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Vestibular Rehabilitation Using Dynamic Posturography: Objective and Patient-Reported Outcomes from a Randomized Trial

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Abstract

Objective. Balance deficits are common and debilitating. Standard treatments have limitations in addressing symptoms and restoring dynamic balance function. This study compares a rehabilitative computerized dynamic posturography (CDP) protocol, computerized vestibular retraining therapy (CVRT), with a home exercise program (HEP) for patients with objectively confirmed unilateral vestibular deficits (UVDs).

Study Design. Single-center, randomized, interventional trial, with 1-sided crossover.

Setting. A tertiary neurotology clinic.

Methods. Patients with UVDs and Dizziness Handicap Inventory (DHI) score >30 were randomized to receive either CVRT or HEP. After completion of treatment, the HEP group was crossed over to CVRT. Outcome measures were the sensory organization test (SOT) and 3 participants reported dizziness disability measures: the DHI, Activity-Specific Balance Confidence Scale (ABC) scale, and Falls Efficacy Score—International (FES-I).

Results. We enrolled 37 patients: 18 participants completed CVRT and 12 completed HEP, 11 of whom completed the crossover. Seven participants withdrew. The CVRT group demonstrated a greater improvement in SOT composite score than the HEP group ($P = .04$). Both groups demonstrated improvement in participant-reported measures but there were no differences between groups (DHI: $P = .2604$; ABC: $P = .3627$; FES-I: $P = .96$). Following crossover to CVRT after HEP, SOT composite ($P = .002$), DHI ($P = .03$), and ABC ($P = .006$) improved compared to HEP alone.

Conclusion. CVRT and HEP were both associated with improved participant-reported disability outcomes. CVRT was associated with greater improvement in objective balance than HEP. Adding CVRT after HEP was superior to HEP alone. Multimodal CDP-based interventions, such as CVRT, should be considered as an adjunct to vestibular physiotherapy for patients with UVD.

Keywords

dizziness, postural balance, rehabilitation, vestibular system

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It is estimated that 36.8 million American adults (15.5%) experience dizziness or balance issues and this number increased between 2008 and 2016.[1] Emerging evidence has identified associations between symptomatic dizziness and cognitive decline,[2] increased risk for dementia,[3] and all-cause mortality.[4] Vestibular dysfunction is the most common cause for dizziness-related visits to the emergency department[5] and patients may experience imbalance, blurred vision, and vertigo. Adverse effects on quality of life include an increased risk of falling, reduced independence, inability to work, anxiety, and social isolation.[6,7] Thus, identifying patients with vestibular deficits and offering effective treatment has the potential to make meaningful improvements in quality of life, and reduce morbidity and mortality.

Vestibular rehabilitation is recommended to reduce symptoms, reduce disability,[8,9] and reduce the risk of falling.[6] Vestibular rehabilitation protocols vary between practitioners; however, it's not clear that customized protocols are superior to standard approaches.[10] Furthermore, 27% to 43% report no improvement or worsened symptoms after treatment.[2,11-14]

Computerized dynamic posturography (CDP)-based rehabilitation has been the subject of limited recent research.[9] Legacy CDP technology has limited use for the diagnosis of vestibular disorders[15]; however, current generation CDP systems offer more capability and are better suited to treatment applications. We have developed a vestibular training protocol, which we refer to as computerized vestibular retraining therapy (CVRT), that uses advanced CDP systems to guide patients through

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exercises that are standardized, progressive in difficulty over the treatment course, and that provide visual feedback on technique and performance as the patient completes the exercises.

We previously assessed CVRT in a single-group pilot study of patients with unilateral vestibular deficits (UVDs) and found that CVRT was associated with significant and durable improvements in postural stability and participant-reported measures of disability.[16-19]

The objective of the current randomized controlled trial is to compare CVRT to a home exercise program (HEP) previously shown to improve disability, dizziness, depression/anxiety, and postural stability.[11,20] We included a 1-sided crossover design in which participants randomized to the HEP group would receive CVRT after completing the HEP protocol. We measured both objective posturographic outcomes and participant-reported measures in individuals with stable, persistent UVD.

Methods

This interventional randomized controlled trial was approved by the Clinical Research Ethics Board at the University of British Columbia (study # H21-03343) and all experiments were performed in accordance with the Declaration of Helsinki. All participants provided written informed consent. Clinicaltrials.gov registration NCT05115032; October 29, 2021.

Eligible patients were aged between 18 and 80, reported symptomatic dizziness and imbalance for more than 6 months, and had symptoms that negatively affected their day-to-day activities. Inclusion required clinical confirmation that symptoms were caused by a stable vestibular deficit rather than an active or irritative vestibulopathy, based on the consensus criteria.[21] 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 1 ear with intact responses in the other ear.[22] Participants were excluded if they scored ≤30 on the Dizziness Handicap Inventory (DHI); exhibited fluctuating symptoms of an active vestibulopathic cause within the last 6 months, such as active Meniere's disease[23]; had a concurrent diagnosis of benign benign paroxysmal positional vertigo (BPPV); had clinical and audiometric evidence of a perilymphatic fistula, or otosyphilis; had a deficit that precluded providing informed consent or completing the rehabilitation exercises, such as orthopedic, or neurological deficits.

Randomization and Masking

Participants were randomized to receive either CVRT or HEP by a computer-generated 1:1 blocked randomization sequence with randomly selected block sizes (either 2, 4, or 6 per block). Allocation concealment was achieved through sequentially numbered, sealed, opaque envelopes, which were assigned to a participant in advance of opening. The study member that generated the allocation sequence and prepared the envelopes did not enroll or assign participants.

Interventions and Assessments

Consenting participants were invited to the clinic for their baseline assessment. The participants completed the sensory organization test (SOT),[24] the DHI,[25] the Activity-Specific Balance Confidence Scale (ABC scale),[26] and the Falls Efficacy Score—International (FES-I).[27] SOT scores were calculated by the instrument software. We calculated an average score for conditions 1-3 (which each are performed on a fixed platform) and defined this as the "Static Equilibrium Score," and the average for conditions 4 to 6 (performed on a moving, sway-referenced platform), defined as the "Dynamic Equilibrium Score." During the posturography tests and all retraining exercises, the participants were supported by a harness as a precaution against falls.

Participants in the CVRT group completed 12 twice-weekly sessions of CVRT in the clinic. The CVRT training was performed on a Bertec Balance Advantage computerized dynamic posturography system (Bertec).[28] The system is equipped with a library of preprogrammed exercises. The principal investigator (E.A.D.) assembled a sequence of exercises (approximately 8 exercises per session for about 20 to 30 minutes total session time). During these exercises, participants were challenged to volitionally shift their weight along the lateral and anteroposterior axes as directed by an interactive display or to maintain their balance, while the visual display and support surface either gave congruent sensory feedback, or incongruent feedback (ie, created the illusion of rotation). The exercises grew progressively more difficult over the course of the treatment protocol by changing several parameters: (1) the gain between the measurement of the center of pressure by the platform and the movement of the cursor on the display, (2) the degree to which the platform tilts forward and backward, (3) the time allowed for participants to complete an exercise or the speed at which they had to respond to visual stimuli, and (4) the complexity of the visual environment (Supplemental Table S1, available online). The protocol included repetition in order to consolidate learning. The exercise programs were predetermined and each participant received the same protocol, except to account for the laterality of their deficit.

Participants in the HEP group were given a validated exercise booklet.[29] The principal investigator reviewed the booklet with the participants and demonstrated the exercises. Participants were asked to perform the exercises twice daily for the intervention period of 6 weeks. The exercises involved nodding and shaking of the head with eyes open looking ahead, or fixed on a point in front of them, or with eyes closed. The HEP also suggested adding

activities such as walking, catching a ball, or standing on 1 foot, according to the capability of the participant. The starting difficulty for the exercises was determined using the timed exercise scoring test, which is detailed in the booklet. Participants were instructed to perform this test weekly to gauge when to progress to a more difficult variation of the exercise. A study member contacted participants by phone every 2 weeks to check in, answer any questions, and help determine the appropriate exercise difficulty.

After completion of either CVRT or HEP, participants returned to the clinic to repeat the assessments. Immediately upon completion of assessments, participants assigned to the HEP group were invited to crossover to CVRT. Upon completion of the 12 sessions of the CVRT protocol, these participants repeated the assessments once again.

Analysis

Demographic variables are reported as a percentage of the total or as median and range. Questionnaires were scored according to instructions. Changes in scores are reported as mean change and 95% confidence interval (95% CI). Within-group comparisons were analyzed by Wilcoxon matched-pairs rank test and between-group comparisons of the changes were analyzed by 2-tailed Mann-Whitney test. The crossover data was analyzed by mixed-effects model with Bonferroni correction for multiple comparisons. For comparison of baseline status between groups, *P* values were calculated by the Student's *t* test for continuous variables and Fisher's exact test for dichotomous variables. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting cohort studies. Analysis was performed using Prism 9 version 10.2.3 (GraphPad Software).

Results

This study enrolled 37 participants and randomized them to either the CVRT group (n = 20), or the HEP group (n = 17). Two withdrew from the CVRT group before completing the intervention and 5 withdrew from the HEP group (**Figure 1**). There were no adverse events for either treatment. Prior to treatment, the 2 groups were similar with respect to age, DHI, ABC, FES-I, and SOT composite score (**Table 1**). All participants had undergone previous physiotherapy for their balance disorder.

Treatment Associated Changes in Objective Posturography

After treatment, the SOT composite score improved by 14.3 (95% CI: 8.9-19.8) in the CVRT group while there was no significant change in the HEP group (mean 5.8, 95% CI: −0.9 to 12.4) and there was a between-group difference in favor of CVRT ($P = .04$). The Static Equilibrium Score did not change after treatment in either group and there was no difference between groups ($P = .84$). The dynamic equilibrium score improved by 20.0 (95% CI: 12.4-27.5) after CVRT while there was no significant change after HEP (6.9, 95% CI −2.5 to 16.4) and this represented a significant between-group difference in favor of CVRT ($P = .04$) (**Figure 2A**).

After CVRT, the majority of participants had SOT scores within the normative range for healthy individuals.[30] In contrast, following HEP, fewer than half of the participants had scores within 1 SD of the normative mean for conditions 3 to 5, and the composite score (**Figure 3**).

Participant-Reported Outcome Measures

Both CVRT and HEP groups demonstrated improvement in all 3 participant-reported measures (**Figure 2B**). DHI improved by a mean of 11.8 points (95% CI: 2.4-21.3) in the HEP group and 18.2 points (95% CI: 10.5-25.9) in the CVRT group. ABC scale scores improved by a mean of 8.2 points (95% CI: 0.6-15.9) in the HEP group and 15.1 points (95% CI: 8.8-21.6) in the CVRT group. FES-I scores improved by a mean of 6.3 points (95% CI: 1.3-11.3) in the HEP group and 6.6 (95% CI: 2.5-10.7) in the CVRT group. These changes were not different between treatment groups (DHI: $P = .26$; ABC: $P = .36$; FES-I: $P = .96$).

Crossover to CVRT

After completion of the HEP intervention and assessment, 11 of 12 participants completed the CVRT protocol. There was no change in the SOT composite score after HEP alone. Adding CVRT after HEP was associated with improvement in the SOT composite score compared to baseline and to the post-HEP scores (**Figure 4A** and Supplemental Table S2, available online). Completion of HEP alone was associated with improvement of DHI and FES-I. Adding CVRT after HEP was associated with significant improvement in DHI and ABC compared to HEP alone, while there was no significant additive benefit of CVRT after HEP for FES-I (**Figure 4B** and Supplemental Table S2, available online).

Discussion

A 2022 Clinical Practice Guideline (CPG) developed by the Academy of Neurologic Physical Therapy of the American Physical Therapy Association (APTA) evaluated current evidence and made recommendations for rehabilitation interventions for patients with peripheral vestibular hypofunction.[8] The CPG strongly recommended vestibular physiotherapy for individuals with chronic unilateral vestibular hypofunction. A 2015 Cochrane systematic review came to a similar conclusion.[9] One limitation of the CPG and Cochrane review is that the majority of the studies they cite are no-treatment or sham treatment-controlled studies. The authors of the CPG recommended that future research should be

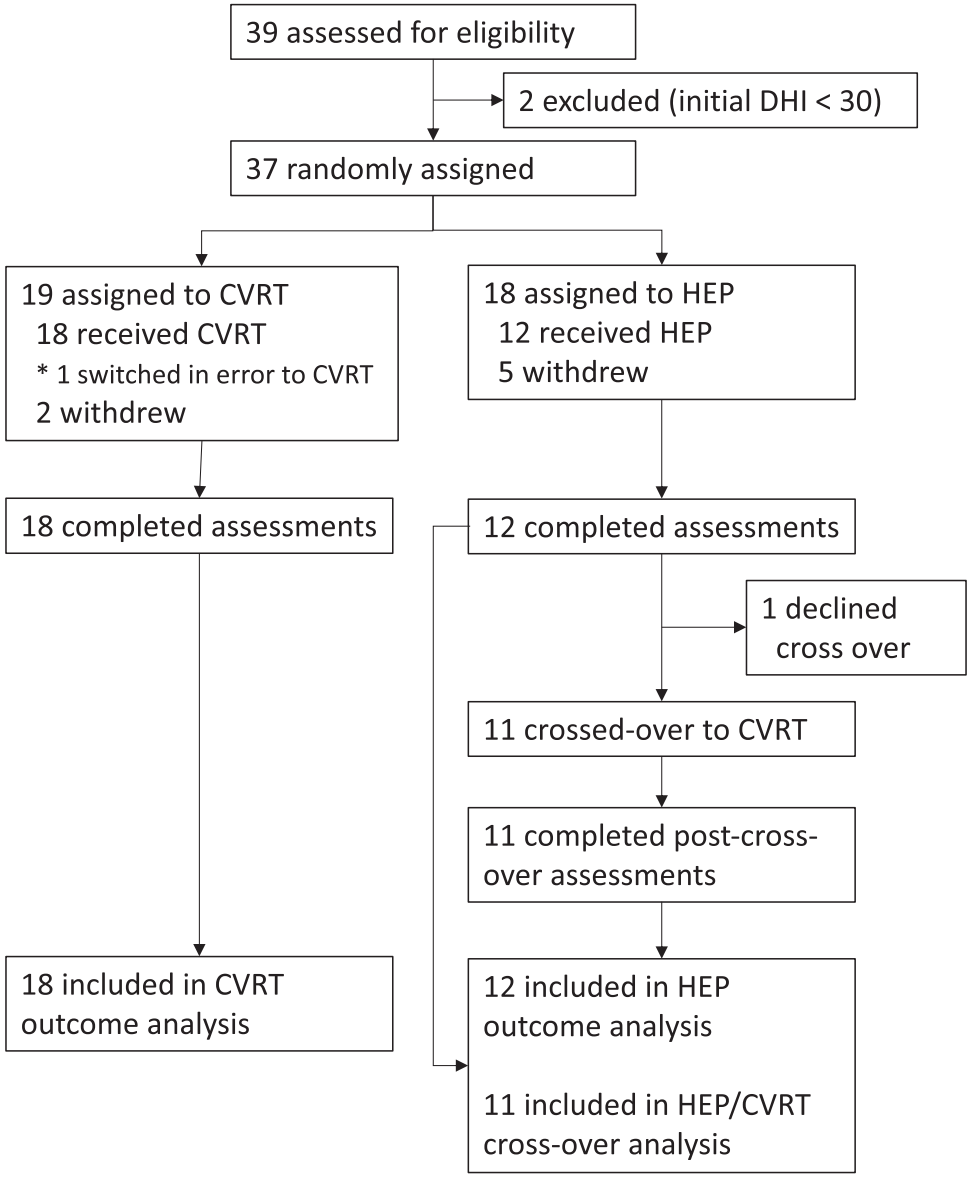

Figure 1. Trial profile. *One subject randomly assigned to HEP was placed into the CVRT group due to human error and is discussed in Limitations. CVRT, computerized vestibular retraining therapy; DHI, Dizziness Handicap Inventory; HEP, home exercise program.

directed at comparative studies to help inform treatment decisions. A systematic review of treatment modes and dose is currently underway.[31]

There have been few comparative studies to date and the majority of these found that different treatments were similarly effective.[8,9] When differences have been reported, results suggest a complimentary effect of different treatment modes. For instance, a study comparing optokinetic exercises with CDP-assisted exercises found that the former improved visual preference in the SOT, while the latter improved visual and vestibular performance.[32] Another study found that home exercises alone improved participant-reported measures but that adding exercises on a tilting platform improved the dynamic gait index.[33] Several studies have found that adding virtual reality training to a physiotherapy program led to superior outcomes to physiotherapy alone.[34-36] One commonality among these studies is that they each observed that adding a dynamic sensory element through the use of a technological adjunct, improved response. CVRT and HEP are expected to evoke different compensation mechanisms, so adding CVRT to a multidomain suite of interventions may confer complimentary or synergistic effects.

All of our participants had previously received supervised vestibular physiotherapy, reflecting the current standard of care in the community. This may have contributed to the greater rate of withdrawal in the HEP group than in the CVRT group; specifically, participants assigned to HEP may have been frustrated to be assigned exercises that they had tried previously without satisfactory resolution of their symptoms. Furthermore, the HEP exercises, if performed correctly, induce uncomfortable symptoms of dizziness,

Table 1. Participant Demographics, Vestibular Test Results, and Assessment Measures Prior to Treatment

	Home exercise program (n = 12)	Computerized vestibular retraining therapy (n = 18)	*P* value
Median age (range)	61.5 (27-76)	56 (25-72)	.13
Sex	9 female/3 male	9 female/9 male	.26
Abnormal vestibular test			
VNG	6 (50%)	11 (61%)	.71
oVEMP	9 (75%)	10 (56%)	.44
cVEMP	9 (75%)	10 (56%)	.44
Pretreatment assessment			
DHI	53 (32-88)	51 (30-82)	.56
ABC	55.6 (21.9-88.8)	60.9 (21.9-91.9)	.57
FES-I	34 (17-57)	32 (19-48)	.57
SOT composite	61.5 (35-74)	64.5 (36-81)	.81

Assessment scores are reported as medians and range.
Abbreviations: ABC, Activities-Specific Balance Confidence Scale; cVEMP, cervical vestibular evoked myogenic potential; DHI, Dizziness Handicap Inventory; FES-I, Falls Efficacy Scale—International; oVEMP, ocular vestibular evoked myogenic potential; SOT composite, sensory organization test composite score of conditions 1 to 6; VNG, videonystagmography;

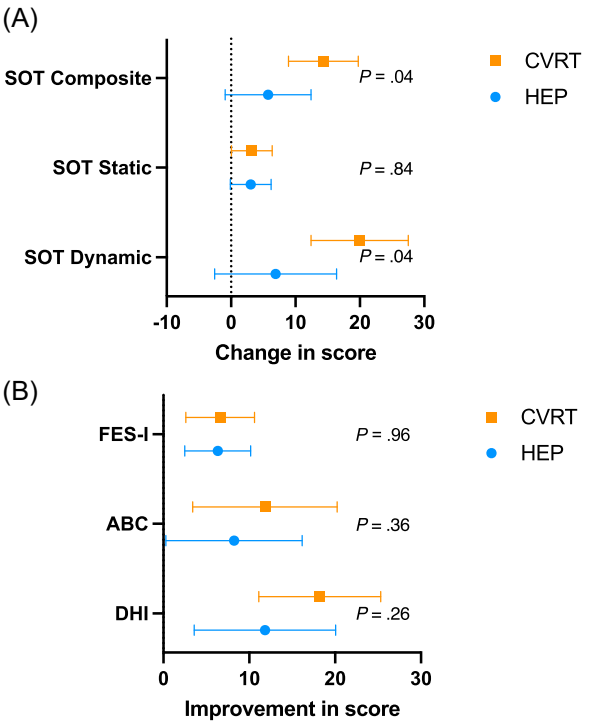

Figure 2. Mean changes in scores for (A) the SOT composite, SOT static, and SOT dynamic and (B) the FES-I, ABC scale, and DHI after CVRT or HEP. Error bars indicate 95% confidence interval. ABC, Activity-Specific Balance Confidence Scale; CVRT, computerized vestibular retraining therapy; DHI, Dizziness Handicap Inventory; FES-I, Falls Efficacy Score—International; HEP, home exercise program; SOT, sensory organization test.

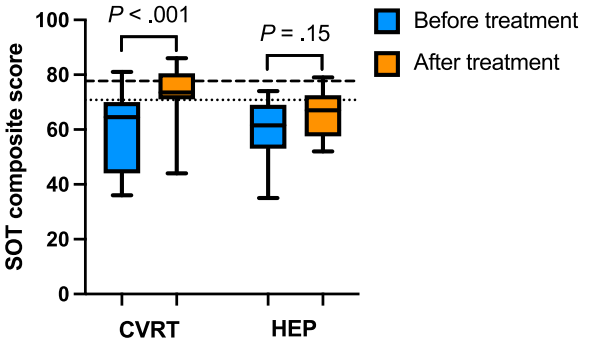

Figure 3. SOT scores before and after either CVRT or HEP. The normative mean (heavy dashed line) and 1 standard deviation below the mean (light dashed line) are indicated.[30] CVRT, computerized vestibular retraining therapy; HEP, home exercise program; SOT, sensory organization test.

which may have led to higher withdrawals in this group. Indeed, a previous study employing a similar intervention to HEP had fewer participants complete the treatment arm than the no-treatment control arm.[14]

We included both objective posturographic outcomes as well as participant-reported outcomes, chosen to be consistent with the International Classification of Functioning, Disability, and Health measures.[37] The 1-sided crossover design, whereby participants assigned to the HEP group were offered CVRT immediately following completion of the HEP protocol, was included because many patients with persistent symptoms of UVD have received previous treatment—often vestibular physiotherapy—and it was important to determine whether CVRT conferred an additional benefit.

In all 3 participant-reported measures and in the SOT composite score, the combination of HEP followed by CVRT resulted in a significant improvement over baseline. Importantly, there was an additional improvement in posturography outcomes, the DHI, and the ABC scale following HEP and CVRT compared to HEP alone. While our design included only a crossover from HEP to CVRT, not the reciprocal, the improvement in the CVRT group after 6 weeks of CVRT alone was nearly equal to the improvement in the HEP/crossover group following 6 weeks of HEP and 6 weeks of CVRT. This suggests that patients would benefit from CVRT, whether or not they have had previous treatment. Unfortunately, this study cannot make any predictions about whether home exercises following a course of CVRT may confer additional benefits.

As part of an exploratory analysis, we defined 2 new composite scores for the SOT. The Static Equilibrium Score is calculated from conditions in which the platform upon which the participant stands is immobile, providing a reliable somatosensory reference. The Dynamic Equilibrium Score is calculated from conditions in which the support surface is sway-referenced to directly follow anterior-posterior body sway, making somatosensory cues through the feet and ankles unreliable. The rapid movements of the platform in response to participant sway also tend to perturb postural stability and,

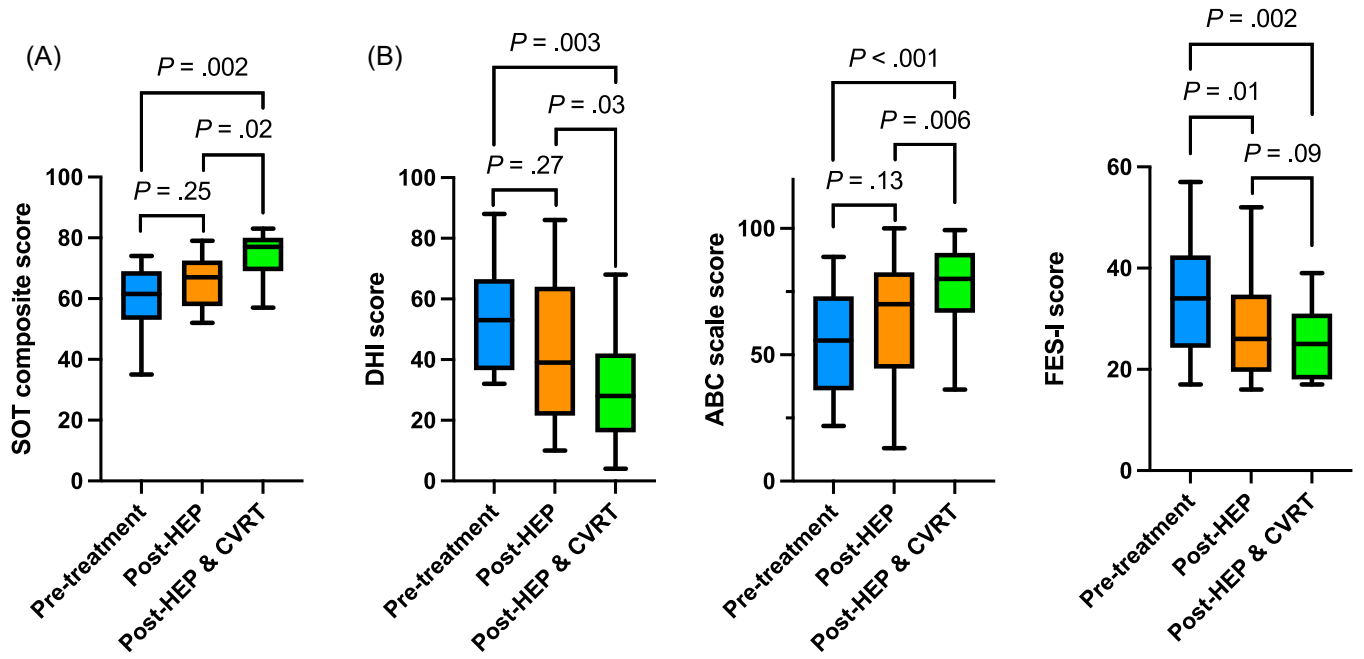

Figure 4. (A) SOT and (B) participant-reported outcome scores before treatment, after HEP, and after sequential HEP and CVRT interventions. ABC, Activity-Specific Balance Confidence Scale; CVRT, computerized vestibular retraining therapy; DHI, Dizziness Handicap Inventory; FES-I, Falls Efficacy Score—International; HEP, home exercise program; SOT, sensory organization test.

accordingly, scores for conditions 4–6 are much lower than for conditions 1–3. The dynamic equilibrium score, thus, measures the participant's ability to accommodate conflicting somatosensory (via the sway-referenced platform) or visual (via sway-referenced visuals) information, or both. In these conditions, vestibular information, from the contralateral side and/or from unaffected organs on the ipsilateral side, may be the only sense that is providing veridical information.

Baseline static equilibrium scores were high in both groups and did not improve with treatment. The dynamic equilibrium scores, however, improved in the CVRT group, while there was no improvement in the HEP group, suggesting an improvement with training for the use of vestibular cues in the CVRT group only. Interestingly, another study that investigated a CDP-based intervention found greater improvements in the visual and vestibular sensory ratios of the SOT, which align with the dynamic equilibrium score, than an optokinetic treatment that served as the comparator.[32] Those latter results corroborate our findings that using CDP as a treatment modality for UVD is superior to alternative treatments with respect to use of vestibular information over visual and somatosensory cues.

The current study compared CVRT against HEP, in accordance with the research recommendation in the APTA CPG to study comparative effectiveness as sufficient evidence exists that vestibular exercises are superior to no treatment or placebo.[8] Thus, we chose as a comparator, an active control that has been found to be effective in multiple previous studies.[11,20,38] This study design, however, did not allow for comparison against spontaneous changes in severity over time in the absence of any intervention. We can make some inferences though. First, our we recruited participants whose symptoms had been stable for at least 6 months and, thus, had already progressed through the period of acute habituation and adaptation that leads to rapid amelioration of symptoms and reduction of disability. Second, we excluded patients with no objective evidence of a UVD, patients with benign self-limiting conditions such as BPPV, or with conditions known to fluctuate, such as Meniere's disease. Third, we know from the APTA CPG and a Cochrane systematic review, that there is robust evidence that many treatments, including those which our HEP group received, are superior to no treatment.[8,9] Therefore, according to the literature, changes seen in either group in this study would be expected to be greater than any natural variability or spontaneous improvement. Fourth, our single-group pilot study of CVRT found that, in patients with moderate or severe symptoms, improvements observed after CVRT were stable at 4-to-6 and 10-to-12-month time points.[16] We observed no evidence of spontaneous improvement in this group outside of the treatment period.

One challenge in interpreting the current literature is the inclusion in many studies of patients with no objective evidence of a UVD, with benign self-limiting conditions such as BPPV or fluctuating symptoms, such as in Meniere's disease. Treatment recommendations differ between diagnosis,[8,39,40] so studies that include mixed populations or that don't report objective diagnoses are difficult to apply to real-world patient populations. Inclusion of patients with conditions that are subject to natural symptom variation confounds the attribution of

changes associated with treatment from natural symptom variability. Furthermore, it is likely that conditions that are associated with variable vestibular symptoms may respond differently to treatment. The retraining that CVRT seeks to evoke relies upon learned use of remaining vestibular senses, partial or defective though they may be, to orient and maintain equilibrium. High variability in vestibular function over time would be an impediment to this type of retraining and, likely, to other treatments as well. For these reasons, all participants in this study had unambiguous evidence of UVD confirmed by VNG,[41] or by VEMP testing according to our published protocol.[22]

Much of the literature to date has used vestibulo-ocular reflex (VOR) measurement criteria that are not consistent with the recent consensus statement for video head impulse test (vHIT) diagnosis of UVD.[41] Prior to this publication, there was a lack of consensus for gain and refixation saccade (RS) criteria in vHIT protocols, high prevalence of artifacts,[42] and the overall low sensitivity for vHIT to detect UVD independent of RS amplitude and frequency.[43] These were important factors in our decision not to include VOR measurement in the current study.

Conclusion

We found that CVRT was associated with improved postural stability by objective posturography, where no improvement was observed with HEP in patients with UVD who had received prior vestibular physiotherapy. Furthermore, CVRT and HEP were both associated with improvement in participant-reported measures, indicating reduced fear of falling, greater confidence in participating in activities of daily living, and reduced perceived disability. CVRT is one of a small number of interventions that have been found to be superior to an alternative therapy for the treatment of UVD and, further, the crossover design of this study demonstrated an additive effect to HEP alone in both participant-reported disability measures and objective postural stability. CVRT represents a treatment modality that is likely to represent a valuable adjunct therapy to the current CPG-recommended treatments for patients with UVD.

Incorporation of this type of treatment in a multidomain intervention is consistent with the World Guidelines for Falls Prevention recommendation for multidomain interventions[6] and may help prevent falls and reduce dementia risk and mortality.[3,4]

Limitations

The patients in this study had stable symptoms for at least 6 months prior to the study; however, the possibility of a change in baseline symptoms caused by the natural history of the underlying disease cannot be ruled out. One participant who was allocated to HEP was entered into the CVRT group due to human error and they were included as if they had been allocated to CVRT. The HEP group received an intervention supported by strong evidence; therefore, we cannot assess the relative benefit of CVRT compared with no treatment. The lack of therapist supervision and customization of the control intervention falls short of the strongest CPG recommendation but is similar to the level of care offered to many UVD patients worldwide. The HEP and CVRT groups had similar results in baseline assessments prior to treatment and were similar in their distribution of ages; however, the fraction of female participants was higher in the HEP group. There was a higher withdrawal rate in the HEP group, which is a potential source of bias and resulted in fewer than expected participants in this group (n = 12). Fewer still (n = 11) completed the crossover to CVRT. The 1-side crossover design did not allow for comparison between groups who received an equal treatment dose (ie, on the course each of HEP and CVRT) nor account for a potential effect of treatment order. The researcher who oversaw the treatment and those who performed the analysis were not blinded.

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Author Contributions

Eytan A. David, developed the experimental treatment, designed the study protocol, screened and enrolled participants, administered the treatment, collected data, interpreted the results, and co-wrote the manuscript; **Navid Shahnaz**, contributed to the study design, data analysis, and co-wrote the manuscript.

Disclosures

Competing interests: The authors declare no competing interests.

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Data Availability Statement

Following publication, the data that underlie the results reported in this article are available from the corresponding author to researchers who provide a methodologically sound proposal and sign a data access agreement, the conditions of which must protect participant confidentiality.

Supplemental Material

Additional supporting information is available in the online version of the article.

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