felt out of it". The BTrackS mCTSIB demonstrated decreased postural control in Standard (41st percentile), Proprioception (49th percentile), and Vision (59th percentile) conditions, and decreased postural control in the Cervical Flexion, Cervical Extension, Right Cervical Rotation and Left Cervical Rotation Cervical Challenge conditions.[10,19] Dysmetria of the right hand was observed during finger-to-nose testing, and DDK was observed on the right upper extremity. The patient fell to the left after three secs in the sharpened (Tandem) Romberg test with eyes closed. Cervical spine musculoskeletal assessment identified decreased performance on the deep neck flexor endurance test (26-secs). Other physical examination and testing procedures including cranial nerve examination, sensory examination, muscle stretch reflexes, muscle tone and strength, and cervical spine orthopaedic examinations were unremarkable.

Case 3

A 28-year-old male, recently retired elite professional AFL player presented with a 2-year duration of PPCS. He had sustained 14 concussions in his professional career and had been forced into retirement due to the repeated concussions. He stated his symptoms have had "slight improvements, here and there, but still struggle with a lot of things". He reported irritability, having a short temper, and being easily frustrated. He explained that when he has to multi-task, he will "crumble, get really frustrated and angry, and get bad brain fog". He further elaborated that "sensory overload" (e.g., a noisy environment such as a coffee shop), will trigger symptoms of "bad brain fog, can't communicate, and get irritated, frustrated and angry". While "lights at night, could also be an overload that creates the brain fog". He said that he gets reoccurring dizziness – which, upon further questioning he described as light-headedness – and could simultaneously experience a dull pain "like my brain is swelling". The dizziness could be aggravated by "serious concentration", or "even when I go from laying down

to standing up". He had been treated with vestibulo-oculomotor rehabilitation, acupuncture and naturopathy, which had "helped slightly". Additionally, he described trying to perform an aerobic exercise program, but had not been able to increase his HR as he would feel like his "head was going to blow off my shoulders".

On physical examination, OVS assessment was indicative of POTS (Table 1). The BCTT was stopped at 10-mins 14-secs due to a >3/10 onset of feeling like there was "decreased oxygen in the brain, like a choking feeling", with a 128 bpm HR recorded at the time of test termination. The RightEye Dynamic Vision assessment battery, demonstrated increased performance in overall score, pursuits and fixations, but below reference data score for saccades,[9] with rightward pursuits and both horizontal and vertical saccades triggering the patient's light-headedness. Bedside testing of gaze-holding (fixation) made the patient feel nauseous. Anti-saccade testing demonstrated prosaccadic errors to the right, with a slower latency to inhibit the right stimulus. The BTrackS mCTSIB demonstrated decreased postural control in Standard (19th percentile), Proprioception (35th percentile), Vision (50th percentile), and Vestibular (11th percentile) conditions, and decreased postural control in the Cervical Flexion, Cervical Extension Cervical Challenge conditions.[10,19] Dysmetria of the left hand was observed during finger-to-nose testing, and DDK was observed on the left upper extremity. The patient was unable to maintain balance for more than 8-secs in the sharpened (Tandem) Romberg test with eyes closed. Dual-task gait revealed a loss of arm swing on the right side. Cervical spine musculoskeletal assessment identified decreased performance on the deep neck flexor endurance test (22-secs). Other physical examination and testing procedures including cranial nerve examination, sensory examination, muscle stretch reflexes, muscle tone and strength, vestibulo-oculomotor assessment including NPC, OKN, VOR and HIT, and cervical spine orthopaedic and sensorimotor examinations were unremarkable.

DIAGNOSIS

In each of these cases, the author made a clinical diagnosis of POTS, exertional intolerance, vestibulo-oculomotor dysfunction, motor coordination impairments, and cervical spine musculoskeletal impairments that were contributing to each patient's PPCS.[1,11]

The clinical presentation and physical examination findings that were suggestive of POTS included: dizziness (light-headedness); headache; exercise intolerance; fatigue; brain fog (reduced mental clarity); OVS demonstrating (1) a HR increase ≥30 bpm or a sustained HR >120 bpm when moving from recumbent to a standing position, (2) symptoms (light-headedness, unsteadiness, headache, nausea, fatigue, dimming or blurring of vision, confusion, or diaphoresis) that occurred with standing, and (3) the absence of orthostatic hypotension (>20 mm Hg drop in systolic blood pressure (BP) (Table 1).[7,12,20] Exertional intolerance and physiological (ANS) dysfunction was able to be clinically quantified by the results of the BCTT.[13] Each patient's specific vestibulo-oculomotor impairments were identified and quantified with VOG and RightEye eye tracking analysis,[9] as well as through bedside assessments.[11,14] Individual motor coordination impairments were determined through a variety of assessments, which included: postural stability through the BTrackS mCTSIB and Cervical Challenge assessment battery; motor coordination

and control assessments; static and dynamic balance tests; and dual-task activities.[10,11,19] The deep neck flexor endurance test results were indicative of cervical musculoskeletal dysfunction in all patients.[11,15]

Each patient was educated about POTS and that the diagnosis should ideally be confirmed with passive tilt-table testing and further medical evaluation,[12] to provide each patient with all possible management options. All three patients decided to trial individualised, multi-system treatment and management that addressed the specific dysfunctions and impairments identified on clinical assessment in a hierarchical manner.

Multi-system management approach

The multi-system treatment and management approach for each patient was individualised, and first targeted and addressed the POTS and ANS dysfunction identified on clinical assessment. Orthostatic tolerance training (variations of active and passive tilt training) coupled with various exercise strategies (Table 2) were implemented to induce modification in the autonomic nervous system (ANS). An individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme was applied for the exertional intolerance and ANS dysfunction. The target HR was calculated from the results of the BCTT,[13] but modifications were made if the patients were not tolerating exercising at 80% of the BCTT threshold HR. Modifications included: using recumbent cycling and gradually progress to upright stationary cycling; or base pace exercise training (a further reduction in exercise intensity determined as 75% to 85% of the maximal steady state training zone calculation).[7] Targeted vestibular and oculomotor rehabilitation strategies were executed to match the individual clinical dysfunctions. However, all vestibulo-oculomotor rehabilitation commenced with gaze stabilisation training and rehabilitation strategies that were implemented to improve each patient's ability to gaze-hold (fixate), before other ocular-movement based exercises (e.g., smooth pursuits, saccades, convergence, OKN) were commenced. Cervical spine musculoskeletal and motor coordination interventions, including deep neck flexor strength and endurance exercises, as well as somatic sensorimotor movements involving complex movements of the upper and lower extremity (e.g., passive and active figure eight movements) were performed. Importantly, all treatment and management approaches were initially performed while monitoring HR responses. Notably, strategies that appeared to induce a positive modification in the ANS, especially when performed and compared from recumbent to upright postures (e.g., HR not increasing ≥10 bpm), were coupled with the initial orthostatic tolerance training. However, any strategy that resulted in a HR increase >15 bpm was modified or removed from the patients' management program, until OVS testing was considered normal. Any treatment or management approach which exacerbated the patients' symptoms by >3/10 were modified or removed throughout the course of patient management. Follow-up consultations were utilised to re-assess the patients' key clinical examination findings, and to appropriately determine the targeted rehabilitation progressions that the patients would perform. The targeted rehabilitation strategies were organised into a 10-20 min routine to be completed by the patient at home, three times a day. Additionally, the individualised, graduated

sub-symptom-threshold submaximal aerobic exercise programme was to be completed once daily.

OUTCOMES

All three patients demonstrated significant decreases in PPCS symptoms and changes in mental health, as measured by the Post-Concussion Symptom Scale (PCSS), Rivermead Post-concussion Symptoms Questionnaire (RPQ) and 9-Item Patient Health Questionnaire (PHQ-9) (Table 3).

Patient 1 attended 16 consultations over 51 weeks, which included the multi-system management approach outlined above. After six consultations (11 weeks) OVS testing was considered normal, with an appropriate HR response and no symptoms occurring when moving from recumbent to a standing position (Table 1). Prior to the sixth consultation, the patient had decided to retire from the AFL, citing concerns about the long-term consequences of concussions, and the realisation he had been playing with a lot of these symptoms for a number of years. Follow-up consultations and rehabilitation progressions over the next nine months were interrupted with the patient travelling overseas, as well as having three minor surgical procedures to treat pre-existing orthopaedic conditions. In those nine months, the patient had 10 follow-up consultations. After the 16 consultations, he reported having lots of energy, no headaches and being able to exercise and participate in reactional sporting activities without symptoms. The patient demonstrated improvements in all objective and quantitative assessments (Table 4).

Patient 2 attended 12 treatment sessions over 15 weeks. Due to the patient's location being in a different state to the author, the 12 treatment sessions were performed over three different weekends, with each weekend consisting of a detailed multi-system clinical assessment, four treatment sessions (passive and active strategies), and the prescription of an individualised, targeted management approach (outlined above and in Table 5). Following the 12th treatment session, follow-up consultations were transitioned to telehealth. This was due to his travel commitments and professional competition schedule, and then the arrival of the Coronavirus disease (COVID-19) pandemic. Telehealth consultations were used to progress and modify the targeted, multi-system management approach, based upon the patient's feedback of activities (daily living, training, competing) that were symptom provocative. Ten months following the initial consultation, the patient reported that he is doing some of the best surfing in his career and that "symptoms have been going great"

Patient 3 attended 6 consultations over six months, which included the multi-system management approach outlined above. After three consultations (three months), he reported "feeling way better overall", capable of coaching Australian rules football drills at youth training without symptom aggravation. During the fourth consultation (four months) he discussed being able to undertake media interviews and participate in prolonged phone conversations, which he stated not been able to do for the past five years At this time, OVS testing was considered normal (Table 1, 6). However, busy, and noisy environments could still create a sense of being overwhelmed, and he would "shut down and remove (him)self from the situation." At the sixth

consultation (six months) he enthusiastically reported gaining new employment, the first time he had been able to work since retiring from the AFL. The new employment hours, and arrival of the COVID-19 pandemic then disrupted follow-up consultations. The patient demonstrated improvements in all objective and quantitative assessments (Table 4).

DISCUSSION

There has been minimal documentation regarding the identification and management of POTS in individuals' post-concussion. A recent review of the literature revealed four studies documenting the identification of POTS in some individuals with PPCS.[8,16,17,21] The literature suggests that there is a relationship with POTS being a complication post-concussion, and could account for PPCS remaining refractory to typical interventions. However, there are no published randomised controlled trials addressing conservative therapy intervention in patients presenting with POTS post-concussion.

This case series demonstrated quantitative subjective and objective improvements in symptoms and function of three elite, professional athletes with PPCS following individualised, multi-system management that first targeted and addressed the POTS and ANS dysfunction identified on clinical assessment. According to the literature, the incorporation of an individualised POTS program into best-practice concussion management may be useful.[7] It is the opinion of the author that the improved outcomes seen in all three patients were related to the initial implementation of orthostatic tolerance training with coupled exercise strategies, to first address the POTS identified on clinical assessment. This is supported by Heyer et al[16] who demonstrated that individuals with resolution of POTS also had corresponding improvements in PPCS. It should be noted that the individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme was also co-prescribed for the exertional intolerance and ANS dysfunction. However, Patients 1 and 3 had reported previously trying to complete a concussion aerobic exercise program, unsuccessfully.

According to the literature, management of PPCS should be individualised and target the impairments identified on clinical assessment.[1,11] The literature supports the implementation of a symptom-guided, progressive aerobic exercise training program for individuals who have experienced a concussion and exhibit exertional intolerance.[11] However, Miranda et al[17] suggest in cases of ongoing exercise intolerance, the presence of POTS may need to be identified and managed before commencing an individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme. To the author's knowledge, this is the first case series to demonstrate the concept of a POTS and ANS hierarchically targeted, multi-system treatment approach in the management of PPCS.

Research on the relationship between concussion, PPCS and POTS is limited, which is compounded by the nonexistence of literature regarding a multi-system management approach that first targets and addresses the POTS and ANS dysfunction. This paper contributes to the body of empirical evidence that suggests some individuals with PPCS may be due to POTS, and provides clinicians with a

model for the conservative management of POTS post-concussion. However, this is only a case series and demonstrates only a small sample and only short-term outcomes. Therefore, the management protocol cannot be generalised to all cases of POTS or to all athletic populations. Further research involving larger randomized controlled and clinical trials with long-term follow up are both required and warranted to clarify the effectiveness of a POTS and ANS hierarchically targeted, multi-system treatment approach in the management of PPCS. Future directions for research should investigate targeted multi-system management of PPCS in patients both with and without POTS and/or ANS dysfunction, incorporating additional functional outcome assessment tools such as the Dizziness Handicap Inventory (DHI), and composite autonomic symptom score 31 (COMPASS 31).

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Table 1. Orthostatic Vital Sign Results

Orthostatic Vital Signs Procedure[a]				
1. Patient lies down with head flat for minimum of 3 mins (up to 10 mins). Measure the BP and HR. 2. Instruct the patient to stand. Upon transition to standing, observe the HR and monitor for symptoms 3. Record symptom provocation, BP, and HR, at minimum after 1 min and 3 min of standing (up to 5, 7 and 10 mins of standing)				
POTS Diagnostic Criteria[12]				
(1) a HR increase ≥30 bpm (or ≥40 bpm in individuals 12 to 19 years of age), or a sustained HR >120 bpm when moving from recumbent to a standing position, (2) symptoms (light-headedness, unsteadiness, headache, generalised weakness, nausea, fatigue, dimming or blurring of vision, confusion, or diaphoresis) that occurred with standing, and (3) the absence of orthostatic hypotension (>20 mm Hg drop in systolic blood pressure (BP)				
Patient 1 | 26-year-old male, professional AFL player				
Date	**Supine BP and HR**	**Stand 1min BP and HR**	**Stand 3 min BP and HR**	**Symptoms**
18/5	128/65 mm Hg HR 53 bpm	125/77 mm Hg HR 101 bpm	134/78 mm Hg HR 91 bpm	Light-headedness, headache, unsteady
22/6	124/64, HR 51	129/78, HR 100	128/77, HR 80	Light-headedness, unsteady
1/8	121/66, HR 56	130/77, HR 77	125/79, HR 73	None
19/12	129/66, HR 54	124/73, HR 76	128/78, HR 74	None
10/5	134/72, HR 60	132/80, HR 74	133/79, HR 74	None
Patient 2 | 29-year-old male, professional surfer				
27/4	116/64 mm Hg HR 55 bpm	106/70 mm Hg HR 80 bpm	113/78 mm Hg HR 87 bpm	Light-headedness, unsteady
14/6	119/68, HR 58	111/75, HR 74	120/79, HR 84	Light-headedness, unsteady,

				perceived weakness in legs
9/8	117/66, HR 52	110/74, HR 73	115/79, HR 68	None
Patient 3 | 29-year-old male, professional AFL player				
31/3	129/72 mm Hg HR 65 bpm	118/69 mm Hg HR 88 bpm	131/81 mm Hg HR 109 bpm	Light-headedness, headache, neck tightness
16/4	127/68, HR 63	119/73, HR 98	128/77, HR 85	Light-headedness, headache, a perceived internal sensation of choking
15/7	123/66, HR 73	118/74, HR 93	125/78, HR 88	None
22/9	120/67, HR 66	117/73, HR 82	123/75, HR 78	None

[a]Adapted from Miranda et al,[7] and Matuszak et al.[18]

Table 2. Orthostatic Tolerance Training

Active and Passive Tilt Variations	
Active	• Patient lays supine and performs appropriately determined coupled exercise strategies • Patient transitions to a seated position and performs the same exercises • Patient transitions to a standing position and performs the same exercises • Sets, repetitions and/or duration was determined based upon the patients HR response
Passive (Option 1)	• Patient lays supine on an inversion table for a minimum of 2 min to establish a baseline HR • The table was passively tilted towards an upright position, while monitoring the patients' HR • If HR increased ≥10 bpm, the table was passively lowered (slowly) back to the recumbent position, and kept horizontal until the patients' HR returned to baseline • The table was again passively tilted towards an upright position, monitoring the patients' HR • The passive tilt process was continued for minimum of 5 mins (up to 20 min), with a goal of being able to keep the patient passively upright without a HR increase ≥10 bpm or symptom provocation
Passive (Option 2)	• Patient lays supine on an inversion table for a minimum of 2 min to establish a baseline HR • The table was passively tilted towards an upright position, while monitoring the patients' HR • If HR increased ≥10 bpm, the table was passively lowered (slowly) approximately 10º from the position of HR elevation, and appropriately determined coupled exercise strategies were performed in this position. • The table was again passively tilted towards an upright position, monitoring the patients' HR • The passive tilt process was continued for minimum of 5 mins (up to 20 min), with a goal of being able to keep the patient passively upright without a HR increase ≥10 bpm or symptom provocation
Coupled Exercise Strategies	
Any strategies that had a positive modification in the ANS (e.g., HR not increasing ≥10 bpm), were coupled with the initial orthostatic tolerance training.	

Exercise strategies included: gaze stabilisation exercises; breathing exercises; hip and/or thigh isometric exercises; repetitive peripheral nerve stimulation; somatic sensorimotor movements involving complex movements of the upper and lower extremity.

Table 3. Patient-Reported Outcome Measures (PROMs)

Patient 1 | Duration of symptoms = 7 weeks					
	PCSS		RPQ		PHQ-9
Date	Total number of symptoms	Symptom Severity Score	RPQ-3	RPQ-13	
18/5	15 of 22	67 of 132	9	30	16
22/6	13 of 22	41 of 132	8	19	7
1/8	9 of 22	24 of 132	4	8	5
19/12	6 of 22	19 of 132	3	5	4
10/5	3 of 22	3 of 132	0	2	2
Patient 2 | Duration of symptoms = 8 months					
27/4	20 of 22	77 of 132	5	35	15
14/6	19 of 22	45 of 132	2	22	10
9/8	19 of 22	40 of 132	0	19	8
5/11	7 of 22	23 of 132	0	9	5
31/3	4 of 22	12 of 132	0	4	3
Patient 3 | Duration of symptoms = 2 years					
31/3	18 of 22	73 of 132	6	39	11
16/4	12 of 22	29 of 132	3	19	9
15/7	11 of 22	22 of 132	2	17	5
22/9	8 of 22	12 of 132	0	12	3

PCSS = Post-Concussion Symptom Scale; RPQ = Rivermead Post-concussion Symptoms Questionnaire; RPQ-3 = first three items of the questionnaire (headaches, dizziness and nausea), associated with early symptom clusters of concussion symptoms; RPQ-13 = remaining 13 items of the questionnaire, associated with later cluster of symptoms, where higher scores reflect greater severity of PPCS; PHQ-9 = 9-Item Patient Health Questionnaire, where 0-4 suggests minimal depression, 5-9 suggests mild depression, 10-14 suggests moderate depression, 15-19 suggests moderately severe depression, and 20-27 suggests severe depression

Table 4. Patient 1 Follow-up and Outcomes

Date	Objective Clinical Assessments	Multi-System Management
18/5	• OVS = POTS (Table 1) • BCTT = physiological PPCS • VOG = vestibulo-oculomotor dysfunction • RightEye = decreased performance in saccades and fixation • mCTSIB = decreased postural control across all test conditions	• Active Orthostatic tolerance training with coupled exercise strategies (Table 2) • Individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme
22/6	• VOG = WNL	• Continuation and progression of the previous strategies • Additions of oculomotor exercises
25/7	• mCTSIB = WNL, except vestibular test condition	• Continuation and progression of the previous strategies • Inclusion of machine-based leg weights at <60% MVC (e.g. leg press, leg extension)
1/8	• OVS = WNL • RightEye = decreased performance in saccades	• Continuation and progression of the previous strategies • Additions of balance and motor coordination exercises • Additions of cervical spine strength and endurance exercises
19/12	• mCTSIB = all test conditions WNL	• Continuation and progression of the previous strategies
10/5	• All clinical assessments WNL	• Discharged from care

OVS = orthostatic vital signs; POTS = postural orthostatic tachycardia syndrome; BCTT = Buffalo concussion treadmill test; PPCS = persistent post-concussion symptoms; mCTSIB = modified Clinical Test of Sensory Integration in Balance; WNL = within normal limits; MVC = maximal voluntary contraction.

Table 5. Patient 2 Follow-up and Outcomes

Date	Objective Clinical Assessments	Multi-System Management
27/4	• OVS = POTS (Table 1) • BCTT = physiological PPCS • VOG = vestibulo-oculomotor dysfunction • RightEye = significant decreased performance in overall score, pursuits and saccades • mCTSIB = decreased postural control across all test conditions, except vestibular was WNL	• Active Orthostatic tolerance training with coupled exercise strategies (Table 2) • Individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme
14/6	• VOG = WNL • RightEye = below reference data for saccades • mCTSIB = decreased postural control in vison test condition	• Continuation and progression of the previous strategies • Additions of oculomotor exercises
9/8	• All quantitative assessments were scored to be WNL • However, vestibulo-oculomotor assessments (VOG, RightEye and bedside antisaccade testing) were slightly symptom provocative	• Continuation and progression of the aerobic exercise programme • Continuation and progression of oculomotor exercises • Additions of cervical spine strength and endurance exercises • Additions of scapula stabilisation exercises • Additions of hip and leg strengthening exercises • Additions of balance and motor coordination exercises

OVS = orthostatic vital signs; POTS = postural orthostatic tachycardia syndrome; BCTT = Buffalo concussion treadmill test; PPCS = persistent post-concussion symptoms; mCTSIB = modified Clinical Test of Sensory Integration in Balance; WNL = within normal limits.

Table 6. Patient 3 Follow-up and Outcomes

Date	Objective Clinical Assessments	Multi-System Management
31/3	• OVS = POTS (Table 1) • BCTT = physiological PPCS • VOG = WNL • RightEye = below reference data for saccades • mCTSIB = decreased postural control across all test conditions	• Active Orthostatic tolerance training with coupled exercise strategies (Table 2) • Individualised, graduated sub-symptom-threshold submaximal aerobic exercise programme • Oculomotor exercises
16/4	• RightEye = WNL	• Continuation and progression of the previous strategies
15/7	• OVS = WNL • BCTT = WNL	• Continuation and progression of the previous strategies • Additions of breathing/breath challenge exercises during aerobic exercise
22/9	• All clinical assessments WNL	• Continuation and progression of the previous strategies

OVS = orthostatic vital signs; POTS = postural orthostatic tachycardia syndrome; BCTT = Buffalo concussion treadmill test; PPCS = persistent post-concussion symptoms; mCTSIB = modified Clinical Test of Sensory Integration in Balance; WNL = within normal limits.