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Comparison of Virtual Reality Based Therapy with Customized Vestibular Physical Therapy for the Treatment of Vestibular Disorders

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Abstract

We examined outcomes in persons with vestibular disorders after receiving virtual reality based therapy (VRBT) or customized vestibular physical therapy (PT) as an intervention for habituation of dizziness symptoms. Twenty subjects with vestibular disorders received VRBT and 18 received PT. During the VRBT intervention, subjects walked on a treadmill within an immersive virtual grocery store environment, for 6 sessions approximately one week apart. The PT intervention consisted of gaze stabilization, standing balance and walking exercises individually tailored to each subject. Before, one week after, and at 6-months after the intervention, subjects completed self-report and balance performance measures. Before and after each VRBT session, subjects also reported symptoms of nausea, headache, dizziness, and visual blurring. In both groups, significant improvements were noted on the majority of self-report and performance measures one week after the intervention. Subjects maintained improvements on self report and performance measures at 6 months follow up. There were not between group differences. Nausea, headache, dizziness and visual blurring increased significantly during the VRBT sessions, but overall symptoms were reduced at the end of the six-week intervention. While this study did not find a difference in outcomes between PT and VRBT, the mechanism by which subjects with chronic dizziness demonstrated improvement in dizziness and balance function may be different.

Index Terms

virtual reality; dizziness; habituation; vestibular rehabilitation; balance

Introduction

Dizziness is one of the most common complaints to physicians in the United States responsible for over 8 million medical visits per year [1]. Hannaford et al. reported that 20% to 30% of the general population have complaints of dizziness [2]. Among 546 individuals presenting to the emergency room who had falls of unknown origin, 80% had symptoms of vestibular disorders and 40 % were complaining of vertigo [3].

Individuals with vestibular disorders have complaints of dizziness, vertigo, balance problems, falls, and difficulty focusing [4]. They also may report blurred vision with activities requiring head movements while walking such as looking for products in shopping malls or reading signs while driving [5, 6]. Furthermore, they may report increased symptoms in visually complex environments that have been described in the literature as “space and motion discomfort”, “space phobia”, “supermarket syndrome”, “height vertigo”, and “visual vertigo” [7–11]. Situations that have been reported to precipitate space and motion discomfort or visual vertigo include: walking in supermarket aisles or shopping malls, or complex and confusing visual stimuli.

One of the most common interventions for individuals with vestibular disorders is vestibular rehabilitation, a treatment that combines physical movements with exposure to different sensory inputs to reduce symptoms and improve balance problems in both young and older adults [4, 12–20]. Part of the intervention for people with vestibular disorders is to perform exercises that include visual-vestibular and/or somatosensory-vestibular conflict [13, 21]. Visual information can be altered by asking subjects to perform exercises in visually complex environments (such as in a room with highly textured walls or using optokinetic stimuli) or visually impoverished environments (such as in a dimly lit room, or with eyes closed) [13, 21, 22]. The difficulty of the training can be increased by adding vestibular stimulation such as incorporating head movements.

In persons with vestibular disorders, a common co-morbid condition is anxiety [23][24]. Behavioral interventions including habituation exercises using virtual reality (VR) technology have been used to treat patients with anxiety disorders such as fear of flying, panic disorder, social phobia, and post-traumatic stress disorders [25, 26]. Habituation exercises also have been used to treat patients with vestibular disorders [27], and may be particularly helpful in combating the over-reliance on a sensory modality and reducing associated anxiety. Bronstein has suggested that in addition to customized vestibular rehabilitation, desensitizing patients to visual motion and visuo-vestibular conflict may be of benefit to those who have visual vertigo [5]. Furthermore, optokinetic stimulation-based habituation exercises have been shown to be useful during vestibular rehabilitation [6, 28].

Consequently, virtual reality based therapy may provide an effective means of addressing both symptoms of dizziness and anxiety. The gradual exposure to the visual scenes may

allow individuals to habituate to the provocative stimuli and help diminish symptoms [29, 30]. Using virtual reality in vestibular rehabilitation may be a successful way to facilitate desensitization of symptoms resulting from sensory conflict among the visual, vestibular, and somatosensory systems.

The purpose of this study is to describe and compare changes in self report and performance measures in persons with vestibular disorders after a 6-week intervention program of customized vestibular physical therapy (PT) or virtual reality-based therapy (VRBT). A secondary aim was to describe within and between-session changes in symptoms during the VRBT only, over the course of the 6-week intervention.

Methods

Design

The protocol was approved by the University of Pittsburgh Institutional Review Board. A clinical trial was designed to compare VRBT with the standard of care customized vestibular PT in patients with vestibular disorders, using a nonequivalent two-group pretest-posttest design.[31] For the PT intervention, subjects were treated for 6 treatment sessions (one session per week) by a physical therapist. For the VRBT intervention, subjects were treated for 6 treatment sessions (one session per week) using a virtual grocery store displayed in an immersive environment. Both interventions also included prescription of home exercises, consisting of gaze stabilization or static balance sensory integration tasks.

Subjects

The study consisted of 38 subjects with peripheral, central, or mixed vestibular disorders. Inclusion criteria were complaints of dizziness, imbalance, and abnormal objective laboratory testing (caloric testing, rotational chair testing, vestibular evoked myogenic potential testing, spontaneous nystagmus, and/or posturography). Exclusion criteria included the following: a history of neurologic disease, use of assistive devices for ambulation, a total hip or knee replacement, and severe arthritis. Subjects were recruited from the vestibular disorders clinic at the University of Pittsburgh after examination by a neurotologist. All subjects provided informed consent and agreed to participate in the study. The allocation of the subjects to the two intervention groups occurred in blocks of approximately 10 subjects over a four year period.

Interventions

Customized Vestibular PT—Eighteen subjects had six treatment sessions over the course of 6 weeks, a frequency that has been shown to improve outcomes in individuals with vestibular disorders.[16, 19, 32, 33] An initial evaluation of 1 hour duration was followed by five follow-up sessions lasting 45–60 min. Based on impairments and functional limitations discovered during the initial evaluation, the PT program was designed to address: 1) gaze stability in activities that require head movements such as shopping or walking in busy places; 2) space and motion sensitivity, 3) dizziness associated with head movements; and 4) postural instability and disequilibrium. Subjects were provided with home exercises for their dizziness and balance and were asked to maintain a daily exercise diary. In-clinic and home

exercises primarily consisted of gaze stabilization, eye and head movement coordination, static balance sensory integration tasks, and dynamic gait activities [34, 35]. Two physical therapists specialized in vestibular rehabilitation performed the intervention.

Virtual Reality-Based Therapy (VRBT)—Twenty subjects had six treatment sessions in the VRBT grocery store over the course of 6 weeks. During each treatment session, subjects ambulated on a treadmill as if they were moving through aisles in a virtual grocery store (Figure 1). The walking speed was self selected by each subject according to their level of comfort. The therapists asked the subject to locate products on the shelves as they ambulated, and the subjects responded verbally when they located the product. The treatment session lasted one hour and included six trials of habituation training; each trial was 4 minutes duration. The treatment session was conducted in the Medical Virtual Reality Facility at the University of Pittsburgh (see details below). Over the 6-week period, subjects were exposed to more visually complex aisles depending on the subject's tolerance.

The subjects' tolerance to the virtual environments was assessed by recording their vital signs (blood pressure and pulse rate) and their Subjective Units of Discomfort (SUD, 0–100 range) before and after each trial [36, 37]. Scores of 0 indicated no discomfort and scores of 100 indicated maximum discomfort. The investigators also used the SUD score to determine if subjects should move to a more complex or less complex aisle. For instance, if the SUD score was unchanged from the baseline trial, the complexity of the aisle would increase. On the other hand, large changes in the SUD score over the course of a trial would result in a reduction in aisle complexity, or terminating the session. Subjects were given home exercises for their dizziness and balance and asked to keep a daily exercise diary.

The virtual environment consisted of a grocery store modeled in 3D Studio Max and imported into Unreal Tournament (UT2004), adapted for multi-screen environments with the CaveUT modification [38]. The store scene was displayed on three screens that surrounded the subject in a full-field immersive visual environment. The three-projector configuration was designed so that it would encompass a subject's entire horizontal field of view. This is an improvement over smaller field of view displays (such as from a single projector), because movement in the peripheral field of view is an important contributor to postural control [39, 40]. The store contained 16 aisles (20 m long) and had 8 levels of visual complexity that depended on the spatial frequency and contrast of the product textures (Figure 2). The aisles increased in complexity from aisle one to aisle sixteen.

Three 2.4 × 1.8 m (vertical × horizontal) back-projected screens were used. The side screens made an included angle of 110° with the front screen. The front screen was 1.5 m from the user, and the opening of the structure at the location of the subject was approximately 2.9 m from the front screen. The images were displayed using Epson 810p PowerLite LCD monoscopic projectors, with a pixel resolution of 1024 × 768 for each screen. Each projector was connected to an NVIDIA GeForce4 graphics processing unit (64 MB texture memory) installed in a separate PC (Pentium, 2.2 GHz, 512 MB RAM) running Windows XP. The movement of the images on the three PCs was synchronized and controlled by a server via a local area network. The update rate of the images was consistently at least 30 frames per second. The display projectors were not stereoscopic, and thus no active shutter glasses or

passive polarizing glasses were used by the subjects. In addition, head-tracked perspective correction was not used because the movement of the head was negligible compared with the simulated movement of the person throughout the store.

The virtual environment was interfaced to a custom-built treadmill, 2.0 m long and 1.2 m wide with a maximum velocity of 1.2 m/s. At the front of the treadmill was a grocery cart that was instrumented with two load cells on the push bar. The velocity of the treadmill and movement within the environment was controlled by the force applied to the cart [29]. Turns in the virtual grocery store were made by pushing harder on one side of the push-bar compared with the other.

Outcome measures—Subjects were examined one week before, one week after, and six months after the intervention using self-report and performance-based measures of functional balance by a physical therapist blinded to treatment groups.

Self-report measures—The Activities-specific Balance Confidence scale (ABC) was used to record the patient's perceived level of balance confidence during 16 daily living activities.[41] Responses ranged from 0% to 100%; the lowest score indicated low confidence in balance and the highest score indicated high level of confidence [41]. The Dizziness Handicap Inventory (DHI) recorded the level of disability and handicap resulting from dizziness [42]. The DHI score ranged between 0% to 100% with the lowest score indicating low disability resulting from dizziness and the highest score indicating a high level of disability. The sum score of all DHI subscales was reported. For the Situational Characteristics Questionnaire (SCQ), subjects rated situations that elicited anxiety or discomfort for the subject in real life situations [11]. The SCQ (part A) score ranged between 0 and 30 with the highest scores (worse) on the SCQ-A indicating that persons have greater discomfort or anxiety performing normal activities such as shopping, riding in a car or bus, in movie theaters, on escalators or elevators, and in the shower. The SCQ (part A) has shown its ability to distinguish patients with vestibular dysfunction among patients complaining of anxiety disorders [11, 43]. The SCQ (part B) ranged between 0 and 60 with the highest scores (worse) on the SCQ-B indicating that persons have greater discomfort or anxiety associated with vestibular symptoms. The SCQ-B is able to identify people with vestibular disorders [43].

Performance measures—The Dynamic Gait Index (DGI) examined a person's ability to perform various gait activities such as walking with head turns and avoiding obstacles [44]. The scale has 8 items; each item is scored from 0 to 3 (0 means severe impairment, 3 means normal ability). The optimal score on the DGI is 24 and with scores of 19 or below, the subject has a higher risk of falling [45, 46]. The Functional Gait Assessment (FGA) also measured balance control during walking [47]. The FGA has 10 walking tasks. The FGA total score is 30 with each item scored using an ordinal scale (0–3, 0 = severe impairment, 3 = normal performance). Scores of 22 or less have been related to increased fall risk in older adults [48]. To record gait speed, subjects walked 6.1 meters at their comfortable speed 5 times, with their mean speed calculated. Gait speed has shown to be related to falls and functional abilities [49, 50]. The Timed Up and Go (TUG) test required subjects to rise from a chair, walk three meters, turn around, then walk back to the chair and sit [51]. Subjects

were timed during the task; persons with vestibular disorders who score 13.5 seconds or greater are at higher risk of falling [52]. The Sensory Organization Test (SOT) was used to record postural sway in six conditions related to various sensory inputs important for balance (vestibular, vision, and somatosensory input) [53]. The composite SOT score was used in the analysis.

Within-session VRBT symptom measures

Before and after each treatment session, subjects rated the severity of their nausea, headache, dizziness, and visual blurring using a visual analog scale (VAS) [54]. Subjects marked a 10-cm vertical line corresponding to the severity of symptoms. The bottom end of the line was labeled “no symptom” and the top end was labeled “as bad as it can be”. The Simulator Sickness Questionnaire (SSQ) was used to record the severity of 16 different symptoms across three subscales: nausea (general discomfort, increased salivation, stomach awareness, burping, sweating, nausea, and difficulty concentrating), oculomotor stress (general discomfort, blurred vision, headache, eyestrain, fatigue, difficulty focusing, and difficulty concentrating), and disorientation (dizzy with eyes open, dizzy with eyes closed, head fullness, vertigo, blurred vision, nausea, and difficulty focusing) [55, 56]. For each item, a 0 was recorded if none of the component symptoms were present and a 1 was recorded if any degree of the symptom was present (mild, medium, or severe). The sum of the component scores for each subscale were computed.

Statistical analysis

Groups were compared at baseline in demographic characteristics, laboratory tests, location of dysfunction and duration of symptoms using t-tests for continuous and Chi-square tests for categorical variables. A t-test was also used to determine if there were differences in self-report and performance measures at baseline. A 2 × 3 mixed analysis of variance (ANOVA) was performed on self-report and performance measures as a function of time and group. The within-subjects independent variable was assessment time with 3 levels (pre, post, and 6-month follow up). The between-subjects independent variable was the group with 2 levels (VRBT, PT). Post-hoc testing was performed using a Bonferroni correction with 3 planned comparisons (pre vs. post, pre vs. 6-month follow up, and post vs. 6-month follow up) and $\alpha = 0.017$. Intention to treat analysis was used for subjects with missing data at the 6-months follow up.

For the VRBT group, we explored if a short-term change in symptoms (VAS and SSQ subscales) occurred from before the first trial to after the last trial within each session, using the non-parametric Wilcoxon signed ranks test. To determine if there was a long-term habituation effect of VRBT, the post-session VAS and SSQ scores were compared across the six sessions using a non-parametric Friedman test. For all analyses, the level of significance was set at $\alpha = 0.05$.

Results

Participants

The demographic information of all subjects including age, gender, duration of symptoms, and laboratory tests for patients, i.e. oculomotor testing, positional testing, calorics testing, rotational chair testing, and vestibular-evoked myogenic potentials (VEMPs) are presented in Table 1. There were no significant differences between groups in laboratory tests, location of dysfunction and duration of symptoms. Subjects in the PT group were older than subjects in the VRBT group. At the 6-month follow up, 4 subjects did not return in VRBT group and 2 subjects did not return in PT group. Table 2 demonstrates that there were no significant differences between the two groups in all self-report and performance measures at baseline ($p > 0.05$).

Group Comparison

The ANOVA revealed that there was not a significant effect of group or interaction between group and time for any of the self-report measures ($p > 0.05$, Table 3). However, there was a significant time effect for the ABC, DHI, and SCQ-B ($p < 0.001$). Table 3 details the significant improvement in self-report measures immediately after and 6 months after the intervention, compared with baseline. Post-hoc testing demonstrated that significant differences occurred between the initial assessment and post-intervention test, as well between the initial assessment and 6 month follow-up. At the post-test, the average size of improvement was 11 points for the ABC, 12 points for the DHI, and 6 points for the SCQ-B. The SCQ-A did not change significantly over time, with a change of 0.5 points.

As with the self-report measures, there was not a significant effect of group or interaction between group and time for the DGI, FGA, TUG and SOT. ($p > 0.05$, Table 4). A significant interaction between group and time for gait speed indicated that the gait speed for the VRBT was changed minimally at 0.01 m/s whereas the PT group increased by 0.10 m/s from pre to post intervention. It must be noted, however, that the VRBT group started at a higher baseline. In addition, a significant time effect was found for all of the performance measures except for the TUG. At post-intervention, the DGI improvement was 1 point and gait speed improvement was 0.06 m/s for both groups combined. The SOT was significantly higher by 6 points at the six-month follow-up compared with before the interventions.

Table 5 demonstrates changes in the VAS and SSQ scores for the VRBT group from pre-session to post-session, averaged across all sessions. Dizziness, headache, nausea, and visual blurring VAS significantly increased during the session. Likewise, disorientation, nausea, and oculomotor stress SSQ ($p = 0.002$) scores showed a significant increase post-session compared with pre-session.

Subjects who received the VRBT demonstrated long-term symptom habituation to the grocery store environment (Table 6), as indicated by a significant reduction in post-session dizziness and visual blurring VAS, and all subscales of the SSQ.

Discussion

In this study we examined changes in self-report and performance measures in persons with vestibular disorders after they received either customized vestibular physical therapy or virtual reality-based therapy. Groups were similar at baseline in all self-report and performance measures. On average, the entire sample demonstrated significant improvements in 3 of the 4 self-report measures, in 4 of the 5 performance measures, and maintained these improvements six months after the intervention ended. The amount of improvement did not differ amongst the interventions. Therefore, our study findings suggest that using VRBT in vestibular rehabilitation produces equivalent functional outcomes for patients with vestibular disorders when compared with the clinically accepted physical therapy. As seen in Table 1, the mean duration of symptoms was beyond the acute stage (often greater than 6 months), and rotational chair abnormalities suggest that at least half of the subjects were not compensated. Consequently, we believe that improvements made were due to the interventions and not passage of time. Despite these statistically significant improvements, the amount of improvement in the outcome measures did not reach the threshold for the minimal clinically important difference (ABC = 10, DHI = 18, DGI = 3, SOT = 8, gait speed = 0.10) in a majority of the subjects. It is possible that a greater dose of the intervention is required to demonstrate these clinically important improvements.

The current study extends the work of previous studies that examined the use of technology-based visual stimuli for vestibular rehabilitation. Previous studies have delivered optokinetic stimulation in horizontal and vertical directions to persons who had unilateral and bilateral vestibular disease [28]. The subjects were no longer symptomatic after an average of 8 sessions lasting 15 minutes, and subjects had improvements in posturography scores [28]. Viirre and Sitarz (2002) attempted to induce vestibulo-ocular reflex (VOR) gain adaptation in subjects with chronic dizziness by having subjects search for objects within a panoramic scene displayed using a head mounted display (HMD) [57]. After 10 sessions lasting up to 30 minutes, the subjects did increase their VOR gain, in contrast with subjects who did not receive the intervention.

Suarez et al. (2006) used a head mounted display to provide optokinetic stimulation and visual-vestibular interaction for older subjects with balance disorders. At the end of the six-week daily intervention, subjects demonstrated reduced sway [58]. Pavlou et al. (2004) studied 2 groups of subjects with chronic unilateral vestibular disorders; one group received customized physical therapy and the other group received customized physical therapy in combination with exposure to moving visual displays [6]. Both groups demonstrated significant improvements over the course of 8 weeks (16 visits), but subjects who received the additional visual-based treatment had greater improvements, in particular with space and motion discomfort. In contrast, subjects in the VRBT group did not also receive customized physical therapy. Consequently, it is possible that the combination of both VRBT and PT, as used in the Pavlou et al., study, may provide better results than just PT or VRBT alone [6]. In addition, it is possible that dosage has an effect on the outcome. In our study, subjects attended one session per week for 6 weeks, but attended 2 sessions per week for 8 weeks in Pavlou et al. study. The dosage of the interventions in the current study reflected the typical practice pattern in our geographical area.

As mentioned previously, it has been demonstrated that some vestibular disorders have co-occurring physiological and psychological components [23, 24]. Either directly or indirectly, we believe that the VRBT intervention may address both components. For example, if dizziness causes anxiety in an individual, by directly habituating the person's symptoms of dizziness by reducing their visual sensitivity, anxiety will be lessened indirectly.

With regard to the method of delivery of VRBT, several notable differences exist between the previous studies and the current study. Rather than just relying on optokinetic stimulation, the VRBT was designed with the intent of increased subject interaction with the environment. To this end, the environment was based on a situation in which individuals with vestibular disorders commonly report increased symptoms. In fact, several questionnaires (Dizziness Handicap Inventory [42], Situational Characteristics Questionnaire [11], Vestibular Activities of Daily Living [59]) include walking in a grocery store as an item. Also, subjects performed a functional task within the environment, by walking and moving their head to search for products that they would encounter in a real grocery store. This is consistent with what is instructed during vestibular physical therapy, where patients are encouraged to move their head during daily activities because movement is needed for adaptation and reweighting of the sensory signals [60, 61]. In addition, as subjects ambulated, they pushed on a real grocery cart. This served two important purposes. It allowed subjects to control the speed of their interaction with the virtual environment and permitted them to interact with the environment in a natural way. All of these factors would presumably enhance the subjects' sense of presence, which may allow them to more effectively habituate to the stimuli that cause the increased symptoms [60, 61].

Symptom measures during VRBT

Most of the subjects reported symptom increases during the training sessions. While the increase in symptoms may appear to be an unwanted and unintended side effect of the virtual reality intervention, it is a common occurrence in individuals who perform gaze stabilization, dynamic gait and static standing balance exercises that comprise standard vestibular rehabilitation interventions [62]. In fact, vestibular rehabilitation therapists routinely instruct their clients that an increase in symptoms is to be expected [63].

Analysis of the post-session VAS and SSQ scores allowed us to examine how the subjects habituated to the intervention over the course of the 6 week intervention. Significant reductions in dizziness and visual blurring VAS and in the SSQ measures suggest that subjects were habituating to the virtual reality stimuli. It is important to note that during this period, the intensity of the intervention progressed in terms of the simulated optic flow velocity during the locomotion through the store, in that the greater spatial frequency of the product textures in the more complex aisles would be perceived as greater optic flow velocity.

Limitations

Although the subject allocation was not randomized, given the equivalence of the groups at baseline, and that the outcomes assessor was blinded to group membership, the likelihood for bias introduced by non-randomization is low. Providing a home exercise program to both

groups may have also contributed to not finding different outcomes between groups, however, since home exercise programs are the current practice standard for conventional PT, we decided that we needed to add it to the VRBT group so that the intervention time was equivalent between groups. The heterogeneity of subject diagnoses of our sample may have resulted in lack of difference between groups. Examination of the type of dysfunction (peripheral, central or mixed) did not reveal any strong relationship between the magnitude of improvement and site of dysfunction.

Conclusion

Individuals with vestibular disorders demonstrated significant improvements in self-report and performance measures for both interventions at one week and at 6 months after discharge. There were not between group differences. Nausea, headache, dizziness and visual blurring increased significantly during the VRBT sessions, but overall symptoms were reduced at the end of the six-week intervention. While this study did not find a difference in outcomes between PT and VRBT, the mechanism by which subjects with chronic dizziness demonstrated improvement in dizziness and balance function may be different. Although the cost and effort of using VRBT is high compared with PT, VRBT may be a viable option in cases where an individual's symptoms are primarily due to space and motion discomfort. Assuming that VRBT would be approved for reimbursement by insurance providers, the cost of providing the therapy by the physical therapist would be approximately equal, given equivalent amount of treatment times. However, VRBT would incur an extra cost in hardware and software; the estimate of such costs changes frequently.

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Fig.1.

A subject is shown pushing on an instrumented grocery cart while ambulating on a treadmill. The speed of the walking and movement through the virtual grocery store is proportional to the force applied to load cells on the cart. The subject walks inside the store and looks for products randomly called out by the physical therapist.

Fig.2.

Four of the sixteen aisles from the virtual grocery store are shown. The aisles are 2 (upper left), 6 (upper right), 10 (lower left) and 14 (lower right), and there is a progression in visual complexity, primarily determined by the spatial frequency and color contrast of the product textures, as the aisle number increases.

Table 1

Demographics and clinical tests results of subjects in the virtual reality-based therapy group (VRBT) and the customized physical therapy group (PT) at baseline concerning age, gender, duration of symptoms, and laboratory tests [oculomotor testing, positional testing, caloric testing, rotational chair testing, and vestibular-evoked myogenic potentials (VEMPs)].

	VRBT (n=20)	PT group (n=18)	p-value
Age (years)			
Mean ± SEM	53 ± 2	61 ± 3	**0.047**
Range	27 – 70	30 – 78	
Gender			
Female	15	16	0.27
Male	5	2	
Duration of symptoms (months)			
Mean ± SEM	5 ± 1	7 ± 1	0.39
Range	0–16	.25–21	
Abnormal laboratory testing (n)			
Oculomotor	2	0	0.16
Positional	6	9	0.25
Calorics (reduced vestibular response)	6	9	0.46
Rotational Chair (decreased gain, asymmetry)	10	5	0.20
VEMPs	7	9	0.29
Location of dysfunction			0.89
Peripheral	12	12	
Central	3	2	
Mixed	4	3	
Unknown	1	1	

t- test for continuous variables, Chi-square for categorical variables; VEMP: Vestibular evoked myogenic potential

Table 2

Self-report and performance measures (mean ± SEM) for subjects in the virtual reality-based therapy (VRBT) and the customized vestibular physical therapy groups (PT) at baseline.

	VRBT	PT	p value
ABC	66 ± 4	67 ± 7	0.91
DHI	38 ± 4	37 ± 6	0.91
SCQ part A	3.6 ± 0.6	3.8 ± 0.7	0.88
SCQ part B	20 ± 3	20 ± 3	0.98
DGI	21 ± 0.9	19 ± 1.2	0.16
FGA	24 ± 1.6	21 ± 1.6	0.10
Gait speed (m/s)	1.13 ± 0.04	1.05 ± 0.06	0.25
TUG (s)	9.0 ± 0.4	10.5 ± 0.8	0.10
SOT	63 ± 4	55 ± 5	0.20

Higher scores on the Activities-specific Balance Confidence scale (ABC), Functional Gait Assessment (FGA), Dynamic Gait Index (DGI), Gait speed, and Sensory Organization Test (SOT) indicate better outcomes at baseline. Lower scores on the Dizziness Handicap Inventory (DHI), Timed Up and Go (TUG), and Situational Characteristics Questionnaire (SCQ) indicate better outcomes at baseline.

t-test was used for all variables

Table 3

Self-report measures (mean ± SEM) for subjects in the virtual reality based therapy (VRBT) group and the customized vestibular physical therapy group (PT) at pre-treatment vs. post-treatment vs. 6-month (6M) follow-up. P-values obtained from mixed factor repeated measures ANOVA.

	Group	Pre	Post	6-month Follow-up	Group p-value	Time p-value	Group × Time p-value
ABC	**VRBT** **PT**	66 ± 20 67 ± 30	75 ± 20 79 ± 28	81 ± 16 78 ± 29	0.92	< **0.001** **(Post, 6M > Pre)**	0.42
DHI	**VRBT** **PT**	38 ± 17 37 ± 26	26 ± 19 23 ± 23	25 ± 17 22 ± 22	0.75	< **0.001** **(Post, 6M < Pre)**	0.90
SCQ part A	**VRBT** **PT**	4 ± 3 4 ± 3	3 ± 2 3 ± 3	4 ± 3 3 ± 3	0.60	0.33	0.39
SCQ part B	**VRBT** **PT**	20 ± 13 20 ± 14	13 ± 10 14 ± 15	13 ± 10 14 ± 15	0.83	< **0.001** **(Post, 6M < Pre)**	0.77

Higher scores on the Activities-specific Balance Confidence scale (ABC) indicate better outcomes. Lower scores on the Dizziness Handicap Inventory (DHI) and Situational Characteristics Questionnaire (SCQ) indicate better outcomes.

Table 4

Performance measures (mean ± SEM) for subjects in the virtual reality based therapy (VRBT) group and the customized vestibular physical therapy group (PT) for pre-treatment vs. post-treatment vs. 6-month (6M) follow-up. P-values obtained from mixed factor repeated measures ANOVA.

	Group	Pre	Post	6 month Follow-up	Group p-value	Time p-value	Group × Time p-value
DGI	**VRBT** **PT**	21 ± 2 19 ± 5	22 ± 2 21 ± 4	22 ± 2 20 ± 6	0.14	**0.034** **(Post > Pre)**	0.67
FGA	**VRBT** **PT**	24 ± 7 21 ± 7	25 ± 3 24 ± 6	25 ± 4 23 ± 7	0.11	**0.049** **(Bonferroni NS)**	0.49
Gait speed (m/s)	**VRBT** **PT**	1.10 ± .2 1.10 ± .2	1.14 ± .1 1.15 ± .3	1.12 ± .1 1.10 ± .2	0.60	**0.007** **(Post > Pre)**	**0.046**
TUG (s)	**VRBT** **PT**	9.0 ± 1.6 10.5 ± 3.6	9.2 ± 1.3 9.5 ± 3.5	9.3 ± 1.5 9.9 ± 3.2	0.31	0.13	0.29
SOT	**VRBT** **PT**	63 ± 18 55 ± 20	68 ± 19 57 ± 24	69 ± 17 62 ± 20	0.14	**0.040** **(6M > Pre)**	0.50

Higher scores on the Functional Gait Assessment (FGA), Dynamic Gait Index (DGI), gait speed, and Sensory Organization Test (SOT) indicate better outcomes. Lower scores on the Timed Up and Go (TUG) indicate better outcomes.

Table 5

Pre and post symptom ratings (mean ± SEM) of Visual Analog Scale (VAS) and Simulator Sickness Questionnaire (SSQ) for subjects in the virtual reality based therapy (VRBT) group. P-values obtained from Wilcoxon signed ranks test.

	Pre	Post	Time p-value
VAS			
Dizziness	0.5 ± 0.2	1.5 ± 0.4	**0.001**
Headache	0.5 ± 0.2	0.8 ± 0.3	**0.034**
Nausea	0.1 ± 0.1	0.4 ± 0.1	**0.003**
Visual Blurring	0.4 ± 0.2	0.8 ± 0.3	**0.001**
SSQ			
Disorientation	1.7 ± 0.3	2.7 ± 0.4	**0.001**
Nausea	0.8 ± 0.2	1.8 ± 0.3	< **0.001**
Oculomotor Stress	2.2 ± 0.4	3.0 ± 0.4	**0.002**

Table 6

Post symptom ratings (mean ± SEM) at the end of each session for the Visual Analog Scale (VAS) and Simulator Sickness Questionnaire (SSQ) for subjects in the virtual reality based therapy (VRBT) group. P-values obtained from Friedman test.

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session p-value
VAS							
Dizziness	1.6 ± 0.4	1.1 ± 0.3	1.4 ± 0.3	0.8 ± 0.2	1.0 ± 0.3	0.5 ± 0.2	**0.012**
Headache	0.4 ± 0.1	0.7 ± 0.2	0.5 ± 0.2	0.4 ± 0.1	0.6 ± 0.3	0.2 ± 0.1	0.34
Nausea	0.7 ± 0.3	0.3 ± 0.2	0.6 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.04	0.062
Visual Blurring	0.9 ± 0.3	0.8 ± 0.3	0.7 ± 0.3	0.6 ± 0.2	0.5 ± 0.2	0.2 ± 0.1	**0.004**
SSQ							
Disorientation	3.5 ± 0.5	2.6 ± 0.5	3.1 ± 0.5	2.1 ± 0.3	1.9 ± 0.3	1.7 ± 0.3	**0.002**
Nausea	2.3 ± 0.4	1.7 ± 0.3	2.4 ± 0.4	1.6 ± 0.3	1.8 ± 0.3	1.5 ± 0.3	**0.019**
Oculomotor Stress	3.9 ± 0.4	3.1 ± 0.5	3.1 ± 0.5	2.8 ± 0.5	2.4 ± 0.5	1.8 ± 0.4	**0.004**