

# A speed-based approach to vestibular rehabilitation for peripheral vestibular hypofunction: A retrospective chart review

Robert Alan Roller<sup>a,\*</sup> and Courtney D. Hall<sup>b,c</sup>

<sup>a</sup>*Center for Orthopedic and Sports Physical Therapy, Tallahassee, FL, USA*

<sup>b</sup>*James H. Quillen VA Medical Center, Mountain Home, TN, USA*

<sup>c</sup>*Department of Physical Therapy, East Tennessee State University, Johnson City, TN, USA*

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## Abstract.

**BACKGROUND:** Current vestibular rehabilitation for peripheral vestibular hypofunction is an exercise-based approach that improves symptoms and function in most, but not all patients, and includes gaze stabilization exercises focused on duration of head movement. One factor that may impact rehabilitation outcomes is the speed of head movement during gaze stability exercises.

**OBJECTIVE:** Examine outcomes of modified VOR X1 exercises that emphasize a speed-based approach for gaze stabilization while omitting substitution and habituation exercises. Balance training focused on postural realignment and hip strategy performance during altered visual and somatosensory inputs.

**METHODS:** A retrospective chart review of 159 patients with vestibular deficits was performed and five outcome measures were analyzed.

**RESULTS:** All outcomes – self-report dizziness and balance function, dynamic gait index, modified clinical test of sensory interaction and balance, and clinical dynamic visual acuity improved significantly and approached or achieved normal scores.

**CONCLUSIONS:** The combination of modified VOR X1 gaze stability exercises, wherein patients achieved high-velocity head movement (240°/s) during short exercise bouts, with “forced use” gait and balance exercises for postural realignment and hip strategy recruitment, achieved 93–99% of normal scores for all five outcomes. These results compare favorably to the outcomes for current VR techniques and warrant further investigation.

Keywords: Vestibular rehabilitation, peripheral vestibular hypofunction, outcomes

## 1. Introduction

Current vestibular rehabilitation (VR) for peripheral vestibular hypofunction is an exercise-based approach that typically includes a combination of four different exercise elements: 1) gaze stabilization exercises; 2) habituation exercises as needed based on symptoms; 3) balance and gait training; and 4)

endurance and strength exercises. Studies suggest that vestibular rehabilitation improves symptoms and function in most but not all patients [4, 6, 8, 17]. As many as 75–88% (depending on the outcome measure) of patients with unilateral vestibular hypofunction experience meaningful improvements following VR [7].

Gaze stability exercises involve head motion while maintaining focus on a target and were developed based on the concepts of vestibulo-ocular reflex (VOR) adaptation and substitution. The VOR has been shown to be modifiable and retinal slip has

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\*Corresponding author: Robert Alan Roller, PT, 2615 Centennial Blvd, Suite 101, Tallahassee, FL 32308, USA. Tel.: +1 850 656 1837; E-mail: robert.roller@IMCPT.com.

been identified as the primary error signal that drives VOR adaptation [15]. Gaze stability exercises based on vestibular adaptation involve head movement while maintaining focus on a target; whereas, gaze stability exercises based on vestibular substitution were developed to promote alternative strategies (e.g., smooth-pursuit eye movements or central pre-programming of eye movements) to substitute for missing vestibular function. Treatment progression for gaze stabilization exercises involves a number of exercise parameters including duration, speed, background distraction, patient position, distance to target, target size and movement, as well as daily frequency of the exercises. Very little research has directly examined the influence of different exercise parameters on rehabilitation outcomes. One study compared speed of head movement (slow head movement at 0.04 Hz versus rapid head movement at 1-2 Hz) while performing gaze stability exercises and found similar reduction of symptom intensity and perceived disability in both groups [3]. Another study found similar rehabilitation outcomes for gaze stability exercises (rapid head movements while focusing on a visual target for 1-2-minute duration) compared to habituation exercises (rapid head movements to provoke symptoms without a target for 3 sets of 5 cycles) [2]. Both studies have limitations (lack of baseline equivalence between groups and small sample size) that preclude determination of an optimal exercise approach.

A primary emphasis for vestibular exercise performance has been on duration with a goal of achieving 120 seconds of duration of continuous head movement [9]. Current clinical practice guidelines suggest that at least 12 minutes/day of gaze stability exercises are needed for rehabilitation of peripheral vestibular hypofunction in the acute/sub-acute stage and 20 minutes/day in the chronic stage [5]. There is no specific guidance for speed of head movement; although, it is considered an important exercise progression for the patient to increase the speed of head movements in order to challenge the central nervous system and improve the effectiveness of the exercise [9]. Unlike duration, the speed performance parameter is not easily measured and instructions are general (“move the head as quickly as possible as long as the target remains in focus”) with no specific speed goal (e.g., 240°/s). Thus, it is not clear that patients actually train at higher velocities, especially velocities that necessitate vestibular input for maintaining gaze stability during daily activities. It may be that the focus on duration versus speed underlies the lack of improvement in some patients and that patients who partially

improve might have even greater improvement, with a speed-based approach. Additionally, the combination of gaze stability exercises with background distraction, different postural challenges (standing or even walking) and target movements (often referred to as VOR X2) may add unnecessary complexity and difficulty that detract from optimal performance of gaze stability exercises.

The primary purpose of this study was to examine the efficacy of a modified approach to vestibular rehabilitation, which focuses on the attainment of a specific speed of head movement for gaze stabilization exercises and modifies the gaze stability exercises by eliminating additional challenges (e.g., moving target, distracting backgrounds or stance with altered foot positions). Only adaptation exercises (often referred to as VOR X1) were included without any substitution or habituation exercises. A secondary purpose was to evaluate the efficacy of targeted gait and balance exercises to restore vestibulo-spinal reflex (VSR) responses and realign a distorted internal model of verticality through neuromuscular re-education and motor learning principles applied to VR. The combination of these two approaches resulted in patients with peripheral vestibular hypofunction, returning to normal functioning for gait, balance and gaze stabilization.

## 2. Methods

### 2.1. Participants

A retrospective chart review was performed and included 159 patients who were referred for vestibular or balance rehabilitation to an outpatient physical therapy clinic between October 2013 and February 2015. Inclusion criteria included: completion of an individualized physical therapy program and availability of initial and discharge assessments of gait and balance, dynamic visual acuity (DVA), symptom intensity, and functional level. Exclusion criteria included: progressive neurologic pathology, such as severe Parkinson's disease or multiple sclerosis, and severe stroke or moderate to severe open or closed head injury. East Tennessee State University's Institutional Review Board approved a waiver of consent.

Most patients were referred directly by their primary care physician, orthopedic physical therapist, or by self-referral; thus, very few patients underwent caloric videonystagmography (VNG) testing (three of the 159) prior to initial physical therapy (PT)

assessment. The peripheral vestibular hypofunction (PVH) diagnosis was based on clinical assessment by the treating therapist (RAR), who successfully completed all four courses of the APTA co-sponsored vestibular competency-based series between 2007 and 2012. The diagnosis of PVH was determined by a combination of case history, positive head thrust test (HTT) and abnormal clinical DVA test (cDVA). Patients with a negative HTT were excluded from the study.

## 2.2. Outcome measures

Patients were asked to rate their level of function with balance from 0–100% (0 indicating loss of all balance function with gait and activities of daily living and 100 indicating completely able to perform all balance and activities of daily living tasks safely and independently, normal for their age and activity level). Patients also rated their generalized level of dizziness with activities of daily living and gait using a verbal analog scale from 0–10 (with 0 indicating no dizziness at all and 10 indicating severe dizziness that might precipitate an ER visit). Dizziness was defined for each patient as an internal, subjective feeling of ‘lightheadedness’, ‘swimmy-headedness’, or ‘woozi-ness’ and differentiated from disequilibrium (a sense of being off balance or unsteady).

The modified Clinical Test for Sensory Interaction and Balance (mCTSIB) to assess postural control under different sensory conditions was performed using an Airex Balance Pad [1]. A single trial of each of the four conditions (eyes open and closed on firm and foam surfaces) was timed for a maximum of 30 s and the total time (sum of each condition for a maximum possible score of 120 s) was used for statistical analyses.

The Dynamic Gait Index (DGI) was performed as a measure of postural stability during various walking tasks including change in speed, head turns, walking over/around obstacles, and climbing stairs. The DGI has excellent inter-rater and test-retest reliability ( $r=0.96$ ) and a score less than 20 out of a maximum of 24 indicates fall risk [16].

Clinical DVA was performed with a 60° total arc of horizontal active assist head rotations at a metronome-paced 120 bpm (2 Hz) using an Early Treatment Diabetic Retinopathy Study (ETDRS) chart at 10 feet. To ensure proper arc of movement, a paper “bib guide” with 30° degrees of rotation marked off on each side was used to teach the exercises and sent home as a guide as appropriate. The cDVA test

has good validity in identifying vestibular deficits [12] and excellent reliability [13].

## 2.3. Intervention

### 2.3.1. Gaze stabilization exercises

Gaze stability exercises were started with a stable target and horizontal and vertical head rotation with the patient seated 3–5 ft. from an eye level, foveal target. The initial target head speed was set such that the level of symptoms and/or perceived effort was mild to moderate and patients could tolerate the exercises 3–5x/day. The treating therapist (RAR) stressed that the exercise should be completed successfully; defined as the ability to maintain target head speed, range of motion and fixation on the target. Quality of exercise performance was stressed over quantity. Finally, the target speed was quantified and paced using a metronome. A metronome was loaned to the patient as needed. The patient was instructed to perform each gaze stability exercise (horizontal/vertical) for 10 cycles (duration of 6–20 seconds). A typical starting speed was 24–48 beats per minute (bpm; 48–96°/s), but ranged from 20–72 bpm (40–144°/s). A 60-degree arc of movement (30° in each direction from midline) was taught and adherence to that range of motion was emphasized. Patients were instructed to start the motion, and keep the beat in the direction of the vestibular hypofunction; e.g., for a right PVH, the patient started with head rotation of 30 degrees to the right at the first beat and then head rotation leftward to 30° past midline to the left and return to 30° past midline to the right on each successive beat. This is to emphasize the underperforming side and is important to the success of the exercises. Without this emphasis, many patients avoid the side of hypofunction and preferentially rotate more to the normal side and limit rotation to the side of hypofunction. Active assistance was provided until patients were able to correctly perform the movement independently. A ‘Z’ with a small dot in the center was used as a foveal target and placed on a mirror to provide peripheral visual feedback. Patients performed 6 sets of 10 cycles with at least 10 seconds of rest in between each set (concussion and migraine patients were encouraged to increase the duration of rest from 10 to 30 seconds as needed). This exercise was performed both horizontally and vertically and lasted 5–7 minutes. Patients were instructed to perform 3–5 sessions daily with at least 2 hours between each session.

Patients returned for follow-up within a few days to ensure correct performance. Any errors of technique

were corrected and again the quality of the exercise was emphasized over the quantity. Patients with excessive symptoms were taught to “fixate” on the Z target between cycles of head motion and to take longer rests. After successfully completing the correct exercise technique, patients were taught to increase the speed of head motion every 2–4 days based on their level of symptoms and perceived difficulty of the exercise. Patients were instructed not to exceed a level of mild to moderate dizziness and perceived difficulty and to increase their speed by 2–6 bpm when there was a noticeable improvement in symptoms and/or perceived difficulty. Patients were strongly encouraged to achieve proper head movement speeds and range of motion at the goal speed of 120 bpm to achieve 240°/s head rotation both horizontally and vertically. Caregiver assistance was encouraged for patients with cognitive or coordination issues.

Patients who achieved 120 bpm for 6 sets of 10 cycles, but continued to have symptoms (e.g., Migraineurs or patients with severe concussion) were instructed to progressively increase the cycles of head movement from 10 to 60 cycles and reduce the sets from 6 to 3, 2 or 1, all at a speed of 120 bpm (known as “The Migraine Protocol”). Although it was very rare for a patient to have a prior diagnosis of Vestibular Migraine, any patient who had a history of migraines also was determined clinically to have peripheral vestibular hypofunction; thus, all the patients in this chart review have peripheral vestibular dysfunction with some having migraine or concussion as comorbidities.

This Migraine Protocol was developed by RAR when patients with migraine reached 120 bpm with their X1 exercises and were still not symptom-free—even though they were significantly improved. An unpublished study on clinical rotary chair found that patients with migraine had 50–120% longer duration of ‘after-nystagmus’ (when spun at 180°/sec for 2 minutes and then stopped and observed while wearing infrared goggles) than those without migraine. This finding was interpreted to mean that Migraineurs need longer to process vestibular stimuli before returning to homeostasis. The intent of the Migraine Protocol was to increase the duration of the X1 exercise at 120 bpm to give the additional processing time, but to keep the overall workload the same. Most patients with migraine were vestibular symptom-free upon completing this modified approach, and many were also significantly improved with their migraine episodes, some reportedly using

the protocol exercises to successfully abort or prevent migraine episodes. This protocol was also used with some patients with severe concussion with similar benefits. Further research is needed to establish this modified speed-based VR approach as a viable alternative treatment for some Migraineurs.

### 2.3.2. Balance and gait training

Patients were started on VSR training after demonstrating they could consistently do the gaze stability exercise correctly and were progressing to a faster speed, usually the 2nd or 3rd visit. Many vestibular patients have postural malalignment due to a distorted internal model of verticality. Frequently, their center of gravity was aligned over their heels and to these patients, normal postural alignment “doesn’t feel right” and they perceived they were “going to fall forward”. Patients were educated regarding proper alignment of the center of gravity (COG) over the base of support and were often photographed at this time as visual feedback was very helpful for patients to recognize and start correcting this problem. Initially this postural alignment exercise (‘Default Posture’) was repeated 5–10 times, 3 x/day, but patients were instructed to practice proper alignment throughout the day; in other words, they should always ‘default’ to this standard posture.

Once a patient was able to achieve the Default Posture on non-compliant surfaces, they were introduced to compliant surfaces with vision and then progressed to no vision. In the more challenging situation, sway was increased and the patient was ‘forced to use’ the vestibular responses to sense the sway and respond appropriately with a hip strategy as needed. Progression involved adding slow head turns (horizontal and vertical) with eyes closed and then narrowing the base of support. Ultimately, patients were able to perform hip strategy movements correctly (i.e. with both proper timing and scaling) in this challenging condition without loss of balance. The final stage of balance training was to navigate curbs, steps, and unlevel surfaces, including grassy hills, independently without an assistive device or railing, emphasizing head movements and practicing a slight forward torso lean by bending at the hips when facing those balance challenges.

### 2.4. Data analysis

Data were summarized using descriptive statistics. To determine the effect of modified vestibular rehabilitation on the outcome measures (dizziness intensity

based on verbal analog scale, self-report balance function, DGI, mCTSIB, cDVA) Wilcoxon Signed Rank Test for related samples was performed because the data did not meet the assumption of normal distribution. Alpha level was set at 0.01 to control for multiple comparisons. To determine the impact of age on outcomes, patients were classified into one of three age groups: younger adults (YA; age  $\leq 40$  years), middle aged adults (MA; age 41–60 years), or older adults (OA; age  $> 60$  years). The outcome measures (dizziness intensity, function, mCTSIB, DGI, and cDVA) were the variables of interest. Nonparametric univariate testing (Kruskal-Wallis) was performed to determine the impact of age on number of physical therapy visits. Repeated measures (RM) analyses of variance (ANOVA) were performed to identify significant interactions with time (baseline and discharge measures) as the repeated (within subjects) factor and age group (YA, MA, OA) as the between-subjects factor. Alpha level was set at 0.01 for the univariate and RM ANOVA analyses to control for multiple comparisons. Significant univariate or RM ANOVA findings were followed up with appropriate nonparametric univariate statistics, Kruskal-Wallis or Mann-Whitney U tests, for independent samples ( $\alpha < 0.05$ ).

### 3. Results

#### 3.1. Participant characteristics

Baseline characteristics of 159 patients are presented in Table 1. The mean age (SD) of patients was 59.7 (24.0) years (range: 13–96 years) with 65% females. On average, patients completed 7.8 physical therapy visits (range: 2–29) in 60.0 (37.8) days (range: 13–305).

Diagnosis of PVH was determined by a combination of case history, positive HTT and abnormal cDVA. The HTT was performed in accordance with Schubert and colleagues [14]. By ensuring that the

patient's head was flexed  $30^\circ$  and the thrust was performed with unpredictable timing and direction the sensitivity for UVH is 71% and BVH is 84% and specificity is 82% and the positive predictive value (PPV) for UVH is 87% [14]. The cDVA test does not have age-adjusted norms; however, studies have shown a significant age-related decline in the VOR and computerized DVA [10, 11]. We defined cDVA scores as abnormal based on age in an attempt to more accurately reflect the impact of age on DVA. The cDVA difference score (between static and dynamic conditions) was defined as abnormal as follows: (1) a 3-line or greater difference for ages 49 years and younger; (2) a 4-line or greater difference for ages 50–74 years; and (3) a 5-line or greater difference for ages 75 years and older. Based on this definition, 141 of 153 (92.2%) patients who were able to be tested had an abnormal cDVA initially. Six patients were unable to be tested for various reasons (e.g., pain or exacerbating symptoms). Based on the HTT and cDVA test, (300 positives for 312 chances) results were 96.2% positive for UVH.

The mechanism of injury was frequently concussion in the younger patients and for the older patients, viral infection and, to a lesser degree, trauma. The type of trauma varied, but motor vehicle accidents, sports injuries and falls were the most common forms of trauma, often occurring months or years in the past. The percentage of patients arriving with a diagnosis of concussion was 19.5% (31/159).

Rarely, a patient was seen in the acute phase of peripheral vestibular hypofunction, concussion, or during an active migraine episode. These acute patients were very vertiginous and symptomatic at the time; and so were instructed to return for evaluation and treatment in a few weeks, and were not included in data collection until that time. Thus, all patients were in a sub-acute or chronic stage of PVH for initial evaluation and treatment.

#### 3.2. Effect of speed-based vestibular rehabilitation

At discharge, there was a significant effect of modified VR on all five outcome measures ( $p < 0.001$ ): self-report intensity of dizziness and of percentage balance function, DGI, mCTSIB and cDVA (Table 2). At discharge, all outcome measures approached normal scores; i.e., almost a complete relief of dizziness complaints, virtually all patients who initially scored at high risk for falls reduced to low fall risk, and nearly every patient (126/136) who scored abnormally on

Table 1  
Patient demographics

Variable	Mean $\pm$ SD	Range
Age (years)	59.7 $\pm$ 24.0	13–96
Gender (n; %)		
Female	104 (65%)	
Male	55 (35%)	
Number PT visits (n)	7.8 $\pm$ 4.6	2–29
Duration PT days (n)	60.0 (37.8)	13–305

Table 2  
Initial and discharge values (mean (SD)) for outcome measures

Outcome measure	All (n = 159)		Younger Adults (n = 39)		Middle-aged Adults (n = 23)		Older Adults (n = 97)	
	Baseline	Discharge	Baseline	Discharge	Baseline	Discharge	Baseline	Discharge
Dizziness (/10)	4.8 (2.5)	0.2 (1.0)*	5.4 (2.0)	0.1 (0.4)	5.5 (2.2)	0.1 (0.3)	4.4 (2.7)	0.3 (1.2)
Function (%)	55.4 (22.7)	95.2 (8.9)*	62.4 (20.1)	98.8 (2.4)	51.3 (24.3)	97.8 (5.5)	53.5 (23.0)	93.1 (10.5)
DGI (/24)	16.6 (5.7)	23.2 (2.0)*	21.7 (1.9)	24.0 (0.0)	17.4 (5.4)	23.9 (0.5)	14.3 (5.4)	22.7 (2.5)
mCTSIB (s)	89.8 (25.0)	118.9 (4.4)*	105.8 (11.5)	120.0 (0.0)	89.1 (22.9)	120.0 (0.0)	83.7 (26.8)	118.2 (5.5)
cDVA (lines difference)	6.6 (2.3)	2.3 (1.0)*	5.7 (2.0)	1.9 (0.4)	6.9 (2.7)	2.2 (0.9)	6.8 (2.3)	2.5 (1.1)

DGI: Dynamic Gait Index; mCTSIB: modified Clinical Test of Sensory Interaction and Balance; cDVA: clinical Dynamic Visual Acuity.

\*Pre- and post-differences for all subjects were examined using Wilcoxon Signed Rank Test ( $p < 0.001$ ).

the age-adjusted cDVA at evaluation returned to within normal limits at discharge. Five patients could not be tested on the cDVA at discharge.

### 3.3. Effect of age on rehabilitation outcomes

The number of physical therapy visits was significantly different among the three age groups ( $p < 0.001$ ). *Post-hoc* testing determined that OA received more visits (mean = 8.6 visits) than YA (mean = 5.3 visits;  $p < 0.001$ ). There was no difference between YA and MA (mean = 8.6 visits;  $p > 0.05$ ) or MA and OA in number of visits ( $p > 0.05$ ).

There was a significant interaction between time and age group for intensity of dizziness symptoms ( $p = 0.005$ ). *Post-hoc* testing revealed that each age group (YA, MA, and OA) improved significantly from baseline to discharge ( $p < 0.001$ ). Additionally, the intensity of dizziness was significantly different among the age groups at baseline ( $p = 0.018$ ), but not at discharge ( $p > 0.05$ ). Specifically, on initial evaluation both YA and MA had significantly greater symptoms of dizziness than OA ( $p = 0.016$  and  $p = 0.046$ , respectively), but MA and YA had similar symptom intensity ( $p > 0.05$ ); indicating that YA and MA improved to a greater extent than OA.

The interaction of time and age group for perceived function was not significant ( $p > 0.01$ ); however, the main effect of time ( $p < 0.001$ ) was significant ( $p = 0.004$ ). *Post-hoc* testing revealed that each age group (YA, MA, and OA) improved significantly from baseline to discharge ( $p < 0.001$ ).

There was a significant interaction between time and age group for mCTSIB ( $p < 0.001$ ). *Post-hoc* testing revealed that each age group (YA, MA, and OA) improved significantly from baseline to discharge ( $p < 0.001$ ). Additionally, baseline and discharge mCTSIB scores were significantly different among the age groups ( $p < 0.001$  and  $p = 0.034$ , respectively). At baseline, YA scored significantly

higher than MA and OA ( $p = 0.002$ ,  $p < 0.001$ , respectively) and at discharge YA scored significantly higher than OA ( $p = 0.037$ ), but MA and OA were not significantly different at baseline or discharge ( $p > 0.05$ ).

There was a significant interaction between time and age group for DGI ( $p < 0.001$ ). *Post-hoc* testing revealed that each age group (YA, MA, and OA) improved significantly from baseline to discharge ( $p < 0.001$ ). Additionally, DGI scores were significantly different among the age groups at both baseline and discharge ( $p < 0.001$ ). At baseline, DGI scores for YA were significantly higher than MA ( $p < 0.001$ ) and OA ( $p < 0.001$ ) and DGI scores for MA were significantly higher than OA ( $p = 0.009$ ). At discharge, DGI scores for YA were significantly higher than OA ( $p < 0.001$ ), DGI scores for MA were significantly higher than OA ( $p > 0.015$ ), but DGI scores were not different between YA and MA ( $p > 0.05$ ).

The interaction of time and age group for cDVA was not significant ( $p > 0.01$ ); however, the main effects of time ( $p < 0.001$ ) and age group were significant ( $p = 0.004$ ). *Post-hoc* testing revealed that each age group (YA, MA, and OA) improved significantly from baseline to discharge ( $p < 0.001$ ). Additionally, cDVA was not significantly different between YA and MA or MA and OA at either baseline or discharge ( $p > 0.05$ ). Clinical DVA was significantly better (i.e., fewer lines of difference) in YA than OA at both baseline and discharge ( $p = 0.003$  and  $p = 0.001$ , respectively).

## 4. Discussion

This retrospective chart review demonstrated that a modified, speed-based approach to VR was effective in patients with dizziness and disequilibrium due to peripheral vestibular hypofunction. In this modified approach, only VOR X1 adaptation exercises

were included; substitution and habituation exercises were omitted. As is typical in clinical practice, some patients did not return for follow-up testing; however, patients who finished therapy were relatively free of symptoms and had greatly improved balance at discharge. Complaints of increased dizziness are common with the performance of gaze stability exercises. However, by correcting poor technique, and emphasizing fixation and proper rest between sets, most patients were able to control symptoms and continue with the exercises. Additionally, patients of all ages benefitted.

This modified speed-based approach is consistent with the motor learning principles for practice conditions including task specificity, forced use, and exclusivity. Task specificity refers to training the system under conditions needed for normal function, which for gaze stability include adequate head movement speed, range of motion and accuracy of gaze. For example, many daily tasks require gaze stability during rapid head movements (e.g., driving or looking both directions before crossing the street) at frequencies up to 10 Hz. This modified approach to VR used 120 bpm ( $240^\circ/\text{s}$ ) as the goal for VOR function, (and nearly every patient was specifically trained at that speed), because that speed is commonly used in vestibular testing as the standard for 'normal' function. Standard VR does not have a specific speed goal, such as  $240^\circ/\text{s}$ ; thus, patients may not ultimately perform the gaze stability exercises with such rapid head movements.

The second aspect incorporated into the practice setting was the "forced use paradigm", a concept used extensively in stroke rehabilitation. For example, when patients stand on a compliant surface with the eyes closed, the sensory feedback from the somatosensory and visual systems is greatly reduced or eliminated (constrained) and the patient is forced (induced) to rely mainly on vestibular inputs to maintain balance.

Exclusivity in this context refers to concentrating on a particular task without distractions or extraneous tasks, which is important in the early stages of motor learning. It is likely that performing the gaze stability exercise with the additional task of maintaining balance under challenging conditions may result in the primary goal of VOR adaptation being compromised. Thus, in this speed-based approach to VR the gaze stability exercises were performed in sitting only, without background distractors, and without the VOR X2 exercise (head and target moving in opposite directions).

This speed-based approach has the goal of attaining higher speeds of head rotation during training and so limits the duration of continuous head movement; although, the total dose is quite similar to standard VR and meets the recommendations of the clinical practice guidelines for vestibular rehabilitation [5]. Shorter bouts ('sets') of gaze stability exercise may be the key to attaining higher speeds, since it is difficult to maintain high speed for a longer (1-2 minutes) duration. Additionally, the focus on rotating the head toward the dysfunctional side in time with the metronome may have allowed patients to achieve faster head movement with the external pacing towards that side. This emphasis towards the underperforming side is another attempt to "force the use" of the side with the deficit.

Very few studies have directly compared rehabilitation outcomes for different types of gaze stability exercises. One study found similar rehabilitation outcomes in terms of dizziness and dynamic visual acuity whether patients performed gaze stability exercises (i.e., 1-2-minute duration of head rotation while focusing on a target) versus habituation exercises (i.e., 5 cycles of head rotation without a visual target) [2]. The findings of the current study are in agreement that shorter bouts of gaze stability exercises result in good outcomes.

A second study compared high speed (1-2 Hz) gaze stability exercises compared to low speed (0.04 Hz) head movements without a visual target (similar to habituation exercises) and demonstrated similar reduction in dizziness in both groups [3]. Although both approaches resulted in improvement, the degree of improvement was minimal (symptoms were reduced by approximately one-third) compared to the 95% improvement in the current study. One difference is that in the Cohen study [3], the head movements were performed in the pitch, roll, yaw, and circumduction planes; whereas, in the current study only horizontal (yaw plane) and vertical (pitch plane) head movements were included.

The evidence from previous studies suggests that by following a program of vestibular adaptation and substitution exercises most, but not all patients, with vestibular hypofunction improve. For example, Herdman and colleagues [7] in a retrospective chart review demonstrated that following standard VR, 75–88% of persons with unilateral vestibular hypofunction achieve 'meaningful change', depending on the outcome measure examined. In the current study 93–99% of patients achieve a normal score depending on the outcomes measured. DGI is utilized by

both studies, thus a comparison can be made between the two approaches. Specifically, 88% of the patients from the Herdman study achieved meaningful change in DGI, defined as a 3 point or greater improvement from baseline or a return to low fall risk (DGI score > 19) [7]. Analyzing the current data in a similar fashion (i.e., by omitting patients who initially scored 20 or above at evaluation) 100% of patients who were initially at risk for falls improved by at least 8 points or returned to low fall risk. In fact, the mean (SD) improvement in DGI score in those initially at risk for falls was 9.6 (3.5) points (13.1 at initial assessment compared to 22.7 at discharge), compared to Herdman and colleagues [7] who reported improvement from 14.2 to 19.8, a 5.6 point improvement.

Consistent with previous research and clinical practice guidelines [5], individuals with peripheral vestibular hypofunction of all ages benefitted from this modified VR approach. The results from the current study suggest that a modified, speed-based approach to VR is effective and needs to be further researched given the potential for significant improvement in outcomes compared to standard VR.

## 5. Limitations

Inherent in a retrospective design is the issue of missing data. Patients may not attend their final visit due to financial issues (most patients had a copay) and/or they had achieved their goals of dizziness reduction and balance improvement before the scheduled final visit and so cancelled the final visit. A single trial of each condition of the mCTSIB was performed, instead of the standard three trials, due to the time constraints of a busy outpatient clinic, which may have reduced the reliability of the test results. However, given the magnitude of the change in score from initial evaluation to discharge the improvements would remain significant. The self-report measures of symptoms (dizziness) and balance function used in this study have not been validated. The measures have face validity, but the test-retest reliability is not known.

## 6. Conclusion

Current vestibular rehabilitation for gaze stabilization emphasizes duration of head movement first and speed second; thus, patients may not achieve high speeds in training. By modifying the current

VR approach to a speed-based approach for VOR gaze stability exercises and utilizing short exercise bouts, patients in the current study achieved high velocity of head movement during training, which improved outcomes to near-normal scores and may have increased exercise adherence compared to standard VR. Current VR includes multidimensional gait and balance training that is effective; however, this modified approach that emphasizes “forced use” for hip strategy recruitment and internal model realignment, produced outcomes that compare favorably to standard VR and, therefore, warrant further investigation. Further research is also needed to determine whether there is a significant difference in the actual head velocities practiced by the patient at home using this modified approach and to more directly compare outcomes with standard VR. In addition, using more equipment (e.g., caloric VNG testing, rotary chair, and computerized DVA) to measure physiologic gain would determine the extent of physiologic gain versus functional improvement.

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