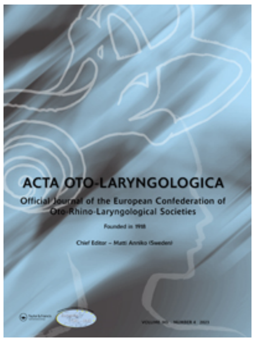

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RESEARCH ARTICLE

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Dynamic posturography after computerized vestibular retraining for stable unilateral vestibular deficits

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ABSTRACT

Background: Balance deficits increase the risk of falls and compromise quality of life. Current treatment modalities do not resolve symptoms for many patients.
Aims/objectives: To measure changes in objective posturography after a computerized vestibular retraining therapy protocol.
Materials and methods: This was a single-arm interventional study of individuals with a stable unilateral vestibular deficit present for greater than six months. Participants underwent 12 twice-weekly sessions of computerized vestibular retraining therapy. Objective response was measured by the Sensory Organization Test and questionnaires were administered to measure subjective changes.
Results: We enrolled 13 participants (5 females and 8 males) with a median age of 51 years (range 18 to 67). After retraining, the Sensory Organization Test composite score improved by 8.8 (95% CI 0.6 to 19.1) and this correlated with improvement in the Falls Efficacy Scale-International questionnaire (r_s −0.6472; 95% CI −0.8872 to − 0.1316). Participants with moderate-to-severe disability at baseline ($n = 7$) demonstrated greater improvement in the composite score (14.6; 95% CI 7.0 to 36.9).
Conclusions and significance: Computerized vestibular retraining therapy for stable unilateral vestibular deficits is associated with improvement in dynamic balance performance. Posturography improvements correlated with a reduction in perceived fall risk.Trial Registration Information Clinicaltrials.gov registration NCT04875013; 04/27/2021

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Posturography; vestibular; rehabilitation; retraining; balance; dizziness

Introduction

Individuals with vestibular deficits have an elevated risk of falling leading to 3 million emergency visits and 30,000 deaths per year in the United States, for those over 65 years of age [1]. Vestibular loss is also associated with depression, anxiety, and cognitive deficits [2].

Maintenance of dynamic equilibrium requires the sensation of orientation and acceleration (through vision, somatosensory, and vestibular senses), the processing of that information by the central vestibular system, and the coordinated response of ocular and musculoskeletal muscles to maintain a stable gaze and balanced posture, respectively. Appropriate weighting of these sensory inputs is required for maintenance of dynamic balance and conflict between inputs can lead to dizziness, motion sickness, and falls [3].

Various forms of rehabilitation have been demonstrated to promote compensation [4]; however, many patients still experience debilitating symptoms many months or years after onset, even with treatment. In published studies, between 1/3 and 2/3 of participants fail to respond to rehabilitation interventions [4].

Computerized Dynamic Posturography (CDP) uses interactive visual stimuli and a mobile platform equipped with force sensors to measure balance performance. CDP may be used as an assessment tool for those with balance disorders; however, there is debate over its utility for diagnosis and for assessment of fall risk [5]. A recent survey found that 20% of vestibular rehabilitation therapists in Europe had access to a CDP instrument [6]. The CDP-mediated test, the Sensory Organization Test (SOT) assesses capacity to maintain stable equilibrium in six conditions in which visual and somatosensory sensory inputs are systematically challenged [3]. The SOT has been used to document changes in postural stability with age [7] and to measure response to rehabilitation interventions among patients experiencing dizziness [4]. SOT test scores also correlate with risk of falling [8].

There have been few reports of interventions that make use of CDP for treatment of vestibular deficits. To our knowledge, only one study has evaluated CDP-assisted therapy in individuals with unilateral peripheral vestibular disorders. This study used a Neurocom CDP instrument that makes use of a visual surround that physically moves with the subject. The authors found that CDP-assisted

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intervention was effective and but was qualitatively different in its effect than optokinetic stimulation [9].

The technology used in CDP systems has advanced since this previous study. The Bertec® Balance Advantage uses a projected image on an immersive wrap-around screen to provide the visual environment. This technology allows for more dynamic, complex training exercises, guided by immersive visuals than previous generation systems. To our knowledge, there have been no studies assessing interventions that make use of this CDP system for individuals with unilateral vestibular deficits.

The objective of this study was to assess objective posturographic measures (SOT scores) and participant-reported disability (by way of questionnaires) before and after completing twelve sessions of computerized vestibular retraining therapy (CVRT) in patients with stable unilateral vestibular deficits. We previously reported, for the same cohort, that CVRT was associated with clinically meaningful improvement in the Dizziness Handicap Inventory, the Activities-specific Balance Confidence Scale, and the Falls-Efficacy Scale-International, especially for those with moderate-to-severe vestibular disability at baseline [10]. In this article, we describe objective changes in postural stability after computerized vestibular retraining for the same cohort and determined whether objective changes were associated with changes in participant-reported measures.

Methods

Participants

This prospective, single group, cohort study was approved by the Clinical Research Ethics Board at the University of British Columbia (study # H20-04045) and all experiments were performed in accordance with relevant guidelines, regulations, and the Declaration of Helsinki. The study has been registered (Clinicaltrials.gov registration NCT04875013; 04/27/2021). All participants provided written informed consent.

Candidate participants were identified from patients referred to the primary investigator's otolaryngology practice: eligible patients were aged between 18 and 80 and reported symptoms of imbalance present for more than six months that negatively affected their day-to-day activities. To be included in the study, the symptoms were clinically assessed to be caused by a stable vestibular deficit (Table 1) rather than an active or irritative vestibulopathy based on the criteria of the Barany Society International Classification of Vestibular Disorders (ICVD-1) consensus classification of vestibular symptoms [11]. Objective determination of unilateral peripheral vestibular deficit required at least one of: (a) unilateral weakness during videonystagmography (VNG), as defined by a 25% or greater difference between ears using bithermal caloric testing; (b) significant cervical or ocular vestibular evoked myogenic potential (VEMP) interaural asymmetry, or absent cervical or ocular VEMP responses in one ear with intact responses in the other ear [12]. We excluded individuals who exhibited fluctuating symptoms of an active vestibulopathic cause within the last six months, such as active Menière's Disease (characterized by fluctuating hearing loss, tinnitus and vertiginous exacerbations lasting > 20 min according to American Academy of Otolaryngology-Head and Neck Surgery criteria); patients with concurrent diagnosis of benign paroxysmal positional vertigo; or patients with clinical and audiometric evidence of a perilymphatic fistula, or otosyphilis. We also excluded those with a deficit that precluded providing informed consent or completing the rehabilitation exercises, such as orthopedic or neurological deficits. Those meeting the eligibility criteria were contacted by telephone and invited to enroll in the study. Enrollment and data collection took place from 29 April 2021 to 23 July 2021.

Table 1. Participant demographics and vestibular test results.

Median age (range)	51 years (18 to 67)
Number of female / male participants	5 / 8
Previous vestibular rehabilitation	9 of 13 (69%)
Abnormal vestibular test	
VNG	12 of 13 (92%)
vHIT	1 of 11 (9%)
oVEMP	6 of 13 (46%)
cVEMP	3 of 12 (25%)

Note: VNG: videonystagmography; vHIT: video head impulse test; oVEMP: ocular vestibular evoked myogenic potential; cVEMP: cervical vestibular evoked myogenic potential.

Intervention and assessments

Consenting participants were invited to the clinic for their baseline assessment where they completed a sensory organization test (SOT) and a limits of stability (LOS) test on a computerized dynamic posturography instrument (Bertec Corporation, Columbus, OH). The SOT test comprises six conditions, each performed in triplicate. The instrument software calculates scores for each condition, as well as a composite score (Table 2). During the posturography tests and all retraining exercises, the participants were supported by a harness as a precaution against falls. The participants also completed three questionnaires: the Dizziness Handicap Inventory (DHI), the Activity-specific Balance Confidence Scale (ABC scale), and the Falls Efficacy Score-International (FES-I). These assessments were administered immediately prior to CVRT on the first day of treatment and after completion of the retraining intervention. An improvement of eight points on the SOT was considered to be meaningful, as this was determined exceed normal variability and account for any learning effect of repeated testing [13].

Participants completed 12 twice-weekly CVRT sessions of approximately 30–40 min per session. The exercises were performed using a Bertec® Balance Advantage CDP system. The training sessions were developed by the principal investigator (EAD) from pre-programmed exercises supplied with the instrument software. The CVRT sessions were designed to become progressively more challenging by increasing the limits of stability, reducing the time to complete the movements, and increasing the motion of the visual display and mobile platform. Participants were challenged to shift their

Table 2. SOT testing conditions.

Test	Description
Condition 1	Eyes open, fixed visual environment and support surface
Condition 2	Eyes closed, fixed support surface
Condition 3	Eyes open, moving visual environment and fixed support surface
Condition 4	Eyes open, fixed visual environment and moving support surface
Condition 5	Eyes closed, moving support surface
Condition 6	Eyes open, moving visual environment and moving support surface

Table 3. Computerized dynamic posturography scores.

	Before retraining; median (range)	After retraining; median (range)	Median change (95% CI)
Sensory organization test			
Composite score	68.4 (40.1 to 89.1)	79.4 (68.1 to 85.1)	8.8 (0.6 to 19.1)
Condition 1	90.3 (52.1 to 95.4)	90.5 (84.2 to 94.2)	0.6 (−1.5 to 4.3)
Condition 2	89.4 (44.6 to 93.7)	88.2 (83.3 to 90.6)	−1.8 (−4.2 to 2.0)
Condition 3	89.7 (54.4 to 94.9)	88.8 (85.5 to 91.8)	−1.6 (−3.2 to 2.6)
Condition 4	67.7 (39.2 to (94.6)	81.5 (69.7 to 85.1)	13.9 (3.0 to 27.8)
Condition 5	59.4 (29.3 to 82.7)	70.0 (52.7 to 83.2)	11.1 (1.6 to 23.4)
Condition 6	55.6 (13.9 to 83.8)	70.8 (38.5 to 82.9)	13.1 (2.9 to 34.4)

Note: Absolute score values given as median (range) and change in scores given as median change (95% confidence interval).

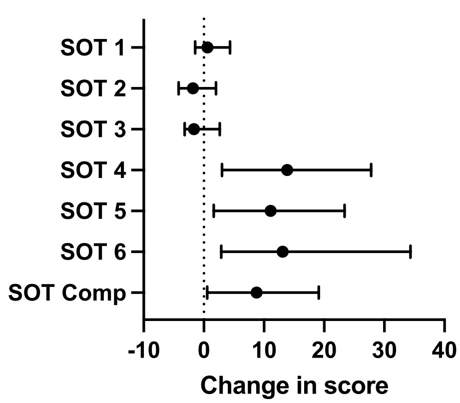

Figure 1. Change in score for SOT conditions 1 to 6 and composite score (SOT Comp). Points indicate the median change and bars indicate 95% confidence interval.

weight along the lateral and antero-posterior axes such that a cursor representing their center of pressure translated to targets projected on the interactive display (Supplementary Figure S1). The exercise programs were pre-determined and each participant received the same protocol, except to account for the laterality of their deficit.

Analysis

Data analysis took place between 7 July 2021 and 4 April 2022. Scores are reported as median (range) and change in scores are reported as the median change and 95% confidence interval (95% CI). Changes in score after treatment were analyzed by Wilcoxon matched-pairs rank test. Participants were stratified according to initial DHI to those with moderate-to-severe disability, (scores > 30) and those with mild disability (DHI ≤ 30). The correlation between changes in SOT composite scores and participant-reported measures was assessed by Spearman correlation. This study followed the STROBE guidelines for reporting cohort studies. Analysis was performed using Prism 9 version 9.3.1 (GraphPad Software, San Diego, CA).

Results

We enrolled 13 participants (8 men [62%]; median age 51 years [range 18 to 67 years]) with stable unilateral vestibular deficits. Five participants had a deficit on the left side and 9 on the right (one had an abnormal ocular VEMP on one side and an abnormal videonystagmogram on the other). Seven showed a vestibular deficit by bithermal caloric testing with normal VEMPs, 1 had abnormal cervical VEMP and ocular VEMP and normal videonystagmogram, and 5 had abnormal VEMP and videonystagmogram results. Nine of 13 had previously received vestibular physiotherapy (Table 1). All 13 completed the full course of retraining sessions and all follow up.

Before re-training, the median SOT composite score was 68.4 (range 40.1 to 89.1) (Table 3). After twelve sessions of CVRT, the median SOT composite score improved by 8.8 points (95% CI 0.6 to 19.1; $p = .0134$). No participants demonstrated significant worsening of their SOT scores. SOT conditions 1 to 3 did not improve with CVRT; however, conditions 4 to 6, which each require overcoming unreliable somatosensory information due to the sway-referenced platform, improved significantly (Figure 1).

There were six participants (three men) with initial DHI ≤ 30 (median age 60 years [range 22 to 67]) and seven participants (five men) with DHI > 30 (median age 41 years [range 18 to 65]). There was no change in scores for SOT conditions 1, 2, and 3 for either group (Figure 2). For SOT conditions 4, 5, and 6, and the SOT composite score, those with mild disability at baseline had modest, if any, improvement. However, among participants with initial DHI > 30, SOT composite score increased by 14.6 points (7.0 to 36.9)

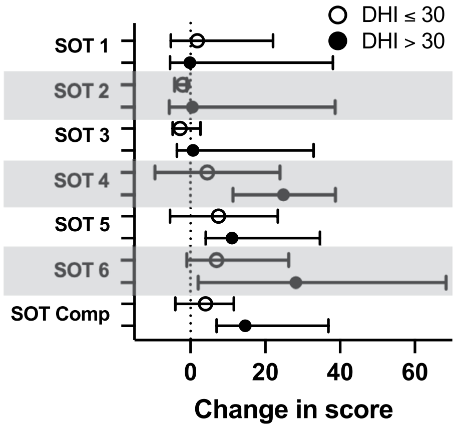

Figure 2. Change in score for SOT conditions 1 to 6 and composite score (SOT Comp) for participants with mild disability (DHI ≤ 30; *n* = 6) compared to moderate-to-severe disability (DHI > 30; *n* = 7). Points indicate the median change and bars indicate 95% confidence interval.

and scores for conditions 4, 5, and 6, all increased significantly (Figure 2).

Prior to CVRT, between 31–62% of participants scored greater than one standard deviation below normative values [7] (hereafter referred to as normal range) for each of the SOT conditions and the composite score. After CVRT, the fraction scoring with the normal range did not increase for conditions 1–3. For condition 4, however, all participants scored within the normal range and for conditions 5 and 6, and the composite score, 92% were within normal range (Figure 3).

Changes in SOT after CVRT correlated well with changes in FES-I (r_s −0.6472 [95% CI −0.8872 to − 0.1316]). The correlation with change in the ABC score was less robust (r_s 0.5585 [−0.0075 to 0.8534]) and there was poor correlation with change in DHI (r_s −0.2545 [−0.7155 to 0.3609]).

Discussion

We found CVRT for individuals with stable unilateral vestibular deficits was associated with improved SOT composite scores and that the degree of improvement was greater for those with more severe disability at baseline.

Following vestibular loss, most patients experience spontaneous compensation in the weeks and up to three months after the onset of the deficit [14]; however, even with treatment, many patients still experience persistent symptoms of imbalance, adopt self-imposed limits on head movement, and are likely to struggle with difficult or dynamic balance tasks.

There is strong evidence that some form of vestibular rehabilitation, commonly consisting of head shaking and nodding exercises, is better than none [4]. These types of exercises seek to promote visual stabilization to correct for impaired vestibular ocular reflex (VOR) and are effective for decreasing retinal image slip and ameliorating blurred vision [15]; however, such exercises are limited in their ability to facilitate improvement in dynamic balance [16] and many patients do not achieve satisfactory outcomes from home-based or supervised exercises [4]. Indeed, the majority of the participants in this study (9 of 13) had received previous vestibular physiotherapy without satisfactory resolution of their symptoms.

CDP may be used as a technological adjunct for promoting vestibular compensation. When used as an intervention, the CDP instrument can offer real-time visual feedback and exercises can be programmed to encourage the subject to lean to greater angles and with increased velocity, as their training progresses. Importantly, the CDP instrument is able to systematically challenge the subject to maintain their equilibrium in scenarios where visual and somatosensory information is concordant with vestibular input, or in scenarios when those inputs are in conflict.

The ability to maintain equilibrium when provided with conflicting sensory cues, such as when standing on the deck of a boat, requires weighting of reliable cues over unreliable ones. Loss or disruption of one or more sources of sensory information can cause dizziness or unsteadiness if the brain is not able to weight reliable inputs over those that are absent or corrupted. Among individuals with a vestibular deficit, some individuals rely more heavily on vision and others on somatosensory inputs [14]. The controlled environment allows for repetition, progression, and consolidation of new reweighting strategies in a manner that is difficult to replicate with standard vestibular physiotherapy. In this way, CVRT seeks to retrain how the brain integrates visual, somatosensory, and vestibular information to help estimate the position and acceleration of the body in space, taking advantage of the natural capacity for neuroplasticity [17].

To date, there has been limited study of CDP-based interventions [4]. One previous study compared a CDP exercise protocol with optokinetic stimulation [9]. Like standard vestibular physiotherapy exercises, optokinetic stimulation seeks to ameliorate impairments associated with a defective VOR. Both the CDP and optokinetic groups demonstrated improvement in the SOT composite score. In this study, the CDP protocol called for daily treatment for five consecutive days. The schedule employed in our study, which calls for twelve sessions, twice per week, for six weeks, more closely follows the treatment and follow up schedules recommended by the Academy of Neurologic Physical Therapy [18].

Published normative SOT data for healthy individuals allows for comparison of the participants in the current study to a normative range, given as a mean ± standard deviation [7]. Prior to retraining, participants scored consistently near normal range for conditions 1–3 of the SOT test, in which the platform is fixed. Retraining did not lead to improvement for conditions 1–3.

Activation of the sway-referenced platform led to lower equilibrium scores and greater variability for the experimental cohort and in published values for healthy participants [7]. In contrast to what was observed for conditions 1–3, the median scores in the experimental cohort for conditions 4–6 and the composite score were below those reported for healthy individuals. These improved after retraining, such that for conditions 5 and 6, only one of 13 was below the normative range and all 13 subjects scored within the normative range for condition 4. The median

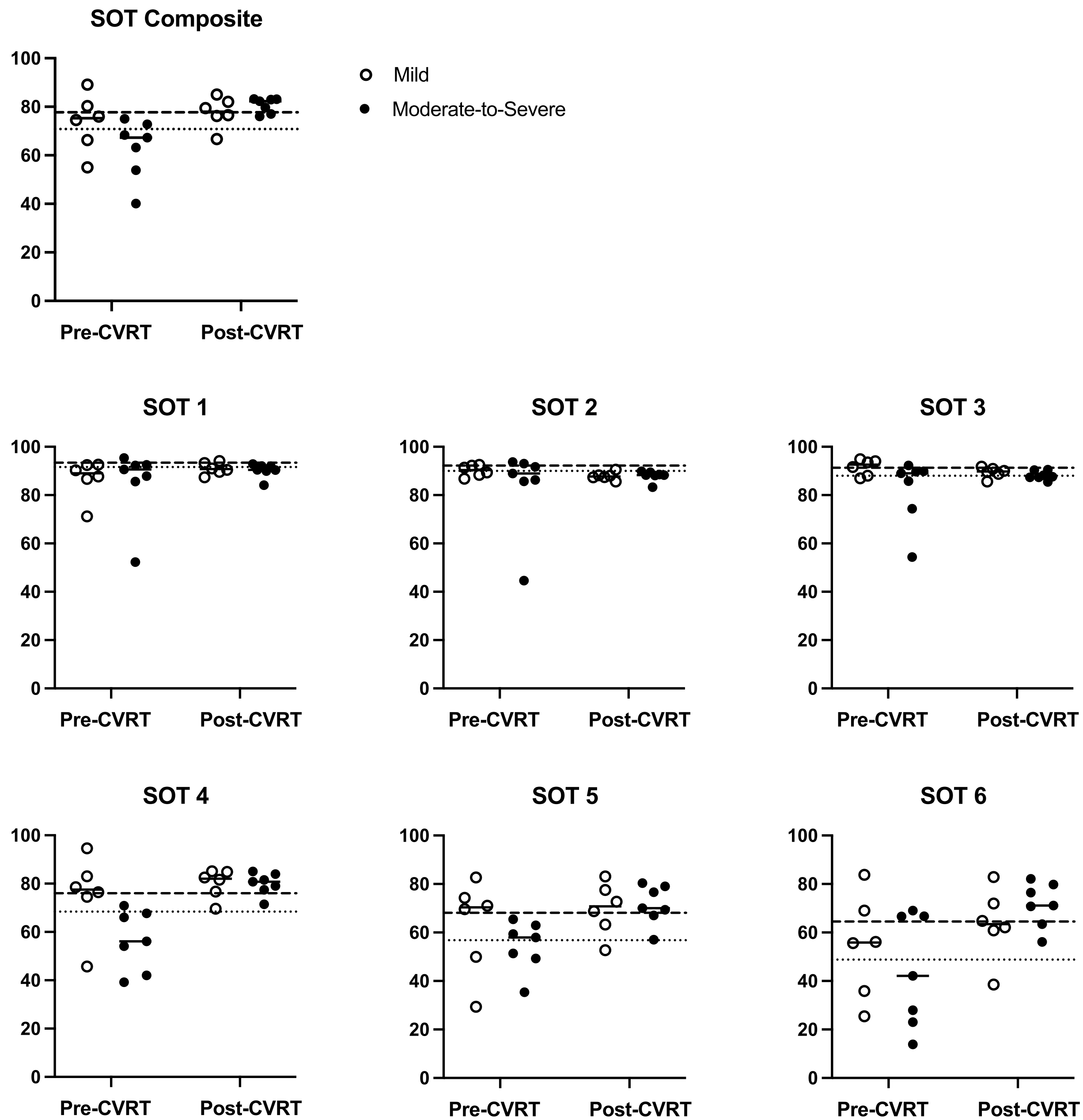

Figure 3. Scores for SOT conditions 1 to 6 and composite score for participants with mild disability (DHI ≤ 30; $n = 6$; open circles) compared to moderate-to-severe disability (DHI > 30; $n = 7$; closed circles). Normative mean (heavy dashed line) and 1 standard deviation below the mean (light dashed line) are indicated for each condition and the composite score [7].

improvement for the composite score was greater than the minimum clinically important difference, as derived by Wrisley et al. [13].

We have previously published participant-reported outcomes for this cohort of participants and found that those with mild cases, as determined by a pre-treatment dizziness handicap inventory (DHI) score ≤ 30, experienced no measurable benefit from CVRT [10]. In the current report, participants with DHI scores ≤ 30, likewise, demonstrated only modest changes in objective posturography performance, whereas patients with pre-treatment DHI > 30 demonstrated significant improvements in the SOT composite score (Figure 2).

We found that prior to retraining, SOT composite scores correlated well with all three participant-reported measures, the DHI, the ABC scale, and the FES-I. Changes in the SOT composite scores after CVRT correlated well with changes in FES-I and less closely with the ABC scale. SOT scores did not correlate significantly with the DHI. Improvement in subjective and objective measures after vestibular therapy without correlation of the two measures is a frequent observation in the literature [19]. Factors such as age, demands of daily activities, and degree of help received from friends, family, and caregivers, may explain the decoupling of objective measures and subjective perception of disability.

Participants in this study demonstrated improved postural stability in a dynamic test with conflicting visual and somatosensory cues and this improvement correlated with reduced perceived fall risk, as measured by the correlation with FES-I scores. We have also reported that CVRT is associated with a larger functional stability region – the area over which the center of mass can be displaced by leaning without causing loss of balance [20]. These findings are all consistent with improved postural control and reduced risk of falls after CVRT for patients with unilateral vestibular deficits.

Conclusions

Participants showed good adherence to CVRT and we observed that CVRT for individuals with moderate-to-severe self-reported disability due to stable unilateral vestibular deficits was associated with improvements in dynamic balance performance. Posturography improvements correlated with decreased subjective assessments of fall risk.

Methodological considerations/limitations

This single-group study did not include a no treatment or alternative treatment control and enrolled a small sample size of 13 participants. No sample size calculation was performed *a priori.* We enrolled participants with persistent, stable symptoms in an effort to minimize variability; however, we cannot rule out symptom variability unrelated to treatment. Individuals with mild impairment showed no benefit but we cannot determine whether this was because of a ceiling effect of the SOT or whether those with mild impairment do not respond to treatment. Improvement in SOT scores due to learned familiarity with the test [13] is a potential source of bias.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

De-identified data on vestibular diagnosis and sensory organization test scores are available from the corresponding author on reasonable request, for a period of five years after publication. In order to protect the privacy of participants, data on age and sex will not be shared.

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