Platform Tilt Perturbation as an Intervention for People With Chronic Vestibular Dysfunction

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Background and Purpose: Training to improve responses to perturbations may be beneficial for individuals with unilateral vestibular dysfunction. We evaluated the effects of an incrementally increasing surface tilt perturbation intervention for individuals with chronic vestibular pathology on gait, activities of daily living, and dizziness.
Methods: Participants (n = 29) were randomly assigned to 1 of 3 groups. The first group received random surface tilt perturbations of increasing angles and speed, half of the trials with vision-occluding goggles, 3 times weekly for 3 weeks (P group). The second group received tilt perturbation intervention (as above) plus a home program of vestibular rehabilitation exercises (P + EX group). The third group performed only the vestibular rehabilitation exercises (EX group). Outcome measures included temporospatial gait measures, Dynamic Gait Index (DGI), Dizziness Handicap Inventory (DHI), Patient Specific Functional Scale (PSFS), and a Perceived Outcomes Scale (POS).
Results: The P and P + EX groups showed greater improvement on the PSFS and the POS compared to the EX group. DGI scores indicated decreased fall risk in 8 of 9 individuals who participated in P or P + EX training and who initially scored below the 19-point cutoff score. Both the P and P + EX groups showed significant within-group changes on some gait characteristics, DGI, DHI, PSFS, and POS measures. The EX group showed within-group change only on the DHI.
Discussion and Conclusion: Surface tilt perturbation training appears to be more effective for improving abilities at the activities and participation levels than vestibular exercises alone. In addition, tilt perturbation training reduced fall risk as measured by the DGI.

Key words: *chronic vestibular dysfunction, dizziness, platform perturbation*

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BACKGROUND AND PURPOSE

Vestibular dysfunction is a common impairment in adults, disrupting daily life by making simple tasks such as cleaning house or going to the grocery store nearly impossible. From 2001 through 2004, 35.4% of US adults aged 40 years or older (69 million Americans) had vestibular dysfunction.[1] Vestibular rehabilitation improves or alleviates symptoms in 70% to 85% of the cases,[2-4] leaving a significant number of people with chronic symptoms including dizziness and disequilibrium. Besides detecting head movement, perceiving vertical and coordinating eye-head movement, the vestibular system assists in preparing for self-generated movements and responding to external perturbations. The vestibular system is also necessary for integration of somatosensory and visual information, is important in developing and maintaining internal spatial representation, and may play a significant role in extrapersonal space representation.[5]

After vestibular dysfunction, there is a mismatch of incoming sensory information causing dizziness and disequilibrium that can be disabling. Input from the intact vestibular end organ is incongruent with input from the damaged side. The central nervous system responds by "reweighting" sensory input so that reliance switches to either visual or somatosensory information for determining position in space and balance threats.[4] Without accurate vestibular information, appropriate internal spatial representation may become deficient, impacting accuracy of external spatial maps and resulting in balance and movement impairments.[5]

Horak[6] demonstrated that individuals with unilateral vestibular loss who reweighted to the uninvolved vestibular system (rather than the visual or somatosensory systems) had better compensation and functional performance when on unstable surfaces than those who did not reweight. If the vestibular system is not accessed, there is a resulting inability to shift to appropriate reference frames in any given sensory context and errors in movement occur.[5] Bray et al[7] provide evidence that vestibular rehabilitation interventions work best when individuals gain information about orientation through actions and reactions. Providing balance experiences (actions) that require the use of vestibular information are key. People with vestibular dysfunction often have decreased balance experiences through self-curtailed movement.[8] This likely prevents the adequate amplitudes of movement that promote adaptation.[7]

Typical vestibular rehabilitation programs drive recovery through central nervous system changes.[9,10] As a healthy person initiates a movement, the nervous system predicts what the sensory input from that movement will be and compares the predicted input to the actual input. After vestibular damage, the predicted vestibular firing pattern during a movement will not match the actual firing pattern of the damaged vestibular system. With multiple repetitions of a movement adaptation occurs. After adaptation, the predicted firing pattern for the movement is modified so it matches the current (impaired) firing pattern and the individual is more stable during movement.

In contrast to the predictive system, the reactive balance system provides correction for unexpected balance losses. Exercises that engage the reactive balance system (such as pushing an individual unexpectedly) require unexpected and changing perturbations and are difficult to design, especially for home programs. A potential intervention using reactive balance training is suggested by studies demonstrating that tilt perturbations of the standing surface could be effective in isolating the vestibular system. Multiple studies have confirmed that tilting platforms, using low to midlevel frequencies, require the use of vestibular cues when vision is occluded.[11-14] Allum and Pfaltz[11,15] investigated balance responses in healthy individuals and individuals with bilateral vestibular loss. Vision was occluded and platform tilts using 3° of toe-up (or toe-down rotation) were given at 36°/s. Healthy subjects demonstrated activation of the tibialis anterior muscle to correct the backward balance loss and neck muscle activation to right the head in respect to gravity. The tibialis anterior muscle responses in the subjects with bilateral vestibular loss were significantly decreased. This diminished response led to decreased production of tibialis anterior muscle torque and subsequently to backward falls. Allum and Pfaltz[11] compared electromyography (EMG) and torque responses of the healthy subjects with those with bilateral vestibular loss and reported that about 80% of the balance responses at the short latency (80 ms) and at least 60% at the medium latency (125 ms) were due to vestibular spinal reflexes in healthy individuals. On the basis of this information, one can hypothesize that surface tilt perturbations could be an effective intervention for forcing the use of vestibular information in people with partial vestibular loss.[16]

Although random tilt perturbation of the support surface with vision occluded would appear well suited for forcing use of remaining vestibular information in people with vestibular system impairment, there is no published research using this technique for intervention. There is research using forward and backward predictable platform translation for intervention. Corna et al[17] compared Cawthorne and Cooksey exercises to a program, using a platform that perturbed balance. Participants stood on the platform, with trials including both eyes open and closed, and received sinusoidal perturbations in the forward, lateral, and backward directions twice daily for 5 days. The Dizziness Handicap Inventory (DHI), anterior-posterior sway with eyes open and closed, and standard deviation of anterior-posterior sway served as outcome measures. Although both groups showed significant within-group improvements in sway and DHI scores on the pre- to posttests, the group receiving platform translation training showed a significantly greater improvement ($P < 0.05$) than the Cawthorne and Cooksey group on both measures. The subjects who received platform translation training had a mean improvement of 27 points on the DHI, a change that exceeded the minimal clinically important difference of 18 points.[18] DHI scores of the Cawthorne and Cooksey exercise group improved an average of 14 points.

The purpose of this study was to evaluate the effect of an incrementally increasing platform tilt perturbation on individuals with known vestibular pathology of greater than 6 months duration on gait ability, activities of daily living (ADL), and handicap who had not responded to traditional vestibular rehabilitation programs. We hypothesized that individuals who participated in a combination of vestibular rehabilitation exercises and platform tilt perturbations would have greater improvement in gait activities and ADL status,[5,6] as well as decreased handicap related to dizziness and disequilibrium compared with those who participated only in platform tilt perturbation training, or those who had vestibular rehabilitation exercises alone. Our theory was that surface tilt perturbation more effectively promotes reweighting of vestibular inputs.

METHODS

This study was approved by Regis University institutional review board. A convenience sample of 40 potential participants with peripheral or central vestibular dysfunction were recruited by posting flyers in physical therapy and medical vestibular specialty clinics in the Denver-metro area. Medical providers who specialized in treating individuals with dizziness were contacted by phone to explain the research study.

To be included in this study, subjects had to be 18 to 75 years old, had chronic problems of dizziness and/or disequilibrium from vestibular dysfunction of 6 months duration or longer, and have had completed a vestibular rehabilitation program. Other inclusion criteria were functional range of motion and strength (manual muscle test scores of ≥4-/5) in the lower extremities and trunk, lower extremity sensation intact to vibratory sense and superficial touch,[19,20] and ability to stand unassisted for 1 min with feet shoulder width apart. People with vestibular hydrops needed to be stable, that is, no acute episodes of vertigo in the past 6 months. Exclusion criteria were benign positional vertigo, bilateral vestibular system involvement, and other neurological, postural or orthopedic deficits that could influence posture or balance. Participants could not be on vestibular depressant medication nor change their medication regimen during the study.

Individuals were randomly assigned by drawing, to 1 of 2 experimental groups or a group receiving traditional vestibular rehabilitation exercises. The first experimental group received platform tilt interventions only (P group). The second experimental group received the same platform tilt perturbation interventions plus a vestibular rehabilitation home exercise program (P + EX group). The third group received only a vestibular rehabilitation home exercise program intervention (EX group).

OUTCOME MEASURES

Outcome measures were chosen using the International Classification of Function, Disability and Health[21] at the activity level (gait characteristics and fall risk) as these measures have shown change with vestibular rehabilitation in individuals with chronic symptoms.[22-24]

Dynamic Gait Index

The Dynamic Gait Index (DGI) assesses postural stability during gait tasks and measures risk for falling. The scoring for the DGI is based on a 0 to 3 ordinal scale with 0 being unable to perform the task, while a score of 3 indicated a normal completion of the task. The best possible score on the DGI is 24. Wrisley et al[25] found a moderate interrater reliability (kappa = 0.64) when the DGI was used with individuals with vestibular disorders. Marchetti et al[26] demonstrated fair- to excellent-intertrial reliability and good validity of the DGI items, with the ability to differentiate between a healthy control group and people with vestibular or balance problems using the continuous gait items. The DGI has a specificity of 70% for identifying people with vestibular impairments who are at risk of falling.[24]

Temporspatial Gait Measures

The GAITRite (CIR Systems, Inc, Havertown, PA) was used to acquire temporospatial gait measures. Walking began and ended at 6 feet (1.8 m) before the beginning and ending edges of the mat. No assistive devices were used. Two trials were averaged. High correlation between the GAITRite and the clinical stride analyzer have been reported for gait speed and stride length (ICC = 0.99 for each).[27]

Dizziness Handicap Inventory

The DHI[18] is a 25-item questionnaire intended to quantify perceived handicap due to dizziness and disequilibrium. Questions cover the areas of functional, emotional, and physical aspects of disability related to dizziness. A score of zero is given for a *no/never* response, 2 for *sometimes*, and 4 for *yes/always* responses. The total scores can range from 0 to 100 where zero indicates *no handicap*. Test-retest reliability is high ($r = 0.92$-0.97).[18] A change in score of 18 points or greater defines the minimal clinically important difference.[28]

Patient Specific Functional Scale

The Patient Specific Functional Scale (PSFS) is a self-report questionnaire that asks subjects to identify their 3 most important activity losses and rank the perceived severity of each loss on a 0 to 10 scale.[29] A score of 0 indicates inability to perform the activity while a score of 10 indicates the ability to perform the activity at the same level as before the vestibular problem developed. The PSFS was used because it has face validity, and there are no clinical scales that quantify individual activity losses for individuals with vestibular dysfunction. The PSFS is reliable, valid, and sensitive in individuals with knee dysfunction, low back pain, and neck dysfunction.[29,30] Chatman et al[31] found the PSFS to have excellent test-retest reliability (ICC = 0.84), sensitivity ($r = 0.78$), and construct validity for individuals with knee dysfunction; change of 3 points was the minimally detectable change on a single item. Individuals in our study listed their most important loss of function under PSFS Question 1.

Perceived Outcome Scale

The Perceived Outcome Scale (POS) is a 4-item questionnaire intended to assess perceived changes in dizziness, balance, ADL performance, and overall improvement in life function. The questionnaire uses a 5-category Likert scale (*strongly disagree, disagree, neutral, agree,* and *strongly agree*). For the purpose of data analysis categories were converted to a numerical scale of 1 (*strongly disagree*) to 5 (*strongly agree*; see Appendix A, Supplemental Digital Content 1, http://links.lww.com/JNPT/A14, for POS). This instrument was developed for this study as an "anchor" scale to tie the individual's perceived improvements with other outcome measures and was administered only at the 1-month follow-up visit. As there is no validity or reliability data for this instrument, we performed a brief assessment of test-retest reliability by calling 4 subjects 2 weeks after completing the questionnaire, and asking them to answer the questions again. Of the 16 responses (ie, 4 participants, 4 items) only 2 responses differed between the first and second administration of the questionnaire, suggesting reasonable test-retest reliability.

Intervention Equipment

Platform tilt perturbation training utilized a commercial, computer-controlled system designed for balance training (Proprio 5000, Perry Dynamics, Decatur, Illinois; see Figure 1). The device can be programmed for direction, speed, and angle of the perturbation. Platform movement options include predictable motion, random motion, variable speeds (12.6°/s to 126°/s), and adjustable degrees of tilt motion (2°-25°). Tilt was in the anteroposterior and lateral directions. We used 20-preprogrammed levels of random tilts at different speeds and angles. Speed was progressed from 12.6°/s to 114°/s, and angles started at 2° progressing to a maximum of

Figure 1. Proprio 5000™ Reprinted with permission from Perry Dynamics, Decatur, Illinois.

25°. Lower levels (Levels 1-8) of the protocol involved lower speed (12.6°/s and up to 38°/s) progressing through low to high angles of tilt (2° through 25°). A harness attached to the cross bar of the frame of the unit was used for safety against falls. There were also grab bars built into the unit, and a trainer stood in front of the individual with a hand resting lightly on the harness, to assist in case of a severe backward loss of balance. The potential for a backward fall was high as the harness was configured loosely (to allow large amplitudes of sway and losses of balance) and there was a potential for an individual to hit their head on the frame directly behind the platform.

Procedure

The primary investigator evaluated individuals for appropriateness of study inclusion and discussed the informed consent form that was read and signed by the participants. At this time individuals were instructed of the need to report any change in medications, and that they should not begin any new exercise programs until after the 1-month follow-up visit. Potential participants were screened based on 1-min standing ability, functional range of motion, strength, and superficial touch and vibration of the lower extremities. Individuals meeting the inclusion criteria were randomly assigned to a group and scheduled for a pretest session at which base-line outcome measures were acquired. These included the DGI, DHI, PSFS, gait of velocity, step width, double support time, and stride length were acquired using the GAITRite. Subjects then participated in the assigned intervention for a 3-week period. At the end of the third week, subjects participated in a posttest session wherein the same 4 outcome measures were acquired. At 1 month following the posttest session, follow-up tests were administered wherein the same 4 measures plus the POS were acquired.

Participants in the P and P + EX, received perturbation platform training using a protocol standardized for this study. The level of random platform speed and angle perturbation used for training was determined following the pretest session. The standing surface has 3 lines that intersect in the center of the standing platform, (see Figure 2). Each line has divisions that are equally spaced and consecutively numbered starting at 1 near the center of the platform and increasing toward the periphery. When the medial aspect of the foot is over the number 1 on the left-to-right line, the medial malleoli are 6 in (15.2 cm) apart. This foot position was used for determining the initial perturbation training level. Perturbations of 30 s were given at low speed (12°/s-38°/s) and small tilt angles (3°-7°) to determine the initial intervention perturbation setting. Participants were told to try to maintain their balance without the use of hands. Speed and tilt angles were increased on the preprogrammed protocol until the individual lost balance twice. *Loss of balance* was defined by either grabbing the railing, falling into the harness, or requiring physical assistance from the trainer.

The procedure was repeated with vision occluded using opaque goggles. The level of speed and tilt angle that resulted in more than 2 falls was used as the starting level for the first intervention. Once the participant had 2 falls or less during a 30-s trial of platform training, the next trial was progressed by repeating the same program level but standing with feet together. When the participant had 2 falls or less in this position, the next 30-s trial was performed using the same perturbation level, but with the participant standing in a narrow stride position with the medial aspect of each foot on the respective side of the vertical line with approximately 1 inch (2.54 cm) between the heel of the front foot and the great toe of the back foot. Once the participant had 2 falls or less in narrow stride position, they progressed to the next program level and repeated the foot position sequences. Using this protocol, each participant progressed through the same program, but at levels customized to their balance ability.

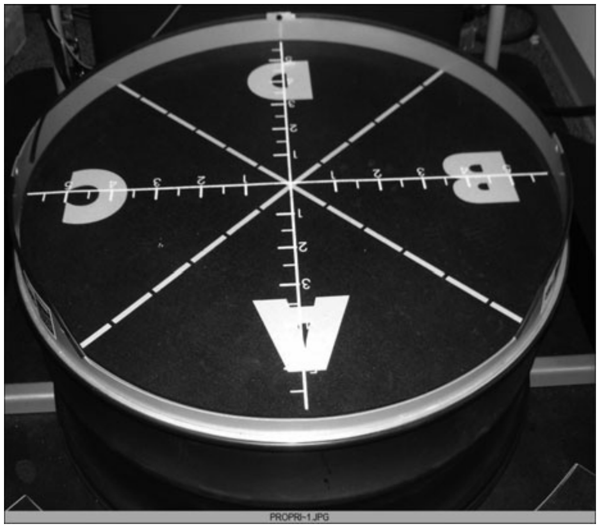

Figure 2. Proprio 5000™ plate with foot placement markings. Reprinted with permission.

Each visit included 10 platform perturbations lasting 30 s each; 5 with eyes open and 5 with eyes occluded by opaque goggles. The eyes open or eyes occluded pattern of 30-s perturbations was determined by blinded drawing. Although the total time of actual perturbations was only 5 min, positioning, repositioning, and time between perturbation training resulted in a total contact time of 20 to 25 min for each intervention session. The length of the treatment sessions on the perturbation platform was determined based on data from a previous project[32] using optokinetic stimulation to improve balance in a group of subjects with disequilibrium due to vestibular damage. Five to 10 min of optokinetic stimulation performed 3 times weekly for 3 weeks was found to be effective in changing balance for this population.

The P and P + EX groups followed the same platform perturbation protocol. However, during the pretest session, the P + EX participants were evaluated and given an individualized vestibular rehabilitation home exercise program. These exercises were designed to reduce dizziness, improve gaze stability, and improve postural stability in sitting, standing, and walking using a progression through a specified set of exercises (see Appendix B, Supplemental Digital Content 2, http://links.lww.com/JNPT/A15 for home exercise program) with the beginning program based on results of the pretest examination. The level of difficulty and number of exercises were determined based on provocation of dizziness using a visual analog scale (VAS) of 0 to 10 where 0 = "no dizziness" and 10 = "dizziness so severe I would fall down," disequilibrium, and visual blurring during testing. Test positions for dizziness started with rolling and progressed to roll-to-sit, sitting with left/right head motion, sit-to-stand, standing with left/right head motion, or walking with left/right head motion. Postural exercises started with the first position in which the individual showed disequilibrium (either with eyes open or closed) through increased sway or loss of balance. Balance loss was indicated by use of the hands/arms to recover balance in any position, taking a step, lifting the arms during standing tests, taking lateral steps during walking, or requiring physical assistance from the tester to prevent a fall. Positions tested were sitting, standing feet together and tandem, walking, tandem stepping, and backward walking. Visual fixation exercises were based on individual report of when an object of regard became blurred during head motion. Exercises were started by using visual fixation of the individual's thumb (participants were told to focus on one of the creases on their thumb) or an external object while moving the head back-and-forth, or up-and-down at 2 Hz or more if able to achieve clear focus.

A home vestibular exercise program was customized for each participant and progressed at participant-specific rates in regard to balance, dizziness, and gaze stabilization activities. When a participant had no falls (defined as recovering balance losses by using the hands on furniture, walls, etc, or actually falling to the floor) or only small losses of balance during the assigned exercise, the balance exercises were increased in difficulty by narrowing the base of support and/or closing the eyes. Visual fixation exercises were progressed by increasing the speed of head motion, and further progressed by using an external object for fixation when the participant reported no blurring during head turning. Exercises to habituate dizziness were progressed when the subject reported a lower level of dizziness (on the VAS scale) on their current head-motion home exercise by increasing the amplitude of head motion, full body motion, and decreasing the amount of somatosensory cues during head motion for example, by moving the subject from the lying position to the sitting position for exercising. Increasing the amplitude of head motion might be progressed from rolling over to rolling and coming to sit. Each home exercise program had 3 to 5 exercises and participants were instructed to perform the home exercises 3 times daily, for 5 to 7 min per session. The number of exercise bouts were decreased on the 3 days of the week when training on the perturbation platform was performed to maintain equivalent daily exercise times in the EX and P + EX groups. Weekly progression of each individual's exercise program was guided by findings on reassessment. Participants maintained compliance journals to document the frequency and duration of home program exercise sessions.

An EX group was evaluated and treated with the same vestibular rehabilitation exercise program used for the P + EX group. These subjects received the same reassessment as the P + EX group, looking for progress in gaze stabilization, dizziness and balance. The home exercises were progressed based on the results of each individual's weekly reassessment findings and home exercise program compliance as documented in their compliance journal.

Each participant had approximately the same amount of weekly individual contact with the researchers regardless of group assignment. Participants in the platform tilt perturbation groups (P and P + EX) spent 20 to 25 min per session (60 to 75 min weekly) in the laboratory while the EX group individuals were seen once weekly for re-evaluation and upgrade of their home program, with the visits averaging between 45 min and an hour.

Study Design

An experimental, single-blind, randomized 3 × 3 (group, time) design was used. Assessment of all 4-outcome measures was completed at pretest, posttest (final day of treatment), and at follow-up testing (1 month after the posttest).

Data Analyses

SPSS version 17 (SPSS Inc, Chicago, Illinois) was used for analysis of data. Participant characteristics of age, time since onset, time in rehabilitation, and time since rehabilitation were analyzed using ANOVA. Gender was analyzed using the Kruskull-Wallis test. Gait velocity, step width, double limb support time, stride length, and PSFS were analyzed using repeated measures ANOVA with a Tukey HSD for pairwise comparisons if there was a significant main effect. Because of the small number of individuals in this exploratory study, univariate measures were chosen to reduce the risk of a Type II error. The DGI, DHI, and POS were analyzed using a Kruskull-Wallis H test for between group differences. A repeated measure ANOVA was also used for measurements within each of the 3 groups with a Tukey HSD for pairwise comparisons if there was a significant difference. A Friedman test was used for within-group differences on the DGI, DHI, and POS. A Wilcox Sign Ranked test was used to identify differences between sessions if the primary analysis was significant. In all analyses, the level of significance was set at $\alpha \leq 0.05$.

RESULTS

Demographics

Participant characteristics

Participants included individuals with a diagnosis of peripheral vestibulopathy, vestibular hydrops or central vestibular dysfunction. Twenty-nine people met the inclusion and exclusion criteria. The study flow diagram (Figure 3) illustrates inclusion, exclusion, and withdrawal information. There were no significant differences between groups in participant characteristics. Participant characteristic and diagnosis information are given in Table 1.

At the initial session all participants in groups P and P + EX had balance losses during platform tilt perturbations when vision was occluded, but were able to progress to at least 15° of tilt during training. Of the 29 participants, 25 were able to maintain balance with 20° of platform tilt with vision occluded at the end of the study.

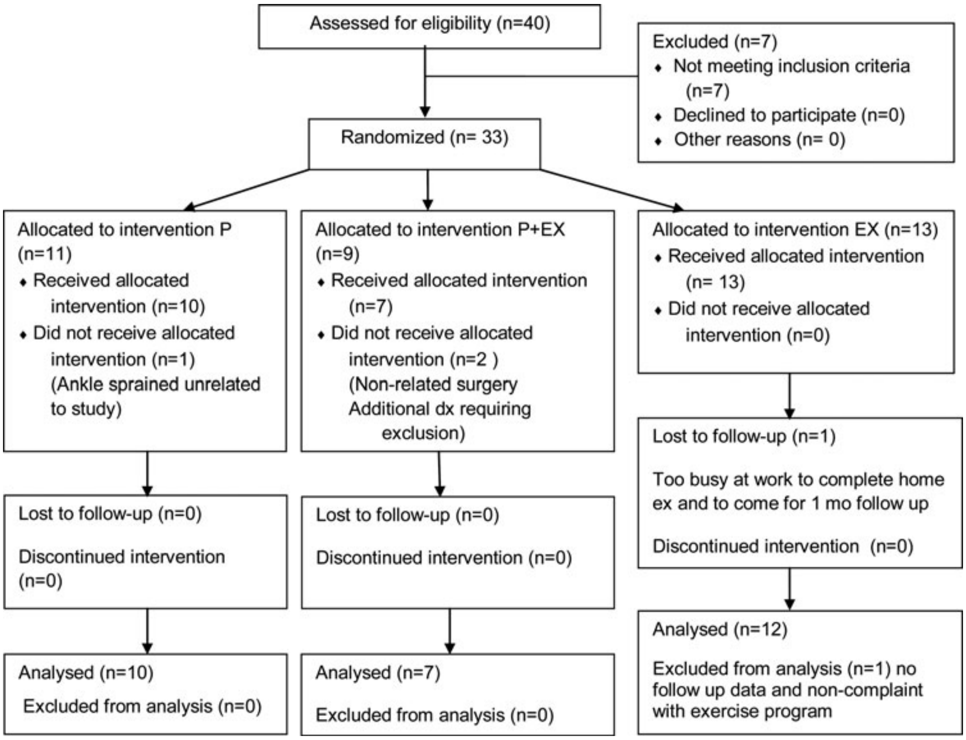

Figure 3. Flow chart of participant recruitment, screening, and retention.

Table 1. Diagnostic Categories and Subject Characteristics by Group

	P Group	P + EX Group	EX Group	Between-Group *P* Values	Diagnostic Testing
Unilateral peripheral hypofunction	7	2	7		Caloric testing with reduced vestibular response ≥25%
Vestibular hydrops	2	4	3		Electrocochleo graphy
Central vestibular Dysfunction	1	1	1		Abnormal oculomotor findings on electronystagmog-raphy
Mean age (years)	55.7	54.0	52.9	$P > 0.05$ ($F_{2,26} = 0.13$)	
Female (n)	8	3	6	$P > 0.05$	
Male (n)	2	4	6	$P > 0.05$	
Average No. months since onset of symptoms	66.8	50.1	56.8	$P > 0.05$ ($F_{2,22} = 0.23$)	
Average No. of months since formal rehabilitation program	19.7	18.4	14.1	$P > 0.05$ ($F_{2,22} = 0.23$)	

Pre-test Data

There were no significant between-groups differences in the pretest data, with the exception that the EX group performed better than the P group ($P = 0.05$) on the DGI. To establish concurrent validity of the PSFS in individuals with vestibular damage, we performed a Pearson correlation to compare the pretest DHI score with the pretest score on the PSFS. There was a moderate correlation ($r = -0.48$, $P = 0.008$) between these measures.

Between-Groups Changes

The DGI, PSFS Question 1, and POS Questions 1, 3, and 4 showed significant between-group changes from pretest to posttest, and from pretest to 1-month follow-up (see Table 2).

Table 2. Between-Group Outcome Statistics and Power Levels

Outcome Measurement	Significance Level (P Values) Between Groups	Significant Findings Between Groups	Power Level (Parametric Tests Only)
Gaitrite			
Velocity of gait	0.07		0.17
Step width	0.08		0.41
Double support time	0.85		0.60
Stride length	0.83		0.10
Dynamic Gait Index	**0.05**[a]	Group EX better than group P	
Dizziness Handicap Inventory	0.53		
Patient Specific Functional Scale Question 1	**0.006**[a] ($F_{4,52} = 40.3$)	Group P better than groups P + EX at posttest ($P = 0.01$) and EX at 1-month follow-up ($P = 0.05$)	0.91
Patient Specific Functional Scale Question 2	0.28		0.38
Patient Specific Functional Scale Question 3	0.07		0.67
Patient Outcome Measure[b] Question 1: dizziness	**0.02**[a]		
Patient Outcome Measure[b] Question 2: balance	0.318		
Patient Outcome Measure[b] Question 3: activities of daily living	**0.01**[a]	Group P + EX better than group EX at posttest and 1-month follow-up ($P = 0.01$)	
Patient report Outcome Measure[b] Question 4: life change	**0.01**[a]	Group P + EX better than group EX at posttest and 1-month follow-up	

[a]bold values are significant at the $P < 0.05$ level.
[b]Values used for statistical analysis; 5 = *strongly agree*; 4 = *agree*; 3 = *neutral*; 2 = *disagree*; 1 = *strongly disagree*.

The DGI demonstrated a reduced number of participants at fall risk (score of ≤19) after intervention. At the time of follow-up testing, none of the 5 participants initially at risk in the P group had scores below the cutoff score of 19, 1 of 4 participants in the P + EX group, and 2 of 3 participants in the EX group had scores remaining below the cutoff value.

Within-Group Changes

Group P showed significant improvements from pretest to posttest and pretest to 1-month follow up on the DGI, step length in gait, DHI, and on the PSFS Questions 1, 2, and 3 ($P < 0.05$; see Table 3). At follow-up testing, POS responses indicated that 60% of participants agreed their dizziness was decreased (Question 1), 70% agreed their balance and ADL were better (Questions 2 and 3), and 80% felt their life was improved (Question 4) at follow-up testing. Of the 5 possible responses for each of the 4 questions, 68% (n = 27) were *agree* or *strongly agree*, 15% (n = 6) were *neutral* and 18% (n = 8) were *disagree* or *strongly disagree*.

The P + EX group showed significant improvements between pretest and posttest, and between pretest and follow-up on the DGI, gait velocity, DHI, and PSFS Question 1 ($P <$ 0.05; see Table 3). At follow-up testing, POS responses indicated that 80% of individuals agreed their dizziness, ADL and life functions were better, 60% agreed their balance had improved. Of the 5 possible responses for each of the 4 questions, 5% (n = 15) were *agree* or *strongly agree*, 25% (n = 5) were *neutral* and 0% (n = 0) were *disagree* or *strongly disagree* on any item.

The EX group had significant improvements on the DHI from pretest to posttest, and from pretest to 1-month follow-up ($P < 0.05$; see Table 3). At follow-up testing, POS responses indicated that 33% of the participants agreed dizziness (Question 1) and life functions (Question 4) were improved, 50% felt their balance was better (Question 2) and 25% thought the intervention improved their everyday activities (Question 3). Of the 5 possible responses for each of the 4 questions, 35% (n = 17) were agree or strongly agree, 33% (n = 16) were neutral and 31% (n = 15) were disagree or strongly disagree.

Finally, there was no significant relationship between age and change in any of the outcome measures.

DISCUSSION

This study examined the effects of using random platform tilt perturbation training on gait, perceived activity status, and dizziness and disequilibrium handicap in individuals with chronic symptoms after vestibular dysfunction (please see Video, Supplemental Digital Content 3,

Table 3. Groupwise Values for Study Outcome Measures at Each Test Session

Outcome Measure	Session	P Group	P + EX Group	EX Group
Dynamic Gait Index	Pretest	**17.9 ± 2.5[a]**	18.6 ± 4.0	20.7 ± 3.1
	Posttest	22.4 ± 2.5	21.4 ± 3.4	22.0 ± 1.5
	1-mo. f/u	21.6 ± 2.2	21.3 ± 5.0	21.9 ± 2.2
Velocity	Pretest	109.3 ± 19.0	89.4 ± 19.3	111.0 ± 17.8
	Posttest	112.1 ± 15.8	107.4 ± 14.4	110.6 ± 17.5
	1-mo. f/u	118.4 ± 14.6	107.0 ± 14.3	113.8 ± 10.4
Step width-heel to heel	Pretest	18.9 ± 4.1	24.6 ± 5.0	27.4 ± 5.4
	Posttest	19.2 ± 6.0	22.2 ± 4.8	27.4 ± 7.0
	1-mo. f/u	19.4 ± 5.8	24.0 ± 3.4	24.0 ± 3.4
Double support time	Pretest	25.9 ± 3.3	23.2 ± 3.4	23.5 ± 8.1
(Average of left and right)	Posttest	26.1 ± 3.4	21.7 ± 4.5	22.0 ± 3.0
	1-mo. f/u	24.7 ± 2.9	21.3 ± 2.6	21.1 ± 3.5
Stride length	Pretest	120.1 ± 17.4	75.3 ± 3.8	95.2 ± 29.8
	Posttest	120.4 ± 14.4	77.0 ± 2.0	98.1 ± 24.9
	1-mo. f/u	124.9 ± 12.3	85.6 ± 15.7	103.1 ± 22.5
Dizziness Handicap Inventory	Pretest	46.0 ± 16.5	48.6 ± 18.0	44.7 ± 22.3
	Posttest	37.4 ± 14.9	36.3 ± 20.1	35.2 ± 23.5
	1-mo. f/u	35.0 ± 12.5	36.3 ± 18.6	36.0 ± 23.2
Patient Specific Functional Scale				
Question 1	Pretest	5.2 ± 1.7	3.6 ± 2.6	4.5 ± 1.9
	Posttest	**7.2 ± 1.6[a]**	3.9 ± 2.7	5.3 ± 2.0
	1-mo. f/u	**7.3 ± 1.4[a]**	6.0 ± 2.5	5.1 ± 2.2
Question 2	Pretest	4.7 ± 2.7	4.4 ± 2.2	4.4 ± 2.2
	Posttest	6.6 ± 2.2	5.0 ± 2.5	4.7 ± 2.7
	1-mo. f/u	6.7 ± 3.0	5.9 ± 2.8	4.8 ± 2.2
Question 3	Pretest	3.1 ± 2.2	3.7 ± 1.9	5.4 ± 2.4
	Posttest	5.8 ± 2.3	5.1 ± 2.8	5.6 ± 2.5
	1-mo. f/u	5.4 ± 3.2	4.9 ± 3.4	5.4 ± 2.8
Patient Outcome Scale[b]				
Question 1. Dizziness	1-mo. f/u	3.6	4.6	3.0
Question 2. Balance	1-mo. f/u	3.8	4.2	3.3
Question 3. Activities of daily living	1-mo. f/u	3.7	4.6	3.0
Question 4. Overall improvement in life	1-mo. f/u	3.9	4.6	3.1

Abbreviation: 1-mo. f/u, 1-month follow-up.
[a]Significant at $P \leq 0.05$.
[b]Values used for mean: 5 = *strongly agree*; 4 = *agree*; 3 = *neutral*; 2 = *disagree*; 1 = *strongly disagree*. *P* values in bold are significant at $P < .05$.

http://links.lww.com/JNPT/A16 for examples of the perturbation platform in use). All pre- to posttest comparisons that were significant remained significant for the pretest to follow-up test comparison, indicating changes were maintained up to 1 month. Both of the platform perturbation training groups (P and P + EX) improved in multiple measures of gait, DHI, and self-assessment of symptoms. The exercise only group (EX) made significant improvements only on the DHI, and fewer than half of the participants in this group felt they had improved in balance, dizziness or ADL as measured by the POS.

Fall risk was decreased as a result of participation in the study. At the pretest, there were 12 participants with scores of 19 or less, a score believed to indicate an increased risk of falling.[24] On posttesting and 1-month follow-up, only 3 participants remained in this at-risk category, 1 in the P + EX group and 2 in the EX group. The P group had the most individuals at risk of falling at pretest (5/10), however none remained in the at-risk group on posttest or follow-up. These findings are consistent with a recent publication in which fall risk factors were shown to decrease after translational perturbation training in older adults.[33]

The results of this study provoke the question of why an intervention using only random platform tilt perturbation of the standing surface would be effective in decreasing symptoms of dizziness and disequilibrium, when the total time of intervention was so brief (ie, 15 min/wk). Our hypothesis was that random platform tilt perturbation training (with vision occluded) is ideal for promoting use of the vestibular system for maintaining standing balance because somatosensory information is rendered ineffective for upright control during platform tilts of low or mid frequency and moderate tilt (3° or more of tilt)[15,34]; therefore, requiring the use of vestibular information to be successful in maintaining balance. The rapidity in which improvement occurred (9 sessions with ten 30-s perturbations) finds a basis in the theory of Borel et al.[5] These researchers reported that vestibular cues are involved in extrapersonal and intrapersonal representations of space, and that this representation is dynamic and continuously updated—a fast-adapting process. Their hypothesis is that, instead of a simple reweighting of sensory information, information from the vestibular system is necessary for visual and somatosensory cues to be integrated for accurate spatial representation (both internal and external) and spatial mapping. Improved spatial mapping, provided through the vestibular system, results in improved balance and movement. A system that permits rapid reorganization of spatial representations would result in relatively broad and rapid changes in an individual's function.

Why would platform tilt perturbation be faster at achieving change than more traditional vestibular exercises? The answer may lie in a publication by Bray et al[7,35] titled: "*We are most aware of our place in the world when about to fall.*" Being off balance (platform tilt perturbation) may promote rapid adaptation through reorganization and use of vestibular information that is necessary to maintain balance on a tilting surface. Perhaps the question we should be asking in vestibular rehabilitation is "Does your patient experience a sufficient number of near falls to promote adaptation?" How they are perturbed to produce loss of balance may also be important.

It may be that forcing use of vestibular information through platform tilt perturbation leads to improved spatial mapping, information about movement, performing half of the perturbations with eyes open would be unnecessary as a losses of balance which is a potent error signal.[7] Error signals are important for changing motor behavior. Some individuals who do not recover well may be producing too small an error signal because they hold their heads still to avoid movement that causes dizziness or blurred vision. In fact, people with vestibular dysfunction often decrease their movement especially at the head and the lower leg.[8] Other people with vestibular dysfunction use canes or light touch to maintain balance, all strategies that decrease balance losses but also decrease the error signals. It is also possible that too large an error signal may be less effective at promoting change.[35] Therefore, a platform that is adjustable in both angle of tilt and speed of movement could ideally match the requirements providing an incrementally increasing error signal. As individuals are forced to use remaining vestibular information rather than ignoring it, integration of sensory information would occur resulting in improved spatial maps. It may be unnecessary to have vision available, as we did in ½ the trials, as the error signal alone may be adequate to promote change.

Traditional vestibular rehabilitation exercises have been shown to improve the DHI scores in people with chronic unilateral vestibular problems[23]; therefore, the significant improvements on the DHI in groups P + EX and EX is expected. The finding that random platform tilt perturbation alone improved the DHI scores (activity and participation level measurements) as well as perceived dizziness (on the POS) supports our theory that random platform tilt perturbation promotes a sensory integration process by changing either the intravestibular or intersensory conflict thought to be the basis of dizziness.

An alternative explanation is that improvements in outcome measures were related to up-training of the somatosensory system during fast and slow surface oscillations (above 32°/s and below 1°/s). The somatosensory system can detect changes and theoretically reestablish balance without vestibular information.[34,36,37] However, the midrange perturbations, as used in this study, do require vestibular system input. In addition, we feel it is unlikely that somatosensory retraining explains for our results due to the very large angles of tilt used at each velocity and the 2 narrow-based foot positions used; both of which require vestibular inputs for re-establishing stability.[34,38]

The PSFS, which had not previously been used to evaluate people with vestibular dysfunction, was easy to use. Individuals were asked to list 3 activities with which they had difficulty, and to rank each activity from 0 (*can't do*) to 10 (*do the same as before injury*). The PSFS reflected the top 3 activity losses on which participants placed the highest importance; however, because these responses changed over the course of training and by the posttest or follow-up session some participants listed activities in the second and third places that they had not yet attempted (eg, skiing), each of the 3 responses was analyzed separately. Activities listed on the PSFS that were commonly among the highest-ranked responses included problems walking outside in low light, bending over without balance loss/dizziness, and driving long distances without dizziness. If this scale is used in future studies of vestibular dysfunction, it is recommended that participants choose more commonly performed activities to improve the use and sensitivity of this scale. Participants receiving platform tilt perturbation training spontaneously reported major changes in life at the follow-up session. One participant reported being able to hike in the moonlight, an activity she had been unable to do in several years. Another participant reported returning to full-time work after 3 years of working only part-time due to symptoms. In neither case did the participants list these activities on the PSFS. In spite of this, we feel the PSFS was sensitive to changes in activities important to individuals; the 2 platform tilt perturbation groups showed significant improvements on the PSFS responses. The PSFS also appears to test components of activity and function that are thought to be tested by the DHI. This was demonstrated by a significant correlation of the pretest PSFS to the pretest DHI, and may be useful for outcome measurements in the clinic.

In the future, comparisons between translational perturbation training and surface tilt perturbation should clarify questions about the optimal perturbation conditions for improving symptoms and fall risk in individuals with vestibular dysfunction. We hypothesize that it is the tilt component that best targets the vestibular system and promotes sensory reintegration of vestibular information. Adding data collection on head displacement and response times in the lower extremities to the perturbation may help clarify how, and for whom, the interventions are effective. Future studies should also compare massed practice to determine whether perturbation training would be more effective using a higher number of perturbations over a shorter period of time. Hadders-Algra et al[39] showed excellent results using massed practice with high numbers of surface tilt perturbations during a 5-day period to establish sitting synergies in presitting infants. If a method of randomizing and controlling the angle and frequency of the tilts on rocker boards could be developed, using surface tilt perturbation for home exercise programs may be very effective in promoting use of vestibular information. There were reports of adverse effects among our study participants. After 4 to 5 sessions, about one-quarter of the participants in the P and P + EX groups were verbally reporting doing better in their environment and with their ADL. However at approximately the 7th session, several individuals reported getting worse again. These individuals were all receiving the high-frequency tilt perturbations (Level 9 vision occluded; Level 13-16 eyes open). Horak[34] states that at midfrequency ranges, the vestibular system is critical to maintain balance on tilting platforms, but that at higher and lower frequencies of tilt, the somatosensory system is able to help. The higher frequencies of tilt in our study may have provoked a reweighting of the sensory systems toward somatosensory promoting individuals to return to a previously used strategy.

LIMITATIONS

A limitation of this study was the use of a self-report measure of dizziness, balance, ADL, and global improvement in life (the POS), for which insufficient formation about reliability and validity is available. However, we felt that this measure was valuable for capturing each individual's point of view regarding changes attributed to participation in the study. Another limitation is that due to circumstances beyond our control, the study was terminated earlier than planned, resulting in imbalance between groups in the number of participants and a lower recruitment (and hence statistical power) than planned. This may have resulted in an increase in the chance of a Type II error in some of the between-group comparisons. Circumstances that lead to early termination of this study included (1) a limited number of participants being referred to the study when a similar intervention became available in the local community, and (2) the burden on financial and assistant resources resulting from study participation.

CONCLUSION

Although vestibular rehabilitation exercises appear to be as beneficial as random platform tilt perturbation at improving DHI scores, perturbation platform training was significantly better than rehabilitation exercise alone for improving function as measured at the activity and participation levels of the International Classification of Function, Disability and Health. Clinically, providing experiences of falling (surface tilt perturbations with balance losses) may help develop rapid adaptive responses, improving extra and intrapersonal spatial representations. Platform tilt perturbation training for people with vestibular dysfunction also appears to be effective in reducing fall risk as measured by DGI.

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