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Vestibular rehabilitation in cerebellar ataxia with neuropathy and vestibular areflexia syndrome (CANVAS)- A case report☆

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ABSTRACT

Background and purpose: Cerebellar ataxia, neuropathy, and vestibular areflexia syndrome (CANVAS) is a neurodegenerative disease of the cerebellum. The disease progression is slow, with up to 25% of people diagnosed needing to use a wheelchair after 15 years from diagnosis. Vestibular symptoms arise from centrally-mediated ocular movement degradation and the reduced vestibular-ocular reflex functioning bilaterally. To date, no report has shown an improvement in VOR gain or gait outcome measures in someone with CANVAS after a course of vestibular physical therapy.
Case description: A 65-year-old male, Patient X, first noticed symptoms in his fourth decade of life and was diagnosed with (CANVAS) in his seventh decade. Patient X reported numbness and tingling in his hands and feet, decreased ability to perform daily activities, and several falls.
Intervention: Patient X completed a four-month course of vestibular physical therapy, including vestibular ocular reflex exercises, balance training, gait training, and the VestAid application for eye gaze compliance monitoring. The Vestaid application uses eyes and facial recognition software to record the percentage of time that the patient kept their eyes on the target.
Outcomes: After vestibular therapy, Patient X had a clinically meaningful improvement in gait speed: from 1.02 m/s to 1.13 m/s and in the Functional Gait Assessment from 20/30 to 27/30. Patient X's eye gaze compliance improved from a median of 43% (range 25–68%) to a median of 67% (58–83%).
Discussion: This case study demonstrates that vestibular rehabilitation improved eye gaze compliance and functional outcomes in a person living with CANVAS.

1. Introduction

Cerebellar ataxia, neuropathy, and vestibular areflexia syndrome (CANVAS) is a neurodegenerative disease of the cerebellum. CANVAS is related to a genetic mutation that is biallelic intronic repeat expansion in replication factor complex subunit 1 (Cortese et al., 2020). Clinical involvement in CANVAS results mainly in sensory neuropathy, bilateral vestibulopathy, and cerebellar dysfunction (Cortese et al., 2020). CANVAS was first identified in 2007 as a cluster of signs and symptoms different than known degenerative cerebellar disorders (Zingler et al., 2007). In 2011, the cluster of signs and symptoms was formally defined as CANVAS and included the addition of sensory neuropathy (Szmulewicz et al., 2011a).

Symptoms usually begin in the sixth decade of life, with unsteadiness, cough, and sensory symptoms being the first to present (Cortese et al., 2020). Symptoms such as oscillopsia, dysautonomic symptoms, dysarthria, and dysphagia, present later in the disease process (Cortese et al., 2020). The diagnosis of CANVAS is usually made clinically (Sullivan et al., 2021). However, the presentation of

Abbreviations: CANVAS, cerebellar ataxia, neuropathy, and vestibular areflexia syndrome; VOR, vestibular-ocular reflex; DVA, dynamic visual acuity; VHIT, video head impulse test; FGA, functional gait assessment; DGI, dynamic gait index; ABC, activities-specific balance confidence scale; DHI, dizziness handicap inventory.

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the first symptoms to diagnosis can take up to ten years (Szmulewicz et al., 2014). The disease progression is slow, with up to 50% of people diagnosed needing an assistive device for ambulation after ten years from diagnosis and up to 25% of people diagnosed needing to use a wheelchair for mobility-related activities of daily living after 15 years from diagnosis (Cortese et al., 2020).

Vestibular symptoms arise from centrally-mediated ocular movement degradation and the reduced vestibular-ocular reflex functioning bilaterally (Dupre et al., 2021). People with CANVAS often present with abnormal vestibular testing. Szmulewicz et al. describe the clinical feature and laboratory testing results of 27 people with CANVAS(Szmulewicz et al., 2011b). Their results include bidirectionally positive horizontal and vertical video head impulse testing, absent or severely reduced horizontal nystagmus responses on bithermal caloric stimulation, and absent or severely reduced horizontal nystagmus responses to rotational chair testing (Szmulewicz et al., 2011b). People with CANVAS who have developed oscillopsia report that the oscillopsia occurs mainly during head movements which is a result of the bilaterally impaired vestibular-ocular reflex (VOR) (Dupre et al., 2021). Anson et al. showed that people with bilateral vestibular hypofunction reported more severe oscillopsia and had lower VOR gain frequency during ambulation compared to healthy controls (Anson et al., 2017).

There is little evidence in the literature regarding rehabilitation for people with CANVAS, however balance outcomes have been reported following balance and vestibular physical therapy for those with other degenerative cerebellar conditions. An intensive 4-week physiotherapy program of static balance, dynamic balance, whole-body movements to train trunk-limb coordination, and fall prevention significantly improved ataxia in those with degenerative cerebellar conditions (Ilg et al., 2010). Hassannia et al. demonstrated an improvement on the Modified Clinical Test of Sensory Interaction and Balance and decreased number of falls in those with idiopathic cerebellar ataxia with bilateral vestibulopathy following vestibular rehabilitation (Hassannia et al., 2022). To date, no report has shown an improvement in VOR gain or gait outcome measures in someone with CANVAS after a course of vestibular physical therapy. Health Insurance Portability and Accountability Act requirements were followed.

2. Case presentation

Patient X is a 65-year-old man who presented to vestibular physical therapy with cerebellar ataxia neuropathy vestibular areflexia syndrome (CANVAS). His diagnosis was confirmed with genetic testing, having identified RFC1 expansion mutation. Additionally, he had migraine, osteopenia, and bilateral neuropathy. At the age of 31 years, he reported an atypical cough that waxed and waned over the years but progressively worsened. At the age of 53 years, he reported difficulty with complex fine motor skills, difficulty riding a bike, and worse balance in the dark. In his mid-50s he fractured his wrist in a fall and noted numbness in his right wrist during exercise, with sensory neuropathy noted on electromyography.

At 65 years of age, he now reports difficulty walking on uneven surfaces and has great difficulty navigating in the dark. His disequilibrium is triggered by movement but not by motion in the visual surroundings. He reports extreme fatigue with reading and two falls within the last year. He has pulsatile tinnitus for the past 13 years and bilateral high-frequency sensory neural hearing loss. Migraines are currently being treated with topiramate. His sister was diagnosed with CANVAS, and his father had a “gait workup,” but no diagnosis was made about his gait disturbance.

Table 1 shows the results of his initial vestibular physical therapy evaluation. His instrumented video head impulse test (vHIT) illustrates his covert saccades and mean gain scores before rehabilitation. (Fig. 1a). During his clinical examination, his near point convergence score was 14 cm. He had mild gaze evoked nystagmus with lateral gaze and upward gaze. Saccades were hypermetric bilaterally and pursuit was mildly saccadic. The initial evaluation also included several outcome measures that are standard in vestibular physical therapy based on the core set of outcome measures recommended by the Academy of Neurological Physical Therapy and the consensus documents of diagnostic criteria for bilateral vestibulopathy by the International Barany Society (Moore et al., 2018; Strupp et al., 2017). Measurement of gait speed with the 10 Meter Walk Test, the vestibular ocular reflex with the clinical Dynamic Visual Acuity (DVA) and vHIT, dynamic ambulatory balance with the Functional Gait Assessment (FGA) and the Dynamic Gait Index (DGI), and self-reported measures of balance confidence and dizziness with the Activities-specific Balance Confidence Scale (ABC) and the Dizziness Handicap Inventory (DHI) were collected (Fritz and Lusardi, 2009; Wrisely et al., 2004; Schubert et al., 2002; Powell and Myers, 1995; Jacobson and Newman, 1990; Wrisley et al., 2003; Tian et al., 2001).

Patient X underwent a course of vestibular physical therapy of seven visits over four months to enhance his balance, balance activities in low vision environments, attempts to narrow his base of support, improve his convergence insufficiency, and gaze stabilization exercises. Table 2a contains a list of interventions used during Patient X's care. His plan of care included use of the VestAid tablet app. The VestAid tablet app can record eye/gaze compliance and head speed accuracy while performing the VOR x 1 exercise designed to create retinal slip, which drives an increase in the VOR gain (Hovareshti et al., 2021; Hall et al., 2022; Schubert et al., 2008). VestAid uses eyes and facial recognition software to record the percentage of time that the patient kept their eyes on the target (eye gaze compliance accuracy). Patient X completed 11 exercises using the VestAid tablet. Table 2b shows the exercise protocol that was used with the VestAid. The 11 exercises were chosen to have varying degrees of difficulty in performing the VOR x 1 exercises based on expert opinion of four experienced physical therapists.

A questionnaire developed to record symptoms and assess quality of life in persons living with bilateral vestibulopathy was completed (van Stiphout et al., 2022). The questionnaire is comprised of 47 items related to the symptoms the person has felt in the past week, with the patient scoring items from one (never) to six (always) (van Stiphout et al., 2022). Items in the balance category of the scale that Patient X scored at five or higher included imbalance in the dark, needing to pay attention to the ground to avoid a fall, tripping, and falling. No items were endorsed at 5/6 for the oscillopsia, other physical symptoms, cognitive, emotional, and behaviors/limitations scales except for a score of 6 for needing to perform activities at a slower pace. He reported that his condition negatively affects his close relationships, that people did not understand his situation, and that sometimes he needs help to perform daily activities at 5/6 or greater. For the item of how limited he was in his daily life due to his CANVAS diagnosis, with 100 being the worst, he scored 70 out of 100 and reported that the symptom he would like to improve the most was his vision.

Patient X also completed the Oscillopsia Functional Impact Scale (OFI), which was designed to determine the effect of oscillopsia on function (Anson et al., 2018). Patient X's OFI score was 68, with Anson reporting a mean OFI score of 65.9 in 69 persons living with bilateral vestibular loss (Anson et al., 2018). The most challenging tasks on the OFI scale were walking and reading a text/email on a mobile phone while walking fast and attempting to read a shopping list.

After seven physical therapy visits, he had a significant, meaningful change in some of his functional outcomes (Table 3). His ABC

Table 1
Results from the initial physical therapy examination.

Testing	Result	Comment
Sensory testing		
Vibration	Diminished	Diminished in both hands and feet, worse in feet
Temperature	Diminished	
Coordination		
Heel-to-shin	Intact	
Ocular-motor		
Acuity	Intact	20/20 with corrective lenses
Smooth pursuits	Impaired	Occasional hypermetric saccades during testing
Saccades	Impaired	Hypermetric
Near Point Convergence	Impaired	>5 cm is considered abnormal
Vestibular		
Video Head Impulse Test (vHIT)	Abnormal	Covert saccades present, mean gain below 0.80. Fig. 1a demonstrates the vHIT test findings
Dynamic Visual Acuity (DVA)	Abnormal	6-line loss with the clinical DVA
Balance		
Romberg	Able to stand unassisted	Increased sway
Functional Gait Assessment	Impaired	20/30
Activities-specific Balance Confidence Score	Abnormal	76%
Function		
Gait Speed	Normal	1.02 m/s
Dizziness Handicap Inventory	Moderate handicap	44
Oscillopsia Functional Impact Scale	Abnormal	68/215

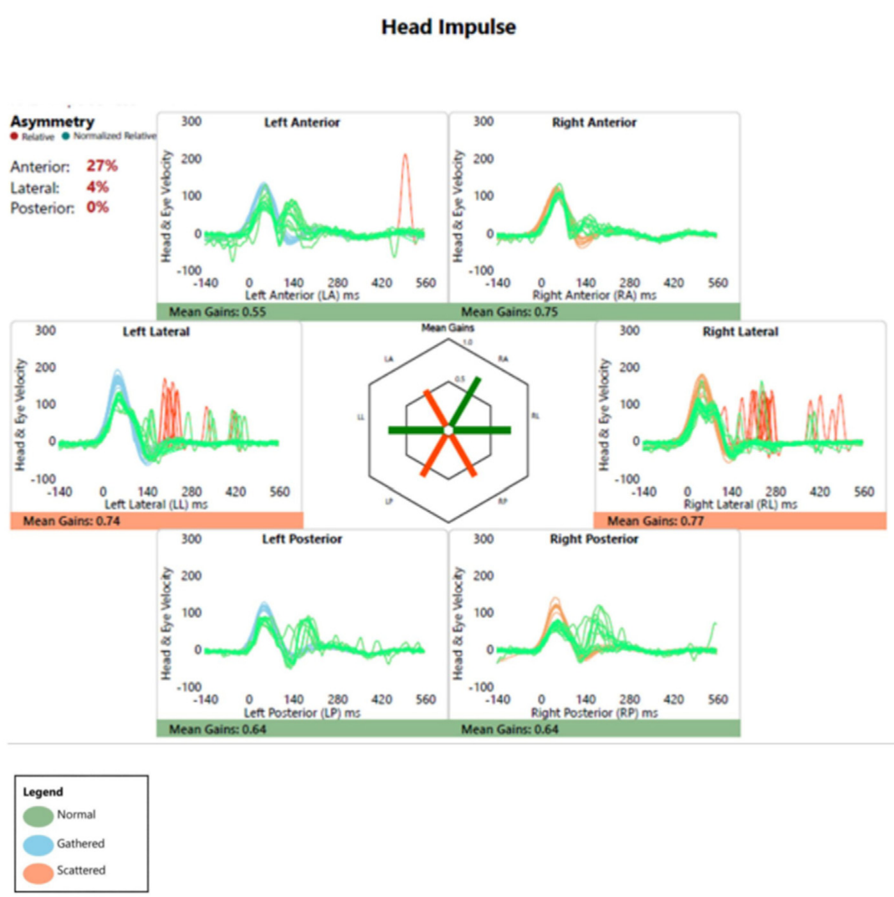


Fig. 1a. Initial vHIT findings. For Fig. 1a and b, the green lines represent VOR gain and blue lines represent head movement during the impulse. Red lines indicate a corrective saccade during the head movement. The VOR gains-which can be found in the bar underneath each graph-are compared to normal: normal horizontal VOR is greater than 0.80 (27) and gain in the right anterior and left posterior and left anterior and right posterior plane is considered normal if the gain is greater than 0.70 (28).

score was 80 out of 100 (Powell and Myers, 1995). His DHI score was unchanged (Jacobson and Newman, 1990). His FGA score improved from 20 to 27 out of 30 (Wrisely et al., 2004). He improved by seven points on the FGA, and the minimally clinically important difference (MCID) is four points (Beninato et al., 2014). Components of Patient X's FGA can be seen in Video 1 found in the Supplemental material. Patient X's gait speed was 1.13 m/s, which indicates he is a community ambulator (Fritz and Lusardi, 2009). A change of 0.1 m/s

Table 2a
Interventions used during Patient X's vestibular physical therapy plan of care.

Interventions:
Eye exercises
VORx1
VOR cancellation
VOR with corrective saccades
VOR with vergence
Optokinetic stimuli- tracking with eyes with head/eye movement checkered background
Pencil pushups
Beads on string (Brock string)
Balance Exercises
Towel curls (toe flexion strengthening)
Weight shifting in standing
Bilateral upper extremity PNF chop and lift
Backward rotation ball toss
Eyes closed/feet together/foam
Static standing in semi-tandem on foam
Tandem stand on foam
Reaching in semi-tandem
Gait exercises
Gait with horizontal head turns
Gait with vertical head turns
Gait with eyes closed
Tandem gait

*VOR: vestibulo-ocular reflex.

is clinically meaningful (Perera et al., 2006). He lost four lines with the clinical DVA testing, which continues to suggest that he has challenges focusing on targets when his head is moving (Schubert et al., 2002).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.joto.2023.06.004

Patient X's initial vHIT was completed using the Natus™ vHIT system with his neurotologist. His VOR in the horizontal canals <0.8 bilaterally, indicating bilateral hypofunction (MacDougall et al., 2009). The vertical canal VOR gain was <0.7 bilaterally, also indicating bilateral hypofunction (Macdougall et al., 2013). Repeat vHIT testing was completed four months later at the final visit. The VOR gain for the left horizontal canal decreased from 0.74 to 0.70 and the right lateral canal gain decreased from 0.77 to 0.74. In the LARP plane, the left anterior canal saw the largest gain change, from 0.55 to 0.09. The right posterior canal decreased from 0.64 to 0.61. The RALP plane had an increase in the left posterior canal from 0.64 to 0.7, and the right anterior canal gain remained the same at 0.64. Fig. 1a shows his initial vHIT results and Fig. 1b shows his follow up vHIT results following vestibular rehabilitation.

The VestAid device can track the participant's compliance regarding head movement and gaze stability. Patient X completed all VestAid exercises seated, three feet away from the tablet, and at a speed of 80 beats per minute. Patient X's initial head compliance percentage was a median of 63%, ranging from 9% to 100%. At discharge, he was 100% compliant on all 11 tests for head movement. His eye gaze stability at the initial assessment was a median of 43%, ranging from 25% to 68%. At the final assessment, his eye gaze stability was a median of 67%, ranging from 58% to 83%. Patient X was asked to rate the challenge of each exercise from extremely easy (0) to extremely hard (10). On initial testing, Patient X's median rate of challenge was 3 with a range of 0–7. On final testing, Patient X's median rate of challenge was 3 with a range of 0–6.

3. Discussion

Patient X's case illustrates that vestibular rehabilitation can improve the functional mobility of someone with CANVAS, even when there are no improvements in VOR gain and dizziness. While there is no cure for CANVAS, vestibular rehabilitation reduced this patient's fall risk and increased his gait speed. Patient X had the typical presentation of CANVAS, including a spasmodic cough, cold or pale feet, reported falls, difficulty walking in the dark, sensory symptoms, and oscillopsia (Cortese et al., 2020; Sullivan et al., 2021). Saccadic dysmetria, broken smooth pursuits, downbeat nystagmus, gait or truncal ataxia, and dysarthria may also be present (Cortese et al., 2020). Patient X's symptom progression does not include ataxia in the extremities, dysarthria, or dysphagia, but did include saccadic dysmetria, broken smooth pursuits, spasmodic cough, oscillopsia, sensory symptoms, and a history of falls. While his symptom presentation indicates he is still in the early stages of the disease, he was able to make meaningful changes in several of the functional outcomes recorded.

One of Patient X's main impairments was dizziness with functional movement. Patient X's DHI scores initially and at discharge placed him in the moderate category (Whitney et al., 2004). People who perceive greater handicap on the DHI demonstrate greater functional impairment (Whitney et al., 2004). Scores on the DHI of greater than 60 have been related to falls, yet Patient X has already had several fall events with one fracture (Whitney et al., 2004). In CANVAS, falls may be more prevalent than with persons with bilateral vestibular loss because of the sensory neuropathy plus the DHI is asking patients about their dizziness. Dizziness and vertigo are only reported in persons with bilateral vestibular loss if they have remaining vestibular function and dizziness is not a hallmark of CANVAS. The DHI may not be the optimal measure to utilize in persons with CANVAS as a result. Patient X's DHI did not improve over the course of vestibular rehabilitation, however he was able to improve his functional mobility regardless of the change in dizziness.

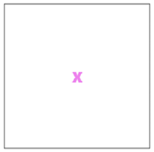
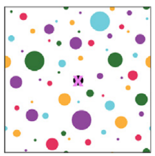
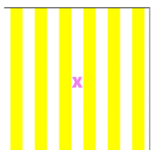
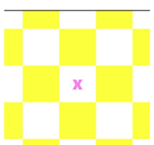
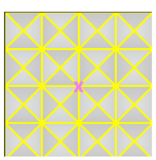
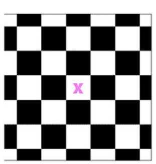
A key component of CANVAS is bilateral vestibular areflexia. On the bilateral vestibulopathy questionnaire, Patient X endorsed all items except for one item (van Stiphout et al., 2022). He stated that he could recognize faces when walking without having to stop. The questionnaire captured his condition with a wide range of scores on the test. Patient X was affected by some of the items much more than others, suggesting that there might be a different profile of responses on the bilateral vestibulopathy questionnaire in persons living with CANVAS than those with more typical bilateral vestibular loss. Further study is required to determine if persons living with CANVAS have different activity and participation limitations than persons living with bilateral vestibular loss.

Patient X experienced oscillopsia throughout his course of vestibular rehabilitation. His total score on the OFI was only two points above the mean for persons living with bilateral loss (Anson et al., 2018), suggesting that his oscillopsia was similar to those living with bilateral loss. He did report that his vision was his most challenging concern. He was challenged with reading and most challenged with reading and walking simultaneously.

Patient X reported several falls prior to starting vestibular rehabilitation and demonstrated an increased fall risk on several functional balance measures. Patient X's ABC scores improved from an initial score of 76% to a discharge score of 80%. Whitney et al. reported that a 10% change in the ABC was meaningful in persons with vestibular migraine (Whitney et al., 2000b). Hassannia reported no difference in ABC scores after vestibular rehab in persons living with CANVAS, which is similar to our finding in Patient X (Hassannia et al., 2022). However, Hassannia et al. did report improvements in standing balance, which was not recorded in Patient X. With CANVAS, peripheral neuropathy is a primary symptom that will affect postural control. There was no outcome measure specifically utilized to determine how Patient X's neuropathy might influence his postural control.

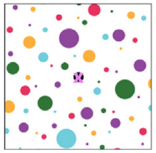
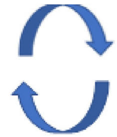
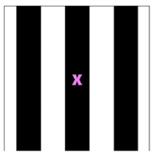
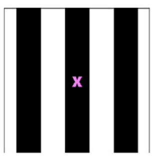
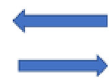
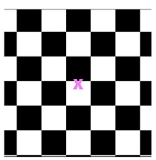
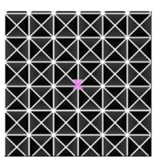
Persons with CANVAS did not improve their gait speed or their

Table 2b
VestAid protocol and head motion and eye gaze compliance results at initial and final vestibular physical therapy sessions. All VORx1 exercises completed in the yaw plane at 80 beats per minute while seated for 30 s with 12-point pink font optotype.

VestAid screenshot	Exercise Background Description		Head Motion Compliance (percentage)		Eye Gaze Accuracy (percentage)		Rating of perceived challenge[a]	
Easy exercises[b]	Color/Pattern (Movement)	Illustration of background movement	Initial	Final	Initial	Final	Initial	Final
	White/No pattern (Static)	n/a	81%	100%	53%	83%	0	0
	White/Dots (Static)	n/a	100%	100%	43%	81%	2	0
	Yellow/Vertical Bars (Static)	n/a	63%	100%	40%	58%	2	2
	Yellow/Checkerboard (Static)	n/a	9%	100%	25%	68%	3	2
	Yellow/Contrasting (Static, low contrast)	n/a	25%	100%	42%	75%	4	3
Hard exercises[b]	Color/Pattern (Movement)	Illustration of background movement	Initial	Final	Initial	Final	Initial	Final
	Black/Checkerboard (Static)	n/a	43%	100%	48%	67%	5	3

(*continued on next page*)

Table 2b (*continued*)

VestAid screenshot	Exercise Background Description		Head Motion Compliance (percentage)		Eye Gaze Accuracy (percentage)		Rating of perceived challenge[a]	
Easy exercises[b]	Color/Pattern (Movement)	Illustration of background movement	Initial	Final	Initial	Final	Initial	Final
	White/Dots (Rotation, medium speed)		63%	100%	68%	65%	5	4
	Black/Verticals Bars (Horizontal left to right, medium speed)		100%	100%	40%	58%	3	4
	Black/Vertical Bars (Horizontal oscillation, medium-slow speed)		91%	100%	39%	63%	3	4
	Black/Checkerboard (Vertical down to up, medium speed)		66%	100%	49%	65%	5	5
	White/Contrasting (Vertical Oscillation, medium speed, high contrast)		30%	100%	52%	83%	7	6

[a] Challenge of exercise rated from extremely easy (0) to extremely hard (10).
[b] The “easy” and “hard” exercises were determined by four experienced physical therapists based on the contrast and movement of the visual scenes.

Table 3
Outcome measures at the initial and final vestibular physical therapy examination.

Outcome measure	Initial evaluation	Final 4 months post initial evaluation	Improved/Worsened (MDIC if applicable)
Dizziness Handicap Inventory	44/100	50/100	Worsened by 6 points
Activities- Specific Confidence Scale	76%	80%	Improved by 4%
Functional Gait Assessment	20/30	27/30	Improved by 7 points (4 points)[a]
Dynamic Gait Index	18/24	21/24	Improved by 3 points (4 points)
Gait speed	1.02 m/s	1.13 m/s	Improved by 0.11 m/s (0.1 m/s)[a]
Dynamic Visual Acuity	6 line loss	5 line loss	Improved by 1 line

[a] Denotes a clinically meaningful change.

DGI score in a previous study (Hassannia et al., 2022). Patient X's DGI improved from 18/24 to 21/24, which, while an improvement, is not clinically significant. The minimally clinically important difference (MCID) for the DGI in those with vestibular disorders is 4 points (Marchetti et al., 2014). However, scores <19 are related to increased fall risk and he did score >19 at discharge, suggesting that his risk of falling had lessened (Whitney et al., 2000a). Patient X had a clinically meaningful improvement in gait speed from 1.02 to 1.13 m/s (Fritz and Lusardi, 2009).

Patient X's FGA score did improve by the MCID of 7 with his initial score of 20/30 and his final score of 27/30 (Beninato et al., 2014). The FGA is more sensitive at detecting a change in gait in a vestibular population as it includes higher level gait tasks (Wrisely et al., 2004). An FGA score of <22/30 predicts greater fall risk (Wrisley and Kumar, 2010). Patient X's discharge score of 27/30 indicates that he is at a lower risk for falls after vestibular physical therapy. These four outcomes measures, the ABC, DHI, gait speed, and FGA, while there was mixed improvement overall demonstrate that over the course of vestibular rehabilitation, Patient X improved his functional mobility and reduced his fall risk.

According to the 2022 Clinical Practice Guideline for Peripheral Hypofunction from the American Physical Therapy Association, vestibular physical therapy should be offered to those with bilateral vestibular hypofunctions (Hall et al., 2022). However, it is still unclear what the optimal dosing of vestibular exercises is for this population (Hall et al., 2022).

One of the principles of vestibular rehabilitation is to improve VOR gain to reduce dizziness and improve gaze stability (Hall et al., 2022). While Patient X's vHIT gain decreased in the horizontal plane, increased in the RALP plane, and decreased in the LARP plane, it is not yet known what a meaningful improvement in VOR gain is. Also present in both vHIT results is the presence of covert saccades, which is to be expected with his CANVAS diagnosis (Dupre et al., 2021). Schubert et al. reported that gaze position error is less if persons with bilateral loss utilize compensatory saccades to stabilize their gaze during head movement (Schubert et al., 2010). Patient X is most likely using compensatory saccades to minimize his oscillopsia. The vHIT is also able to calculate the number of saccades in an impulse which can be used a metric for improvement, a limitation of this study is that an assessment of the

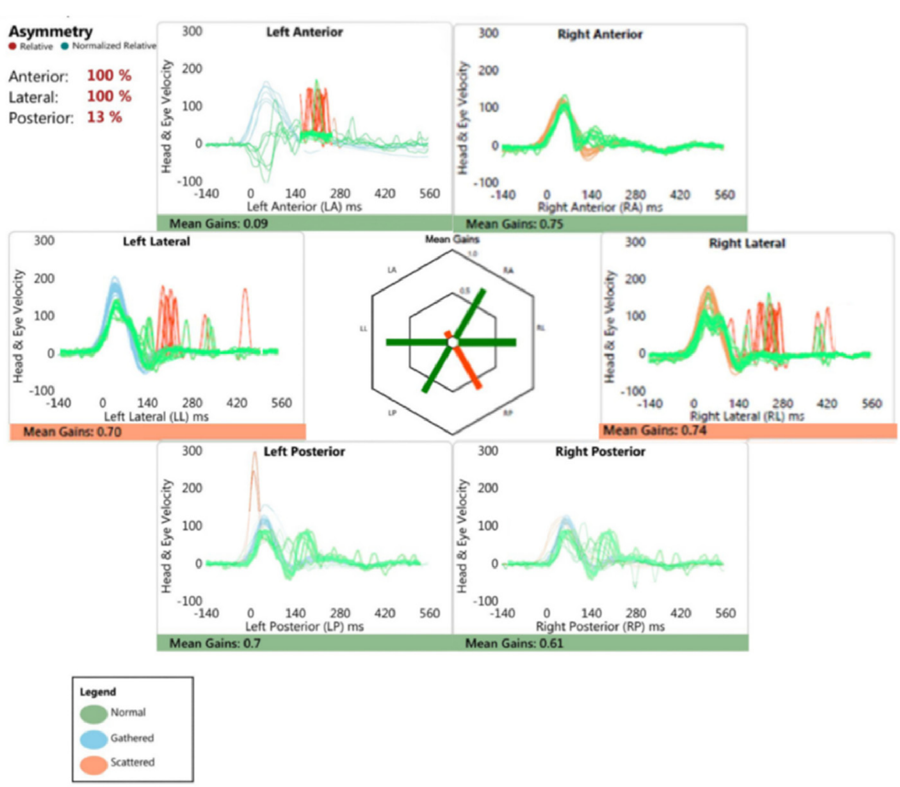


Fig. 1b. For Fig. 1a and b, the green lines represent VOR gain and blue lines represent head movement during the impulse. Red lines indicate a corrective saccade during the head movement. The VOR gains-which can be found in the bar underneath each graph-are compared to normal: normal horizontal VOR is greater than 0.80 (27) and gain in the right anterior and left posterior and left anterior and right posterior plane is considered normal if the gain is greater than 0.70 (28).

number of saccades was not completed.

Even though his VOR gain improved slightly, his eye gaze stability accuracy using the VestAid tablet improved markedly. His ability to coordinate his head movement at beat per minute improved from a median of 63% accuracy at his initial testing to 100% accuracy at final testing. It is possible that there was some mild degree of discoordination that Patient X experienced in trying to accurately time his eye and head movement. Following his vestibular physical therapy exercise program, he improved his head movement motor coordination and could match the 80 bpm 100% of the time for all 11 trials.

The VestAid records eye gaze stability (Hovareshti et al., 2021). Patient X's eye gaze stability percentage improved from a median of 43% accuracy to 67% accuracy. This improvement in gaze stability may contribute to his overall improvement on objective gait measures such as gait speed and his dynamic walking, even with head turns (see Video 1 in the supplemental material that demonstrates the changes in his gait).

The experienced physical therapists and Patient X had similar ratings of perceived exercise difficulty. Patient X's exercise difficulty ratings changed little over the course of his care when recording the median scores, yet when assessed individually, three were rated the same difficulty, six were rated as easier, and two were rated as more difficult. His ratings only changed twice by two points, otherwise all were a one-point change. He was consistent over a 4-month period with his ratings of the difficulty of the 11 exercises. Learning more about how patients rate exercise difficulty warrants future additional study to better prescribe exercise programs for persons living with vestibular disorders.

A limitation of the case study is that joint position sense was not assessed during his plan of care. Joint position sense could have informed the therapist on the status of the vestibulo-spinal reflex. Impaired joint position sense could also contribute to the patient's fall risk. Another limitation is that while the same vHIT device was used for pre- and post-vestibular rehabilitation testing, the testing was completed by two different clinicians. Long term follow up was not completed, so it is unknown if the results of vestibular physical therapy were sustainable after completion of his program.

This case study demonstrates that in the early stages of CANVAS, vestibular physical therapy is beneficial for improving gait speed, dynamic walking performance, and reducing fall risk. Additional study is required to determine if others have similar positive effects from vestibular physical therapy in persons living with CANVAS.

Declaration of competing interest

Dr. Whitney is a paid consultant for Intelligent Automation, a BlueHalo Company, and is a member of the team who has submitted a patent for VestAid.

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